



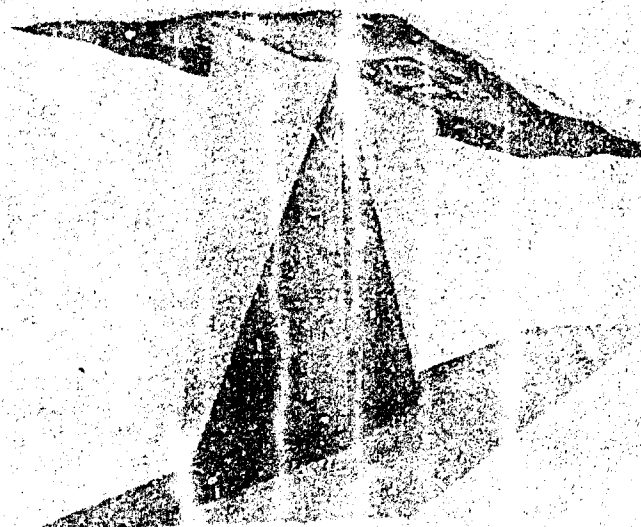
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August 1989

# Direction-of-Arrival Calculations at VLF/LF

R. A. Pappert  
C. R. Hickey



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## I. INTRODUCTION

It has been known for many years that the geomagnetic field, particularly under nighttime propagation conditions, causes the normal modes in the very low frequency (VLF) and low frequency (LF) bands to be hybrid (ref. 1). That is, the modes are neither pure transverse magnetic (TM) nor pure transverse electric (TE) but rather a mixture of the two polarizations. Thus, a vertical electric dipole which radiates pure TM wave will, by virtue of the radio wave interaction with the ionosphere, be a source of TE wave as well. At the ground the TE field is normally constrained, because of relatively high ground conductivity, to be very much less than the vertical electric field component. Nevertheless, the longitudinal rf magnetic field component at the ground can be significant relative to the TM component. This is possible since the longitudinal rf magnetic field component depends upon a height derivative of the TE field component. The longitudinal magnetic field component can, in the case of direction finding with loops, cause appreciable direction of arrival (DOA) error; especially in proximity to ranges where the transverse magnetic field undergoes a modal interference null. Though capability for estimating DOA errors due to the geomagnetic field has existed for sometime, the need for such calculations was minimal. New VLF and LF digital receivers under Navy development will include antenna pattern steering algorithms whose performance depends upon DOA properties of the received signal (ref. 2). This makes timely the modification of VLF/LF propagation codes for the purpose of predicting DOA errors associated with geomagnetic field effects.

Included in the present report is a modification of an early mode conversion program (ref. 3) which allows for error calculations of the DOA as a function of range for both uniform and laterally inhomogeneous guides. As with the earlier program, the present program requires waveguide modal constant inputs

as well as quantities relating to excitation factors and modal polarization. These inputs are standard, NPUNCH = 1, output of the waveguide program "MODESRCH" (ref. 4). Principal outputs of the present program are mode sum plots as a function of range for scaled transverse and longitudinal magnetic field components along with a DOA error curve. Provision is also made for plotting these quantities for fixed transmitter-receiver distance as a function of position of a horizontal inhomogeneity such as the day-night terminator. This option is useful only if the ground conductivity and geomagnetic field magnitude and orientation may be regarded as constant over the path. It is emphasized that the present program is restricted to these outputs. Should the usual electric field components be desired, the user is directed to an update of the program of reference 3 (which can be obtained from L.R. Hitnev) or to the program of reference 5. The latter program can also be easily modified to accommodate DOA capability.

Reference 2 provides results of ground based measurements at San Diego of the variations in the DOA of VLF/LF signals from a number of fixed vertical transmitters. A major purpose of the present study has been to compare computer results with these measurements. Though reference 2 provides results for 24-hour periods, only the all-night and all-day cases are considered here.

In section II the origin of the rf longitudinal magnetic field component is briefly discussed and relevant formulas are summarized. A brief description of the program is given in section III. For a more complete discussion of the program the reader is referred to references 3 and 6. Results are presented in section IV and conclusions are given in section V. The Appendix contains a program listing.

## II. SUMMARY OF EQUATIONS

In the following, an x, y, z rectangular coordinate system is assumed with x-z the plane of propagation and positive z directed into the ionosphere. Invariance in y is assumed. Waveguide theory applied to VLF/LF yields in the asymptotic limit (refs. 7 and 8)

$$\begin{pmatrix} H_y \\ E_y \end{pmatrix} = \frac{K}{[\sin(x/a)]^{1/2}} \sum_m \lambda_m \begin{pmatrix} h_{ym}(z) \\ e_{ym}(z) \end{pmatrix} \exp(-ik \sin(\theta_m)x) \quad (1)$$

where K is a constant, m is a mode index and,

$H_y$  = y component of the scaled rf magnetic field intensity ( $H_y = Z_0 \mathcal{H}_y$  where  $Z_0$  is the characteristic impedance of free space and  $\mathcal{H}_y$  is the y component of the magnetic intensity).

$E_y$  = y component at the rf electric field.

x = range.

a = earth's radius.

z = receiver height.

$h_{ym}$  = modal height gain for y component of the scaled rf magnetic intensity.

$e_{ym}$  = modal height gain for y component of the rf electric field.

i =  $(-1)^{1/2}$

k = free space wave number.

$\theta_m$  = modal eigenangle.

For laterally homogeneous guides  $\lambda_m$  is the excitation factor which depends upon the dipole transmitter altitude and orientation as well as upon functions of the eigenangle. For laterally inhomogeneous guides  $\lambda_m$  depends as well upon mode conversion coefficients. Details of the functional dependencies can be found, for example, in references 3 and 6. However, those details are of no particular significance in the present discussion. What is of consequence is the origin of  $e_y$  for a vertical transmitter. To understand this, use is made of the consistency relation which requires that a downgoing (d) plane wave at the ground must after ground and ionospheric reflections return to its same value upon returning to the ground. Mathematically this may be written as:

$$(1 - R(\theta_m) \bar{R}(\theta_m)) \begin{bmatrix} h_{ym}^d(o) \\ e_{ym}^d(o) \end{bmatrix} = 0 \quad (2)$$

where

$$R(\theta) = \begin{bmatrix} {}_{||}R_{||}(\theta) & {}_{\perp}R_{||}(\theta) \\ {}_{||}R_{\perp}(\theta) & {}_{\perp}R_{\perp}(\theta) \end{bmatrix} \quad (3)$$

is a plane wave reflection coefficient matrix referenced to the ground and represents the reflection from everything above ground level with vacuum below it and

$$\bar{R}(\theta) = \begin{bmatrix} {}_{||}\bar{R}_{||}(\theta) & 0 \\ 0 & {}_{\perp}\bar{R}_{\perp}(\theta) \end{bmatrix} \quad (4)$$

is a plane wave reflection matrix referenced to the ground and represents reflection from everything below ground level with vacuum above it (i.e., the elements of  $\bar{R}(\theta)$  are Fresnel reflection coefficients). Standard notation is used in the sense that the first subscript of the elements of  $R$  and  $\bar{R}$  denotes the polarization of the incident wave (  $\parallel$  for TM,  $\perp$  for TE) and the second subscript denotes the polarization of the reflected wave. Equation (2) represents two equations. Writing out the lower of these gives

$$- \parallel R_{\perp}(\theta_m) \parallel \bar{R}_{\parallel}(\theta_m) h_{ym}^d(o) + (1 - \perp R_{\perp}(\theta_m) \perp \bar{R}_{\perp}(\theta_m)) e_{ym}^d(o) = 0 . \quad (5)$$

Solving for the ratio  $e_{ym}^d(o)/h_{ym}^d(o)$  from the above yields

$$\frac{e_{ym}^d(o)}{h_{ym}^d(o)} = \frac{\parallel R_{\perp}(\theta_m) \parallel \bar{R}_{\parallel}(\theta_m)}{1 - \perp R_{\perp}(\theta_m) \perp \bar{R}_{\perp}(\theta_m)} . \quad (6)$$

Next it is observed that the total modal fields at the ground are by virtue of the definition of  $\bar{R}$

$$h_{ym}(o) = (1 + \parallel \bar{R}_{\parallel}(\theta_m)) h_{ym}^d(o) \quad (7)$$

$$e_{ym}(o) = (1 + \perp \bar{R}_{\perp}(\theta_m)) e_{ym}^d(o) . \quad (8)$$

By dividing Equation (8) by Equation (7) and introducing Equation (6) it follows that

$$\frac{e_{ym}(o)}{h_{ym}(o)} = \frac{(1 + {}_{\perp}\bar{R}_{\perp}(\theta_m))}{{}_{\parallel}\bar{R}_{\parallel}(\theta_m)} \frac{{}_{\parallel}R_{\perp}(\theta_m) {}_{\parallel}\bar{R}_{\parallel}(\theta_m)}{1 - {}_{\perp}R_{\perp}(\theta_m) {}_{\perp}\bar{R}_{\perp}(\theta_m)}. \quad (9)$$

The factor in Equation (9) which involves products of the elements of  $R$  and  $\bar{R}$  is a true global parameter (i.e., independent of source and receiver geometry) and is independent of the reference height chosen for those elements. This factor will be referred to as the modal polarization. The other factor in Equation (9) does depend upon the reference height chosen for  $R$  and  $\bar{R}$ . More generally

$$\frac{e_{ym}(z)}{h_{ym}(z)} = \left[ \frac{1 + {}_{\perp}\bar{R}_{\perp}(\theta_m)}{1 + {}_{\parallel}\bar{R}_{\parallel}(\theta_m)} \right]_z \frac{{}_{\parallel}R_{\perp}(\theta_m) {}_{\parallel}\bar{R}_{\parallel}(\theta_m)}{1 - {}_{\perp}R_{\perp}(\theta_m) {}_{\perp}\bar{R}_{\perp}(\theta_m)} \quad (10)$$

where the subscript  $z$  denotes the reference height for the  $\bar{R}$  reflection elements. Equation (10) gives the admixture of TE and TM components anywhere within the waveguide. It is clear that the modal polarization is proportional to the conversion coefficient,  ${}_{\parallel}R_{\perp}$ , so that a vertical transmitter which launches only TM wave will excite modes of hybrid structure. In the present case interest is principally in the effect of the TE admixture at the ground. Since at the ground,  ${}_{\perp}\bar{R}_{\perp} \approx -1 + \epsilon$  with  $|\epsilon| \ll 1$ , the factor  $(1 + {}_{\perp}\bar{R}_{\perp}(\theta_m))_{z=0}$  constrains the  $e_y$  field to be very small relative to  $h_y$  at the ground. Nevertheless, it will be shown in Section IV that the longitudinal component of the scaled rf magnetic field,

$$H_x = \left. \frac{1}{ik} \frac{\partial E_y}{\partial z} \right|_z = 0, \quad (12)$$

can cause significant DOA error under nighttime propagation conditions when  $R_1$  is the largest. This is particularly true in null regions of  $H_y$ . Included in the results of Section IV are the mode sums

$$\begin{pmatrix} H_y \\ H_x \end{pmatrix} = \frac{K}{[\sin(x/a)]^{1/2}} \sum_m \lambda_m \left[ \frac{h_{ym}(z)}{ik} \frac{\partial e_{ym}}{\partial z} \right]_z \exp(-ik \sin(\theta_m) x) \quad (13)$$

evaluated at the ground for ground based vertical transmitters. It is remarked that  $h_{ym}$  and  $e_{ym}$  are simply linear combinations of Airy functions (or linearly related functions) and so the derivative term in Equation (13) is readily calculable. Formulas for the height gains are given, for example, in reference 6.

If the mode sums are written as

$$H_x = a_1 \cos(\omega t + \delta_1) \quad (14)$$

$$H_y = a_2 \cos(\omega t + \delta_2), \quad (15)$$

the end point of the magnetic intensity traces out an ellipse (see Figure 1), the properties of which are immediately obtainable from reference 9.

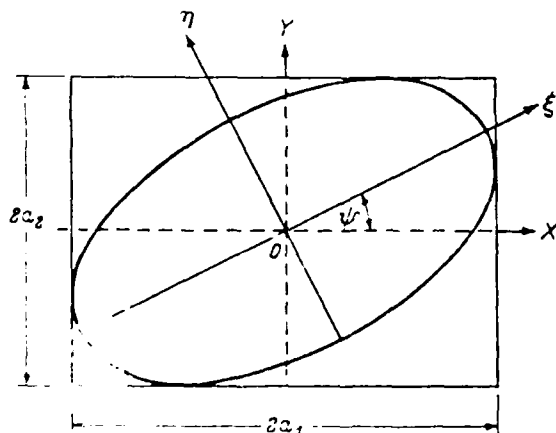


Fig. 1 MAGNETIC INTENSITY ELLIPSE.

In particular the angle  $\psi$  in Figure 1 is given by

$$\psi = 1/2 \tan^{-1}(\tan 2\alpha \cos \delta) \quad (15)$$

where

$$\tan \alpha = \frac{a_2}{a_1} \quad 0 < \alpha \leq \frac{\pi}{2}, \quad \delta = \delta_2 - \delta_1. \quad (16)$$

Recalling that  $x - z$  is the plane of propagation with  $x$  the range coordinate and that  $y$  is the transverse coordinate in a right handed coordinate system the DOA error is

$$\chi = \pi/2 - \psi. \quad (17)$$

Positive  $\chi$  implies arrival from the second quadrant of Figure 1, whereas negative  $\chi$  implies arrival from the third quadrant. In section IV examples of mode sum plots for  $H_y$  and  $H_x$  are given along with plots showing the DOA error for paths examined in reference 2.

### III. BRIEF PROGRAM DESCRIPTION

#### A. GENERAL COMMENTS

The program discussed in this section is a modification of the program discussed in reference 3 and can be used to treat either horizontally homogeneous or inhomogeneous guides. To handle horizontal inhomogeneities the waveguide is divided into a series of slabs as shown in Figure 2 below:

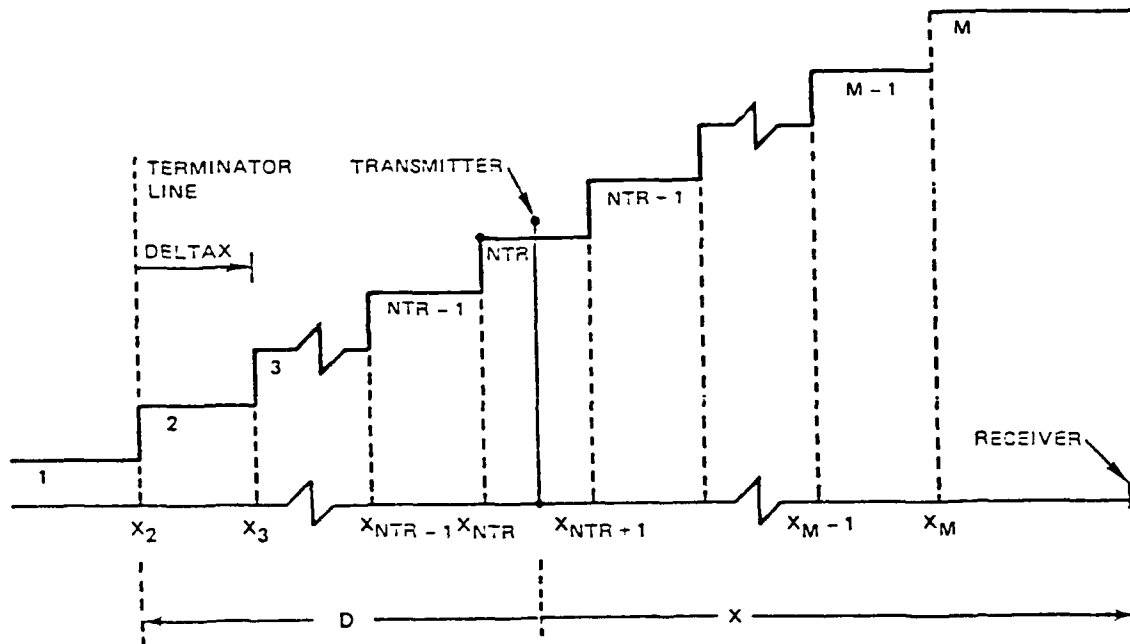


Figure 2. Mode conversion model.

In particular, Figure 2 shows the convention for slab numbering (which is reversed from that of reference 3) and a possible configuration for a terminator type lateral inhomogeneity. The transmitter is at the origin of the coordinate system and the value  $x_1$ , which is not shown, is not used in the calculations but must be assigned a value in namelist DATUM because of array dimensioning. Two options are available with the program. For each slab and

for each mode the ground eigenangles must be supplied along with four independent quantities from which electric point dipole excitation factors are determined. These quantities are supplied by the waveguide program "MODESRCH". Unlike reference 3, the number of modes can vary from slab to slab in the present program. Also, the quantity  $F\theta_{FR}$  defined by Equation (5) of reference 3 (also, equivalent to Equation (9) of the present study) is calculated internally in the present program.

Mode sum plots for  $H_y$ ,  $H_x$  and the DOA error can be generated as a function of range  $x$  for a fixed position of the lateral inhomogeneity or they may be plotted as a function of the transmitter terminator distances,  $D$ , for a fixed receiver site. The latter option can be used only when the ground electrical properties and geomagnetic field magnitude and orientation can be taken as constant over the path. The plots can be generated at an arbitrary height within the waveguide for electric dipole sources of arbitrary orientation and height within the waveguide (see Figure 3).

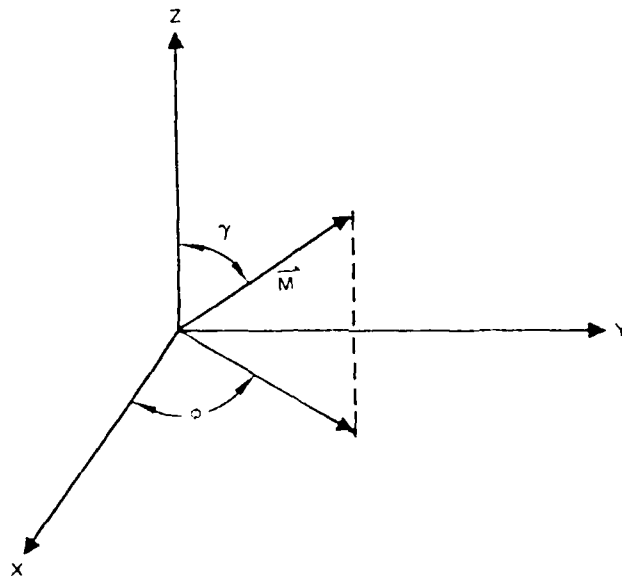


Figure 3. Dipole  $\vec{M}$  orientation within the waveguide where  $\gamma$  is the inclination and  $\phi$  the azimuthal orientation.

## B. DESCRIPTION OF INPUT

All input to the mode conversion program is given in a data file on the standard input unit. A listing of sample input, showing the data file setup for a range calculation for a horizontally homogeneous guide is given on page 12. An input file setup for a moving terminator is given on pages 13 through 15. A sample input for a range variation in a laterally inhomogeneous guide would be similar to the sample given in reference 3.

There are two parts to the input. The first part is read in by means of a Fortran 77 namelist-directed read statement with a group name of DATUM. The following variables and arrays should be specified in the NAMELIST input.

RHOMAX - maximum range in km for which calculations are performed.

RHOMIN - minimum range in km for which calculations are performed.

DELRHO - horizontal increment in km for which successive field strengths are computed.

NRSLAB - Number of slabs in the model.

NTMAX - Number of times the transmitter terminator separation is incremented.

DELTAX - Distance in km by which transmitter-terminator separation is incremented.

# SAMPLE INPUT FOR Laterally Homogeneous Guide

```
$datum
rhomin=25., rhomax=10000., delrho=25.,
deltax=0., ntmax=1,
nrslab=1,
xval=0.,
xmin=0., xmax=10000., xtic=1000.,
ymin=-90., ymax=90., ytic=10., sizeX=5., sizeY=6.,
gamma=45., phi=45.,
zr=10., zt=10.,
iprnta=0,
ipltop=2,
iplflg=2,
ifirst=1,
last=1,
$end
```

Lualualei to San Diego beta=.7, hprime=87.0

```
R .000 F 23.4000 A 59.000 C 40.000 M .413E-04 S 4.000E+00 E 81.0 T 87.0
1 89.97682 -5.920991 1.17507458E-04-1.42930751E-03-2.91159674E-12 1.56223735E-13
2 89.97682 -5.920991 5.15993896E-08 2.86593256E-08 1.00046158E+00 6.63018107E-01
1 89.82555 -5.574832 2.17080335E-04-1.72104372E-03-5.10516109E-12-1.08497217E-12
2 89.82555 -5.574832-6.85928470E-08-5.32394253E-08 1.00075912E+00 6.63700819E-01
1 87.88632 -.224351-2.35080573E-04-2.65855566E-02-1.17070893E-12-1.08537094E-12
2 87.88632 -.224351 1.22134551E-07 1.42263872E-07 1.00533319E+00 6.68529391E-01
1 84.87724 -.264002 9.20612714E-04-1.01905130E-03-9.30642854E-11-3.59403197E-12
2 84.87724 -.264002-2.07534725E-07-2.50064232E-07 1.00777233E+00 6.71742201E-01
1 81.56534 -.157771-9.38259356E-04-2.64533665E-02-7.21719646E-12-7.26697782E-12
2 81.56534 -.157771 3.05091049E-07 3.59546164E-07 1.01319230E+00 6.78170621E-01
1 79.29093 -.254342 1.24309910E-03-1.29618787E-03-2.71744988E-10-1.65220084E-12
2 79.29093 -.254342-4.04487480E-07-4.83902454E-07 1.01797378E+00 6.84924006E-01
1 76.56423 -.180111-1.40988897E-03-2.33948622E-02-2.79152760E-11-2.70179695E-11
2 76.56423 -.180111 5.70840825E-07 6.39522682E-07 1.02576578E+00 6.94986641E-01
1 74.45299 -.317182 1.86981435E-03-1.98888732E-03-5.12932530E-10 1.35284353E-11
2 74.45299 -.317182-6.98896315E-07-7.95034907E-07 1.03191864E+00 7.05408871E-01
1 71.81008 -.208421-2.10860302E-03-2.16372982E-02-7.77475515E-11-7.09266951E-11
2 71.81008 -.208421 9.32243722E-07 9.67916662E-07 1.04210842E+00 7.20323980E-01
1 69.73547 -.405862 2.68813735E-03-2.99302535E-03-8.04118716E-10 5.29969506E-11
2 69.73547 -.405862-1.09387440E-06-1.15510568E-06 1.04884636E+00 7.35498965E-01
1 67.09178 -.237161-2.93348846E-03-2.01747213E-02-1.77707127E-10-1.50172735E-10
2 67.09178 -.237161 1.39038355E-06 1.30640410E-06 1.06097567E+00 7.56687820E-01
1 64.97400 -.520412 3.63010028E-03-4.30195918E-03-1.13163612E-09 1.28242014E-10
2 64.97400 -.520412-1.59059425E-06-1.52464986E-06 1.06673014E+00 7.78390706E-01
1 62.30975 -.265031-3.78178176E-03-1.87656302E-02-3.51571799E-10-2.72375650E-10
2 62.30975 -.265031 1.93094775E-06 1.60819002E-06 1.07958007E+00 8.07601869E-01
```

y  
y

# SAMPLE INPUT FOR MODELING A MOVING TERMINATOR

```

$datum
rhomin=3821., rhomax=4166., delrho=345.,
deltax=25., ntmax=261,
nrslab=9,
xval=-1525., -1500., -1312.5, -1187.5, -1062.5, -937.5, -812.5, -687.5, -500.,
xmin=-1500., xmax=5000., xtic=500.,
ymin=-30., ymax=50., ytic=10., sizex=7.82, sizey=4.92,
gamma=45., phi=270.
zr=15., zt=15.,
iprnta=0,
ipltop=1,
iplflg=1,
ifirst=1,
last=1,
$end
Hprime=86 to Hprime=70
R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 86.0
1 89.95893 -5.614791 8.90918891E-05-2.56474130E-03-3.66113606E-12-1.41053103E-13
2 89.95893 -5.614791 7.23541476E-08 5.82935336E-08 1.04440999E+00 3.08963150E-01
1 89.73230 -5.098552 8.13409977E-04-3.18036205E-03-7.20839404E-12-1.23412988E-12
2 89.73230 -5.098552-9.77022978E-08-1.11584257E-07 1.04662442E+00 3.09465617E-01
1 86.46790 -.276901-6.97296404E-04-2.96539459E-02-2.31411700E-12-2.42465618E-12
2 86.46790 -.276901 1.52632509E-07 2.58247184E-07 1.06115580E+00 3.07544500E-01
1 83.71133 -.318972 1.78535702E-03-1.91355264E-03-1.02256321E-10-2.46968201E-12
2 83.71133 -.318972-2.50906027E-07-4.20881236E-07 1.07172537E+00 3.07309061E-01
1 80.24526 -.275711-2.00039987E-03-2.66215149E-02-1.59478784E-11-1.70393977E-11
2 80.24526 -.275711 3.87197304E-07 6.31316766E-07 1.09389603E+00 3.06244135E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 84.0
1 89.93198 -5.353161 1.86523030E-04-3.80378054E-03-3.72650522E-12-2.66069854E-13
2 89.93198 -5.353161 9.06502038E-08 7.63756844E-08 9.70103979E-01 2.90322542E-01
1 89.67323 -4.842402 9.74733557E-04-3.26375384E-03-9.61524870E-12-1.76274479E-12
2 89.67323 -4.842402-1.15998247E-07-1.39092066E-07 9.72432077E-01 2.91206360E-01
1 85.93787 -.315181-6.77048694E-04-3.09771523E-02-2.07085325E-12-2.71785220E-12
2 85.93787 -.315181 1.47816920E-07 2.84299375E-07 9.89267349E-01 2.90921926E-01
1 83.22681 -.388222 1.78511837E-03-1.55677041E-03-1.17126780E-10-4.95431560E-12
2 83.22681 -.388222-2.37927182E-07-4.57677174E-07 1.00180018E+00 2.92327493E-01
1 79.73028 -.330761-2.05988088E-03-2.73547117E-02-1.47570515E-11-1.97417777E-11
2 79.73028 -.330761 3.79882323E-07 6.98669737E-07 1.02771771E+00 2.94379383E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 82.0
1 89.88525 -5.073801 4.76708548E-04-5.71369240E-03-3.24168990E-12-3.47774489E-13
2 89.88525 -5.073801 1.07369090E-07 9.53978301E-08 8.63476753E-01 2.74763733E-01
1 89.59141 -4.554722 9.79591976E-04-2.88872421E-03-1.31660897E-11-2.77030027E-12
2 89.59141 -4.554722-1.32362615E-07-1.66220417E-07 8.66081953E-01 2.75995642E-01
1 85.41425 -.371091-5.08478784E-04-3.22124176E-02-1.73904988E-12-2.72687819E-12
2 85.41425 -.371091 1.43651306E-07 3.02742137E-07 8.85840416E-01 2.76717037E-01
1 82.72205 -.487472 1.59731111E-03-1.18575653E-03-1.34468672E-10-9.75490175E-12
2 82.72205 -.487472-2.24028838E-07-4.83897225E-07 9.00848508E-01 2.79662967E-01
1 79.18263 -.403351-1.88347534E-03-2.82151829E-02-1.27613467E-11-2.08172975E-11
2 79.18263 -.403351 3.71068296E-07 7.55888038E-07 9.31417108E-01 2.84143299E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 80.0
1 89.82103 -4.781621 1.05937861E-03-8.39334913E-03-2.11253519E-12-2.83353229E-13
2 89.82103 -4.781621 1.13315721E-07 1.01717518E-07 7.26135790E-01 2.78738737E-01
1 89.46140 -4.205672 7.41320197E-04-1.97134237E-03-1.82106691E-11-4.62774090E-12
2 89.46140 -4.205672-1.38748817E-07-1.77048150E-07 7.30000734E-01 2.80761808E-01
1 84.88551 -.447061-1.71756066E-04-3.33595462E-02-1.36530576E-12-2.37677196E-12

```

2 84.88551 -.447061 1.44529494E-07 3.05609575E-07 7.49675095E-01 2.79543728E-01  
 1 82.17252 -.618432 1.24706491E-03-7.74172600E-04-1.54974325E-10-1.78294827E-11  
 2 82.17252 -.618432-1.94097282E-07-4.85529313E-07 7.95087934E-01 2.63119757E-01  
 1 78.59708 -.499461-1.50697830E-03-2.91476566E-02-9.99454252E-12-2.02260205E-11  
 2 78.59708 -.499461 3.56034121E-07 8.13086274E-07 7.94667065E-01 2.58789837E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 78.0  
 1 89.74937 -4.485971 1.78524549E-03-1.14039388E-02-9.32397931E-13-1.85739824E-13  
 2 89.74937 -4.485971 9.78692469E-08 8.47686010E-08 5.76031327E-01 3.11028749E-01  
 1 89.24081 -3.753632 4.48389386E-04-9.48478992E-04-2.46174071E-11-7.50462800E-12  
 2 89.24081 -3.753632-1.24890576E-07-1.59517882E-07 5.78858852E-01 3.12637269E-01  
 1 84.34246 -.546751 2.11181687E-04-3.44251283E-02-8.89651688E-13-1.74506330E-12  
 2 84.34246 -.546751 1.43204801E-07 2.80839743E-07 6.02452695E-01 3.11667144E-01  
 1 81.56769 -.801902 8.28500022E-04-5.05273812E-04-1.80112383E-10-3.04999290E-11  
 2 81.56769 -.801902-2.07465988E-07-4.59239033E-07 6.22810721E-01 3.15373600E-01  
 1 77.96826 -.635241-7.57292029E-04-3.02124228E-02-7.16761546E-12-1.57295739E-11  
 2 77.96826 -.635241 3.67441686E-07 7.59492764E-07 6.61270738E-01 3.18266243E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 76.0  
 1 89.67842 -4.195361 2.45779543E-03-1.41851194E-02-3.12425080E-13-1.36429022E-13  
 2 89.67842 -4.195361 7.04787269E-08 5.99233658E-08 4.21555966E-01 3.88745427E-01  
 1 88.90660 -3.171932 2.70018878E-04-3.39354476E-04-3.21954893E-11-1.11604580E-11  
 2 88.90660 -3.171932-9.63160147E-08-1.28835026E-07 4.29769784E-01 3.76125246E-01  
 1 83.78646 -.656921 5.78613428E-04-3.53961140E-02-4.17128761E-13-1.14611727E-12  
 2 83.78646 -.656921 1.34711897E-07 2.33643163E-07 4.48909104E-01 3.88394594E-01  
 1 80.88498 -.976642 4.98450419E-04-2.34734369E-04-2.11642412E-10-4.63897462E-11  
 2 80.88498 -.976642-1.95438730E-07-3.96136898E-07 4.70917970E-01 3.90501976E-01  
 1 77.29854 -.793811-2.86844370E-05-3.13108861E-02-3.75179878E-12-1.10646362E-11  
 2 77.29854 -.793811 3.55859243E-07 6.66429230E-07 5.09032011E-01 3.89449626E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 74.0  
 1 89.60178 -3.902511 3.09083378E-03-1.67904254E-02-9.43353129E-14-8.49416295E-14  
 2 89.60178 -3.902511 4.56988438E-08 3.96695583E-08 2.91040480E-01 5.15212834E-01  
 1 88.40370 -2.497722 1.53187531E-04-1.08900967E-04-4.13913175E-11-1.51935877E-11  
 2 88.40370 -2.497722-7.22185121E-08-9.34580413E-08 2.95880765E-01 5.15322745E-01  
 1 83.21597 -.773371 8.99333565E-04-3.62679623E-02-1.01535987E-13-7.34521602E-13  
 2 83.21597 -.773371 1.13296082E-07 1.78915556E-07 3.16028774E-01 5.09744406E-01  
 1 80.15169 -1.113712 2.94007245E-04-7.68069804E-05-2.50641397E-10-6.35519415E-11  
 2 80.15169 -1.113712-1.70118525E-07-3.16608464E-07 3.39071542E-01 5.05254328E-01  
 1 76.58773 -.971591 6.23005268E-04-3.23789045E-02-1.09145711E-12-7.29663465E-12  
 2 76.53773 -.971591 3.13271016E-07 5.29444264E-07 3.73405904E-01 5.06903291E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 72.0  
 1 89.50670 -3.593371 3.73883406E-03-1.93957984E-02-2.80016150E-14-4.41833222E-14  
 2 89.50670 -3.593371 2.83041288E-08 2.61669086E-08 2.04742640E-01 6.65039361E-01  
 1 87.66309 -1.927862 8.04060764E-05-3.38098434E-05-5.22675826E-11-1.98142700E-11  
 2 87.66309 -1.927862-5.04189011E-08-6.68672868E-08 2.10287109E-01 6.64982557E-01  
 1 82.62367 -.904771 1.22795266E-03-3.70658040E-02 2.93056933E-14-4.71066925E-13  
 2 82.62367 -.904771 8.56292814E-08 1.32001347E-07 2.27945834E-01 6.60904884E-01  
 1 79.40465 -1.226292 1.72982021E-04-1.48205954E-05-2.95881680E-10-8.13693696E-11  
 2 79.40465 -1.226292-1.35712256E-07-2.37786438E-07 2.47396663E-01 6.59889698E-01  
 1 75.83375 -1.174621 1.18812581E-03-3.33632752E-02 2.17520067E-13-4.73121412E-12  
 2 75.83375 -1.174621 2.44619088E-07 4.01201845E-07 2.78375298E-01 6.56392694E-01

R .000 F 21.7940 A 58.500 C 39.000 M .431E-04 S 4.640E+00 E 81.0 T 70.0  
 1 89.37548 -3.251751 4.42431914E-03-2.21310500E-02-8.24005764E-15-1.95039839E-14  
 2 89.37548 -3.251751 1.75193087E-08 1.72535923E-08 1.63431019E-01 8.03890228E-01  
 1 86.81053 -1.622792 3.89222732E-05-1.11819172E-05-6.52232504E-11-2.57851605E-11

2 86.81053 -1.622792-3.47190507E-08-4.73781974E-08 1.69330418E-01 8.04408669E-01  
1 81.99325 -1.059281 1.60216109E-03-3.78431045E-02 4.95666469E-14-2.86521430E-13  
2 81.99325 -1.059281 6.19566336E-08 9.75383330E-08 1.85555279E-01 8.03614676E-01  
1 78.64407 -1.357022 9.65972431E-05-4.17938452E-07-3.47162410E-10-1.02328881E-10  
2 78.64407 -1.357022-1.01884517E-07-1.78062535E-07 2.05252454E-01 8.05077076E-01  
1 75.02145 -1.414181 1.72621966E-03-3.42926793E-02 5.21807912E-13-2.98834373E-12  
2 75.02145 -1.414181 1.78861782E-07 3.04132669E-07 2.34394595E-01 8.06276321E-01

y  
n

XVAL - Horizontal position in km of boundaries between adjacent slabs. These are denoted by the  $x_i$ 's in Figure 2. Note that XVAL can be negative and that it is dimensioned for 25.

IFIRST - Is set to 1 in the first set of NAMELIST input. If more than one set of input is used set IFIRST = 0 in the second set.

LAST - Is set to 1 in the last set of NAMELIST input. If the user has requested plots this causes the end of file to be written on the plot tape.

IPLTOP - Plotting option flag. If IPLTOP = 1, mode sums for the scaled rf magnetic field components  $H_x$ ,  $H_y$  and the DOA error are plotted as a function of transmitter-terminator distance at a given field point. If IPLTOP = 2,  $H_x$ ,  $H_y$  and the DOA error are plotted as a function of range.

XMIN - Minimum value of x on plot (x either range or transmitter-terminator distance).

XMAX - Maximum value of x on plot (x either range or transmitter-terminator distance).

XTIC - Tic mark interval on x axis.

YMIN - Minimum value of y on plot (y is  $H_x$ ,  $H_y$  and DOA error). Normal setting is -90.

YMAX - Maximum value of y on plot (y is  $H_x$ ,  $H_y$  and DOA error). Normal setting is 90.

YTIC - Tic mark interval on y axis.

SIZEX - Size of x axis in inches.

SIZEY - Size of y axis in inches.

GAMMA - Dipole orientation relative to z axis (see Figure 3).

PHI - Dipole orientation relative to x axis (see Figure 3).

ZT - Transmitter altitude in km.

ZR - Receiver altitude in km.

INTFLG - Printing option flag. INTFLG must be set to 1 if printout of height gain integrals is required.

IPRNTA - Printing option flag. IPRNTA must be set to 1 if printout of generalized mode conversion coefficients is required.

IPLFLG - if  $IPLFLG \neq 0$  plots are determined by IPLTOP. If  $IPLFLG = 0$  no plots are generated.

The y's or n's appearing at the end of the input files on pages 12 and 15 are in response to the questions appearing at the end of the output files on pages 27 and 37.

The second part of the input contains NPUNCH = 1 output from "MODESRCH". The output file contains the frequency in kHz and the following slab data.

SIGMA - Ground conductivity in Si/m. SIGMA is dimensioned for 25 slabs.

EPSR - Relative permittivity of the ground. EPSR is dimensioned for 25 slabs.

TOPHT - A control height in km for the upper limit on the height gain integrals (see reference 6). TOPHT is dimensioned for 25 slabs.

IDPLOT - Literal constant up to 68 characters which is printed on plots produced. For example, in the NAMELIST input data, place the card  
IDPLOT = "CUTLER TO SAN DIEGO PATH".

The NPUNCH = 1 output file from "MODESRCH" also contains for each mode the ground eigenangles along with four auxiliary quantities (called T1, T2, T3 and T4, see reference 3) for calculating excitation factors.

#### C. OUTPUT

The sample output shown on pages 19 through 27 corresponds to the input on page 12. Figure 4 is the plot output. The principal hardcopy output begins with RHO-KM, MAG(HY)-DB, MAG(HX)-DB and DOA ERROR-DEG. RHO is the range  $MAG(HY) = |H_y|$ ,  $MAG(HX) = |H_x|$  in DB above  $1\mu v/m$  and DOA is the direction of

# SAMPLE OUTPUT FOR Laterally Homogeneous Guide

```

SDATUM
RHOVAX = 10000.0,
RHOVMIN = 25.0,
DELTA = 0.0000000000000000E+000,
NPSLAB = 1,
NIMAX = 1,
XVAL = 0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
DELTA = 25.0,
IFIRST = 1,
LAST = 1,
IPLTOP = 2,
IPLFLG = 2,
XMIN = 0.0000000E+00,
XMAX = 10000.0,
XTIC = 1000.0,
YMIN = -90.0,
YMAX = 90.0,
YTIC = 10.0,
SIZE = 5.0,
SIZEY = 6.0,
GAMMA = 45.0,
PHI = 45.0,
ZT = 10.0,
ZR = 10.0,
IPRNTA = 0,
INIFLG = 0
Send

```

Iualualei to San Diego beta=.7,hprime=87.0

| Slab   | 1      | R         | .000      | F         | 23.4000   | A         | 59.000   | C        | 40.000    | M         | .000 | S | 4.000E+00 | E | 81.0 | T | 87.0 |
|--------|--------|-----------|-----------|-----------|-----------|-----------|----------|----------|-----------|-----------|------|---|-----------|---|------|---|------|
| T3     |        |           |           |           |           |           |          |          |           |           |      |   |           |   |      |   |      |
| T2     |        |           |           |           |           |           |          |          |           |           |      |   |           |   |      |   |      |
| T1     |        |           |           |           |           |           |          |          |           |           |      |   |           |   |      |   |      |
| 89.977 | -5.921 | .118D-03  | -143D-02  | -291D-11  | .516D-07  | .287D-07  | .100D+01 | .663D+00 | -170D-04  | .375D-04  | 87.0 |   |           |   |      |   |      |
| 89.826 | -5.575 | .217D-03  | -172D-02  | -511D-11  | -.686D-07 | -.532D-07 | .100D+01 | .664D+00 | .255D-04  | -.431D-04 | 87.0 |   |           |   |      |   |      |
| 87.886 | -.224  | -.235D-03 | -.266D-01 | -.117D-11 | .122D-06  | .142D-06  | .101D+01 | .669D+00 | -.539D-05 | .455D-05  | 87.0 |   |           |   |      |   |      |
| 84.877 | -.264  | .921D-03  | -102D-02  | -.931D-10 | -.208D-06 | -.250D-06 | .101D+01 | .672D+00 | .338D-04  | -.234D-03 | 87.0 |   |           |   |      |   |      |
| 81.565 | -.158  | -.938D-03 | -.265D-01 | -.722D-11 | .305D-06  | .360D-06  | .101D+01 | .678D+00 | -.140D-04 | .110D-04  | 87.0 |   |           |   |      |   |      |
| 79.291 | -.254  | .124D-02  | -130D-02  | -.272D-09 | -.404D-06 | -.484D-06 | .102D+01 | .685D+00 | .386D-04  | -.349D-03 | 87.0 |   |           |   |      |   |      |
| 76.564 | -.180  | -.141D-02 | -.234D-01 | -.279D-10 | .571D-06  | .640D-06  | .103D+01 | .695D+00 | -.287D-04 | .227D-04  | 87.0 |   |           |   |      |   |      |
| 74.453 | -.317  | .187D-02  | -199D-02  | -.513D-09 | -.699D-06 | -.795D-06 | .103D+01 | .705D+00 | .368D-04  | -.386D-03 | 87.0 |   |           |   |      |   |      |
| 71.810 | -.208  | -.211D-02 | -.216D-01 | -.777D-10 | .932D-06  | .968D-06  | .104D+01 | .720D+00 | -.485D-04 | .384D-04  | 87.0 |   |           |   |      |   |      |
| 69.735 | -.406  | .269D-02  | -.299D-02 | -.804D-09 | -.109D-05 | -.116D-05 | .105D+01 | .735D+00 | .319D-04  | -.394D-03 | 87.0 |   |           |   |      |   |      |
| 67.092 | -.237  | -.293D-02 | -.202D-01 | -.178D-09 | -.139D-05 | .131D-05  | .106D+01 | .757D+00 | -.732D-04 | .583D-04  | 87.0 |   |           |   |      |   |      |
| 64.974 | -.520  | .363D-02  | -.430D-02 | -.113D-08 | -.159D-05 | -.152D-05 | .107D+01 | .778D+00 | .248D-04  | -.391D-03 | 87.0 |   |           |   |      |   |      |

62.310    -.265    -.378D-02    -.188D-01    -.352D-09    -.272D-09    .193D-05    .161D-05    .108D+01    .808D+00    -.102D-03    .823D-04    87.0

CANVA(DEC)= 45.0    FHI(DEC)= 45.0    ZT(KM)= 10.00    ZR(KM)= 10.00

| RID-KM  | MAG(HY)-DB | MAG(HX)-DB | DOA      | ERROR-DEG |
|---------|------------|------------|----------|-----------|
| 25.00   | 71.66740   | 47.19645   | 2.74230  |           |
| 50.00   | 66.95757   | 48.26867   | 2.30534  |           |
| 75.00   | 65.70000   | 48.11575   | -2.84984 |           |
| 100.00  | 65.94413   | 46.78099   | -5.02816 |           |
| 125.00  | 65.24773   | 43.89828   | -4.78900 |           |
| 150.00  | 63.18882   | 38.26220   | -3.05750 |           |
| 175.00  | 60.57584   | 23.28412   | .21311   |           |
| 200.00  | 59.59312   | 33.50273   | .12753   |           |
| 225.00  | 59.79551   | 37.33784   | -3.19240 |           |
| 250.00  | 59.08715   | 37.26743   | -4.63417 |           |
| 275.00  | 57.11247   | 35.04356   | -2.22402 |           |
| 300.00  | 55.17791   | 33.48625   | 4.09919  |           |
| 325.00  | 54.98226   | 35.17102   | 3.17968  |           |
| 350.00  | 55.15501   | 36.58604   | -3.25591 |           |
| 375.00  | 54.56257   | 36.38007   | -6.95028 |           |
| 400.00  | 53.80356   | 34.57244   | -4.17061 |           |
| 425.00  | 53.59080   | 31.44646   | 1.72029  |           |
| 450.00  | 53.24369   | 28.32880   | 3.23600  |           |
| 475.00  | 52.00952   | 27.34679   | .45617   |           |
| 500.00  | 50.44985   | 27.31310   | -3.61293 |           |
| 525.00  | 50.10388   | 26.81721   | -2.92516 |           |
| 550.00  | 50.18236   | 25.87212   | .19685   |           |
| 575.00  | 48.76371   | 24.58409   | 2.21200  |           |
| 600.00  | 44.67525   | 22.94579   | 4.27981  |           |
| 625.00  | 39.13107   | 21.25554   | 6.58955  |           |
| 650.00  | 41.42048   | 19.79075   | 1.81254  |           |
| 675.00  | 41.86361   | 19.27004   | 1.92738  |           |
| 700.00  | 38.78941   | 22.12901   | 1.76649  |           |
| 725.00  | 42.75337   | 25.91675   | -5.85495 |           |
| 750.00  | 47.61351   | 28.25690   | -5.81601 |           |
| 775.00  | 49.63649   | 28.81586   | -5.18849 |           |
| 800.00  | 49.81597   | 27.36092   | -3.54744 |           |
| 825.00  | 49.46259   | 23.07137   | -23697   |           |
| 850.00  | 50.10002   | 16.90414   | 1.23950  |           |
| 875.00  | 51.30544   | 22.24642   | -51278   |           |
| 900.00  | 51.92902   | 25.20647   | -2.30038 |           |
| 925.00  | 51.86135   | 24.79284   | -2.49982 |           |
| 950.00  | 51.70081   | 20.61537   | -96648   |           |
| 975.00  | 51.90137   | 4.83619    | .21162   |           |
| 1000.00 | 52.11540   | 18.74664   | -40263   |           |
| 1025.00 | 51.91638   | 23.04480   | -1.74951 |           |
| 1050.00 | 51.47338   | 23.23653   | -2.21019 |           |
| 1075.00 | 51.32445   | 20.07961   | -1.19340 |           |
| 1100.00 | 51.48270   | 10.42288   | -29119   |           |
| 1125.00 | 51.40879   | 13.28231   | -57611   |           |
| 1150.00 | 50.93456   | 19.32901   | -1.46816 |           |
| 1175.00 | 50.58438   | 20.83895   | -1.72658 |           |
| 1200.00 | 50.84156   | 20.35519   | -91484   |           |

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| 1225.00 | 51.23663 | 19.07388 | - .03937 |
| 1250.00 | 51.17233 | 18.28256 | .58708   |
| 1275.00 | 50.73694 | 18.76287 | 1.23926  |
| 1300.00 | 50.58887 | 19.91410 | 1.66871  |
| 1325.00 | 50.98455 | 20.60196 | 1.36975  |
| 1350.00 | 51.33828 | 20.10514 | .78728   |
| 1375.00 | 51.23180 | 18.72502 | .54720   |
| 1400.00 | 50.88161 | 19.37252 | .77047   |
| 1425.00 | 50.80544 | 22.19034 | .84305   |
| 1450.00 | 51.02577 | 24.00334 | .23175   |
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| 1500.00 | 50.63639 | 22.15845 | - .96715 |
| 1525.00 | 50.02036 | 19.52205 | - .67886 |
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| 1575.00 | 49.36560 | 22.95218 | - .91123 |
| 1600.00 | 48.88462 | 23.67390 | -1.94157 |
| 1625.00 | 48.04810 | 22.40328 | -2.57419 |
| 1650.00 | 47.16954 | 19.05075 | -2.18495 |
| 1675.00 | 46.50153 | 14.95611 | -1.42750 |
| 1700.00 | 45.75887 | 15.51513 | -1.43284 |
| 1725.00 | 44.66785 | 16.77215 | -2.08329 |
| 1750.00 | 43.71585 | 15.91819 | -2.32251 |
| 1775.00 | 43.64375 | 14.02518 | -1.88786 |
| 1800.00 | 43.94242 | 14.47407 | -1.92529 |
| 1825.00 | 43.85702 | 16.35606 | -2.37024 |
| 1850.00 | 43.61460 | 17.13508 | -2.26041 |
| 1875.00 | 43.87623 | 16.69878 | -1.35422 |
| 1900.00 | 44.42009 | 15.95260 | - .68891 |
| 1925.00 | 44.54139 | 16.12607 | - .38790 |
| 1950.00 | 44.14115 | 16.89737 | .20487   |
| 1975.00 | 43.78405 | 17.07365 | 1.22186  |
| 2000.00 | 43.88314 | 16.23312 | 1.75282  |
| 2025.00 | 44.01170 | 15.27830 | 1.70164  |
| 2050.00 | 43.77855 | 16.29053 | 2.00919  |
| 2075.00 | 43.52179 | 18.27494 | 2.97961  |
| 2100.00 | 43.81002 | 19.28176 | 3.36810  |
| 2125.00 | 44.43992 | 18.81991 | 2.57500  |
| 2150.00 | 44.93700 | 17.10133 | 1.64778  |
| 2175.00 | 45.37430 | 15.75187 | 1.32209  |
| 2200.00 | 46.06102 | 16.59953 | 1.33148  |
| 2225.00 | 46.90535 | 17.58372 | 1.08310  |
| 2250.00 | 47.57825 | 17.18725 | .64693   |
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| 2300.00 | 48.34611 | 14.78282 | .51319   |
| 2325.00 | 48.73292 | 16.12426 | .64533   |
| 2350.00 | 49.05885 | 17.29521 | .53353   |
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| 2425.00 | 49.21022 | 15.44355 | - .06965 |
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| 2475.00 | 49.16658 | 14.48492 | - .34831 |
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| 2575.00 | 48.19297 | 7.78750   | -47380  |
| 2600.00 | 47.92335 | 7.64850   | -55399  |
| 2625.00 | 47.52505 | 7.49341   | -46822  |
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| 2675.00 | 46.88370 | 7.57973   | .16472  |
| 2700.00 | 46.65430 | 7.78575   | .33504  |
| 2725.00 | 46.32415 | 9.21638   | .50809  |
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| 2775.00 | 45.62033 | 12.28885  | 1.19079 |
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| 3025.00 | 39.33421 | 1.90092   | .33760  |
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| 3100.00 | 35.41099 | -5.42392  | .16164  |
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| 3475.00 | 41.92940 | 6.78982   | .62109  |
| 3500.00 | 42.07103 | 7.73983   | .59836  |
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| 3925.00 | 45.08648 | 16.89143 | - .37872 |
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| 4150.00 | 42.46621 | 6.45811  | - .44896 |
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| 4200.00 | 41.90434 | 3.39545  | - .17620 |
| 4225.00 | 41.63517 | 2.58928  | - .01131 |
| 4250.00 | 41.40548 | 3.21964  | .12048   |
| 4275.00 | 41.17921 | 3.89425  | .16751   |
| 4300.00 | 40.90772 | 3.76009  | .17252   |
| 4325.00 | 40.60022 | 3.25059  | .20999   |
| 4350.00 | 40.30236 | 3.17653  | .27878   |
| 4375.00 | 40.01664 | 3.34088  | .31993   |
| 4400.00 | 39.70124 | 3.09765  | .33167   |
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| 4500.00 | 38.90697 | 4.60592  | .50841   |
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| 4575.00 | 39.72614 | 6.03993  | .31224   |
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| 4625.00 | 40.75378 | 6.51542  | .03525   |
| 4650.00 | 41.25146 | 6.28211  | - .05752 |
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| 4900.00 | 43.22430 | -1.71263 | - .23313 |
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| 4975.00 | 42.94230 | -4.22426 | - .22005 |
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| 5075.00 | 42.49188 | -6.19059 | - .16342 |
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| 5275.00 | 41.27240 | 5.46346   | -58077   |
| 5300.00 | 40.98830 | 6.59142   | -73737   |
| 5325.00 | 40.65309 | 7.42209   | -90801   |
| 5350.00 | 40.27722 | 8.03288   | -1.07985 |
| 5375.00 | 39.87064 | 8.54245   | -1.26121 |
| 5400.00 | 39.42796 | 8.96056   | -1.46167 |
| 5425.00 | 38.94027 | 9.19613   | -1.66620 |
| 5450.00 | 38.41849 | 9.19272   | -1.84284 |
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| 5500.00 | 37.39071 | 8.72498   | -2.07086 |
| 5525.00 | 36.91911 | 8.37513   | -2.13040 |
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| 5575.00 | 36.15332 | 7.14258   | -2.01568 |
| 5600.00 | 35.93303 | 6.24039   | -1.83223 |
| 5625.00 | 35.83246 | 5.25361   | -1.61720 |
| 5650.00 | 35.82935 | 4.16880   | -1.38838 |
| 5675.00 | 35.91076 | 2.86431   | -1.14749 |
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| 5725.00 | 36.26434 | -40740    | -73665   |
| 5750.00 | 36.46849 | -2.20286  | -58620   |
| 5775.00 | 36.66456 | -4.52330  | -43417   |
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| 5825.00 | 37.07220 | -16.31509 | -11177   |
| 5850.00 | 37.28611 | -20.12394 | .02487   |
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| 6000.00 | 39.01590 | 4.41025   | .45304   |
| 6025.00 | 39.39524 | 5.59585   | .43551   |
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| 6075.00 | 40.16638 | 7.32681   | .34435   |
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| 6625.00 | 40.06582 | 3.39362  | .70249   |
| 6650.00 | 39.81897 | 3.61718  | .75305   |
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| 6925.00 | 36.02731 | -.03320  | .85851   |
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| 6975.00 | 35.86073 | .42592   | .92949   |
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| 7075.00 | 36.54640 | 1.07159  | .88601   |
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| 7375.00 | 38.24466 | -1.54931 | .32345   |
| 7400.00 | 38.29610 | -1.17079 | .27352   |
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| 7450.00 | 38.41307 | .02167   | .14794   |
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| 7575.00 | 38.71876 | 4.04039  | -.26961  |
| 7600.00 | 38.75021 | 4.73363  | -.35759  |
| 7625.00 | 38.76359 | 5.36653  | -.44413  |
| 7650.00 | 38.75460 | 5.92312  | -.52932  |
| 7675.00 | 38.71954 | 6.38761  | -.61103  |
| 7700.00 | 38.65716 | 6.75964  | -.68684  |
| 7725.00 | 38.56805 | 7.04940  | -.75635  |
| 7750.00 | 38.45272 | 7.26119  | -.82049  |
| 7775.00 | 38.31152 | 7.38826  | -.87889  |
| 7800.00 | 38.14629 | 7.42431  | -.92927  |
| 7825.00 | 37.96115 | 7.37328  | -.96950  |
| 7850.00 | 37.76112 | 7.24353  | -.99890  |
| 7875.00 | 37.55084 | 7.03639  | -1.01667 |
| 7900.00 | 37.33544 | 6.74855  | -1.02012 |
| 7925.00 | 37.12189 | 6.38758  | -1.00619 |
| 7950.00 | 36.91799 | 5.97905  | -.97468  |

|         |          |           |        |
|---------|----------|-----------|--------|
| 7975.00 | 36.72943 | 5.55376   | -92857 |
| 8000.00 | 36.55875 | 5.13335   | -87109 |
| 8025.00 | 36.40698 | 4.73683   | -80427 |
| 8050.00 | 36.27509 | 4.39502   | -73099 |
| 8075.00 | 36.16283 | 4.14067   | -65647 |
| 8100.00 | 36.06770 | 3.98201   | -58592 |
| 8125.00 | 35.98650 | 3.90129   | -52169 |
| 8150.00 | 35.91798 | 3.87886   | -46408 |
| 8175.00 | 35.86311 | 3.90138   | -41375 |
| 8200.00 | 35.82380 | 3.94975   | -37136 |
| 8225.00 | 35.80304 | 4.00066   | -33543 |
| 8250.00 | 35.80624 | 4.04599   | -30263 |
| 8275.00 | 35.84089 | 4.09815   | -27081 |
| 8300.00 | 35.91354 | 4.17127   | -24010 |
| 8325.00 | 36.02767 | 4.26749   | -21071 |
| 8350.00 | 36.18415 | 4.38689   | -18159 |
| 8375.00 | 36.38207 | 4.53809   | -15218 |
| 8400.00 | 36.61757 | 4.72743   | -12408 |
| 8425.00 | 36.88268 | 4.94373   | -99950 |
| 8450.00 | 37.16663 | 5.16372   | -07900 |
| 8475.00 | 37.45832 | 5.36785   | -06175 |
| 8500.00 | 37.74751 | 5.54319   | -04716 |
| 8525.00 | 38.02473 | 5.67537   | -03513 |
| 8550.00 | 38.28152 | 5.74767   | -02481 |
| 8575.00 | 38.51153 | 5.74944   | -01455 |
| 8600.00 | 38.71087 | 5.67986   | -00297 |
| 8625.00 | 38.87737 | 5.54115   | .01022 |
| 8650.00 | 39.00972 | 5.33201   | .02512 |
| 8675.00 | 39.10769 | 5.05173   | .04240 |
| 8700.00 | 39.17265 | 4.70877   | .06296 |
| 8725.00 | 39.20732 | 4.32043   | .08672 |
| 8750.00 | 39.21474 | 3.90289   | .11261 |
| 8775.00 | 39.19767 | 3.46577   | .13944 |
| 8800.00 | 39.15887 | 3.01776   | .16649 |
| 8825.00 | 39.10140 | 2.57152   | .19301 |
| 8850.00 | 39.02815 | 2.13637   | .21757 |
| 8875.00 | 38.94115 | 1.70898   | .23846 |
| 8900.00 | 38.84153 | 1.27655   | .25453 |
| 8925.00 | 38.72988 | .82604    | .26505 |
| 8950.00 | 38.60622 | .34248    | .26905 |
| 8975.00 | 38.46959 | -         | .26527 |
| 9000.00 | 38.31791 | -84044    | .25292 |
| 9025.00 | 38.14869 | -1.61632  | .23219 |
| 9050.00 | 37.95982 | -2.56467  | .20357 |
| 9075.00 | 37.74945 | -3.73317  | .16721 |
| 9100.00 | 37.51587 | -5.19954  | .12317 |
| 9125.00 | 37.25767 | -7.08314  | .07237 |
| 9150.00 | 36.97468 | -9.54809  | .01670 |
| 9175.00 | 36.66853 | -12.72807 | -04168 |
| 9200.00 | 36.34244 | -15.81708 | -10066 |
| 9225.00 | 36.00112 | -15.20696 | -15764 |
| 9250.00 | 35.65107 | -11.98579 | -20903 |
| 9275.00 | 35.30086 | -9.17100  | -25078 |
| 9300.00 | 34.96067 | -7.06581  | -27951 |

|          |          |           |         |
|----------|----------|-----------|---------|
| 9325.00  | 34.64120 | -5.49782  | -.29276 |
| 9350.00  | 34.35282 | -4.32666  | -.28880 |
| 9375.00  | 34.10516 | -3.46830  | -.26724 |
| 9400.00  | 33.90611 | -2.87158  | -.23056 |
| 9425.00  | 33.76011 | -2.49788  | -.18431 |
| 9450.00  | 33.66722 | -2.31463  | -.13523 |
| 9475.00  | 33.62391 | -2.29905  | -.08919 |
| 9500.00  | 33.62442 | -2.44000  | -.05080 |
| 9525.00  | 33.66175 | -2.73201  | -.02354 |
| 9550.00  | 33.72827 | -3.16813  | -.00926 |
| 9575.00  | 33.81677 | -3.74143  | -.00756 |
| 9600.00  | 33.92160 | -4.45300  | -.01638 |
| 9625.00  | 34.03904 | -5.31516  | -.03340 |
| 9650.00  | 34.16688 | -6.34618  | -.05647 |
| 9675.00  | 34.30410 | -7.56767  | -.08341 |
| 9700.00  | 34.45087 | -9.00870  | -.11204 |
| 9725.00  | 34.60828 | -10.68081 | -.14098 |
| 9750.00  | 34.77739 | -12.41676 | -.17002 |
| 9775.00  | 34.95845 | -13.46797 | -.19954 |
| 9800.00  | 35.15072 | -12.77204 | -.22967 |
| 9825.00  | 35.35270 | -10.70961 | -.26029 |
| 9850.00  | 35.56223 | -8.37833  | -.29144 |
| 9875.00  | 35.77628 | -6.25027  | -.32327 |
| 9900.00  | 35.99095 | -4.41457  | -.35557 |
| 9925.00  | 36.20202 | -2.85577  | -.38758 |
| 9950.00  | 36.40538 | -1.53673  | -.41833 |
| 9975.00  | 36.59714 | -.42198   | -.44697 |
| 10000.00 | 36.77363 | .51508    | -.47271 |

If this is the hp 7550 plotter and you want auto feed,  
then set up the plotter, load a sheet and answer y:  
Do you want auto feed?  
Set up plotter, enter rotation (y/n) when ready

Lualualei to San Diego  $\beta = .7, h_{\text{prime}} = 87.0$

Freq = 23.400 kHz

$Z_t = 10.00$  km  $Z_r = 10.00$  km

$\Gamma = 45.0$  deg  $\Phi = 45.0$  deg

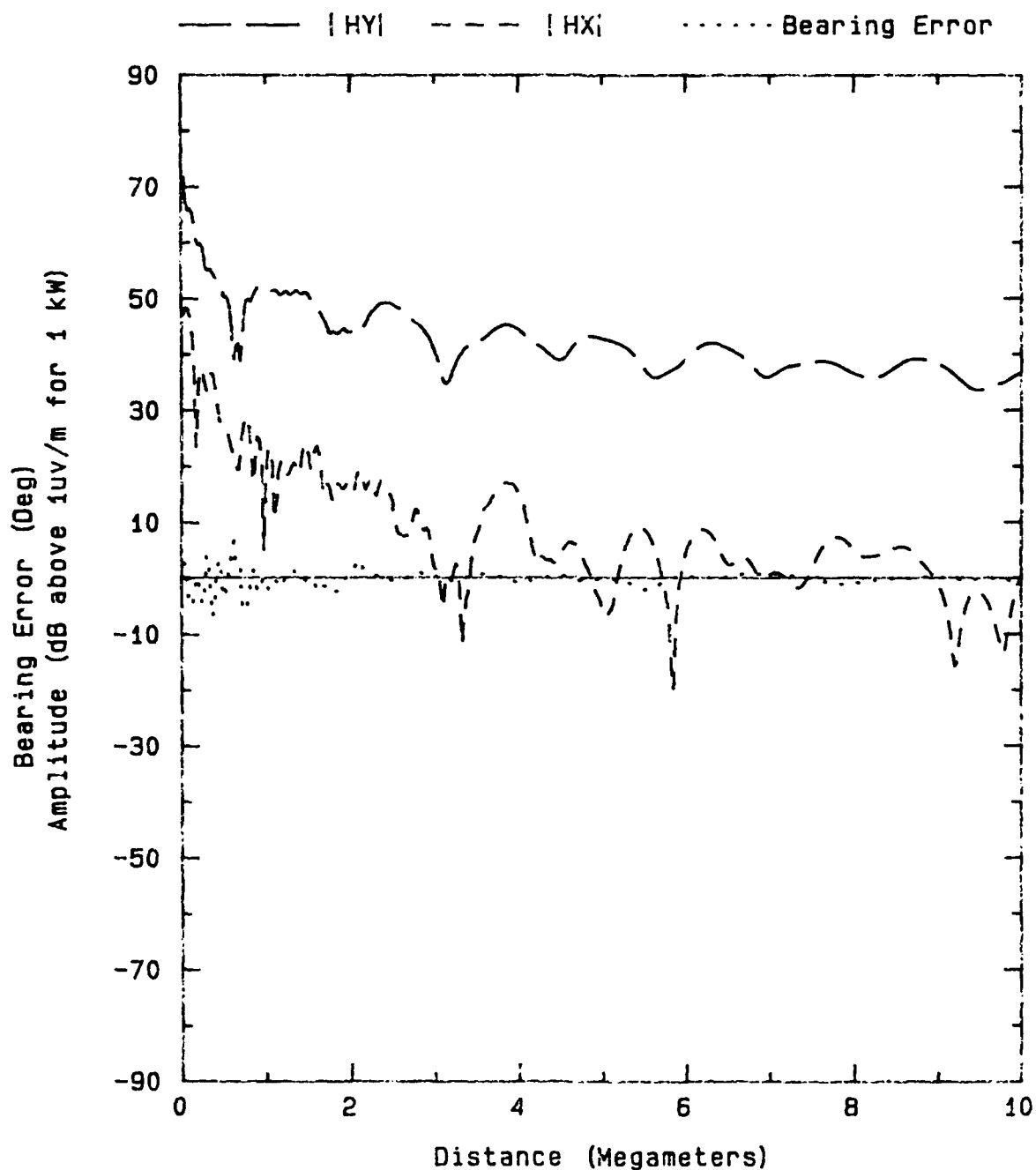


Figure 4. Plot output for laterally homogeneous guide sample input.

arrival error in degrees. The sample output shown on pages 30 through 37 corresponds to the input which begins on page 13 and Figure 5 is the plot output. In this case the transmitter-terminator distance is the distance  $D$  on Figure 2.

```

$DATUM
RHOMAX = 4166.0,
RHOMIN = 3821.0,
DELTAX = 25.0,
NPSLAB = 9,
NIMAX = 261,
XVAL = -1525.0, -1500.0, -1312.5000000000000000, -1187.5000000000000000,
-1062.5000000000000000, -937.5000000000000000, -812.5000000000000000,
-687.5000000000000000, -500.0, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
0.0000000000000000E+000, 0.0000000000000000E+000, 0.0000000000000000E+000,
DELRHO = 345.0,
IFIRST = 1,
LAST = 1,
IPILOP = 1,
IPIFLG = 1,
XMIN = -1500.0,
XMAX = 5000.0,
XTIC = 500.0,
XMIN = -30.0,
XMAX = 50.0,
YTIC = 10.0,
YSIZEX = 7.820000017,
SIZEY = 4.92000008,
CANVA = 45.0,
FHI = 270.0,
ZT = 15.0,
ZR = 15.0,
IPRNTA = 6,
INIFLG = 0,
send

```

[illegible]

|                                                                            |           |           |           |          |          |       |  |  |  |
|----------------------------------------------------------------------------|-----------|-----------|-----------|----------|----------|-------|--|--|--|
| Slab 3 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 82.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.885 -5.074                                                              | .477D-03  | -.571D-02 | -.348D-12 | .863D+00 | .275D+00 | 82.0  |  |  |  |
| 89.591 -4.555                                                              | .980D-03  | -.289D-02 | -.132D-10 | .866D+00 | .276D+00 | 82.0  |  |  |  |
| 85.414 -3.371                                                              | -.508D-03 | -.322D-01 | -.174D-11 | .886D+00 | .277D+00 | 82.0  |  |  |  |
| 82.722 -4.87                                                               | .160D-02  | -.119D-02 | -.134D-09 | .901D+00 | .280D+00 | 82.0  |  |  |  |
| 79.183 -4.03                                                               | -.188D-02 | -.282D-01 | -.128D-10 | .931D+00 | .284D+00 | 82.0  |  |  |  |
| Slab 4 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 80.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.821 -4.782                                                              | .106D-02  | -.839D-02 | -.211D-11 | .726D+00 | .279D+00 | 80.0  |  |  |  |
| 89.461 -4.206                                                              | .741D-03  | -.197D-02 | -.182D-10 | .730D+00 | .281D+00 | 80.0  |  |  |  |
| 84.886 -4.447                                                              | -.172D-03 | -.334D-01 | -.137D-11 | .750D+00 | .280D+00 | 80.0  |  |  |  |
| 82.173 -6.18                                                               | .125D-02  | -.774D-03 | -.155D-09 | .795D+00 | .263D+00 | 80.0  |  |  |  |
| 78.597 -4.99                                                               | -.151D-02 | -.291D-01 | -.999D-11 | .795D+00 | .259D+00 | 80.0  |  |  |  |
| Slab 5 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 78.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.749 -4.486                                                              | .179D-02  | -.114D-01 | -.932D-12 | .576D+00 | .311D+00 | 78.0  |  |  |  |
| 89.241 -3.754                                                              | .448D-03  | -.948D-03 | -.246D-10 | .579D+00 | .313D+00 | 78.0  |  |  |  |
| 84.342 -5.47                                                               | .211D-03  | -.344D-01 | -.890D-12 | .602D+00 | .312D+00 | 78.0  |  |  |  |
| 81.568 -8.02                                                               | .829D-03  | -.505D-03 | -.180D-09 | .623D+00 | .315D+00 | 78.0  |  |  |  |
| 77.968 -6.635                                                              | -.757D-03 | -.302D-01 | -.717D-11 | .661D+00 | .318D+00 | 78.0  |  |  |  |
| Slab 6 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 76.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.678 -4.195                                                              | .246D-02  | -.142D-01 | -.312D-12 | .422D+00 | .389D+00 | 76.0  |  |  |  |
| 88.907 -3.172                                                              | .270D-03  | -.339D-03 | -.322D-10 | .430D+00 | .376D+00 | 76.0  |  |  |  |
| 83.786 -6.57                                                               | .579D-03  | -.354D-01 | -.417D-12 | .449D+00 | .388D+00 | 76.0  |  |  |  |
| 80.885 -9.77                                                               | .498D-03  | -.235D-03 | -.212D-09 | .471D+00 | .391D+00 | 76.0  |  |  |  |
| 77.299 -7.94                                                               | -.287D-04 | -.313D-01 | -.375D-11 | .509D+00 | .389D+00 | 76.0  |  |  |  |
| Slab 7 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 74.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.602 -3.903                                                              | .309D-02  | -.163D-01 | -.943D-13 | .291D+00 | .515D+00 | 74.0  |  |  |  |
| 88.404 -2.498                                                              | .153D-03  | -.109D-03 | -.414D-10 | .296D+00 | .515D+00 | 74.0  |  |  |  |
| 83.216 -7.73                                                               | .899D-03  | -.363D-01 | -.102D-12 | .316D+00 | .510D+00 | 74.0  |  |  |  |
| 80.152 -1.114                                                              | .294D-03  | -.768D-04 | -.251D-09 | .339D+00 | .505D+00 | 74.0  |  |  |  |
| 76.588 -9.972                                                              | .623D-03  | -.324D-01 | -.109D-11 | .373D+00 | .507D+00 | 74.0  |  |  |  |
| Slab 8 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 72.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.507 -3.593                                                              | .374D-02  | -.194D-01 | -.280D-13 | .205D+00 | .665D+00 | 72.0  |  |  |  |
| 87.663 -1.928                                                              | .804D-04  | -.338D-04 | -.523D-10 | .210D+00 | .665D+00 | 72.0  |  |  |  |
| 82.624 -9.05                                                               | .123D-02  | -.371D-01 | -.293D-13 | .228D+00 | .661D+00 | 72.0  |  |  |  |
| 79.405 -1.226                                                              | .173D-03  | -.148D-04 | -.296D-09 | .247D+00 | .660D+00 | 72.0  |  |  |  |
| 75.834 -1.175                                                              | .119D-02  | -.334D-01 | .218D-12  | .278D+00 | .656D+00 | 72.0  |  |  |  |
| Slab 9 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 70.0 |           |           |           |          |          |       |  |  |  |
| THETA                                                                      | T1        | T2        | T3        | T4       | FOFR     | TOHIT |  |  |  |
| 89.375 -3.252                                                              | .442D-02  | -.221D-01 | -.824D-14 | .163D+00 | .804D+00 | 70.0  |  |  |  |
| 86.811 -1.623                                                              | .389D-04  | -.112D-04 | -.652D-10 | .169D+00 | .804D+00 | 70.0  |  |  |  |
| 81.993 -1.059                                                              | .160D-02  | -.378D-01 | .496D-13  | .186D+00 | .804D+00 | 70.0  |  |  |  |

78.644 -1.357 .966D-04 - .418D-06 - .347D-09 - .102D-09 - .102D-06 - .178D-06 - .105D-02 - .185D-02 70.0  
 75.021 -1.414 .173D-02 - .343D-01 .522D-12 - .299D-11 .179D-06 .304D-06 - .858D-05 .565D-05 70.0

GAMMA(DEG) = 45.0 PHI(DEG) = 270.0 ZT(KM) = 15.00 ZR(KM) = 15.00

| RHO-KM   | MAG(HV)-DB | MAG(HX)-DB | DOA ERROR-DEG |
|----------|------------|------------|---------------|
| -1500.00 | 34.47892   | -3.81974   | -.69616       |
| -1475.00 | 34.47892   | -3.81974   | -.69616       |
| -1450.00 | 34.47892   | -3.81974   | -.69616       |
| -1425.00 | 34.47892   | -3.81974   | -.69616       |
| -1400.00 | 34.47892   | -3.81974   | -.69616       |
| -1375.00 | 34.47892   | -3.81974   | -.69616       |
| -1350.00 | 34.47892   | -3.81974   | -.69616       |
| -1325.00 | 34.47892   | -3.81974   | -.69616       |
| -1300.00 | 34.47892   | -3.81974   | -.69616       |
| -1275.00 | 34.47892   | -3.81974   | -.69616       |
| -1250.00 | 34.47892   | -3.81974   | -.69616       |
| -1225.00 | 34.47892   | -3.81974   | -.69616       |
| -1200.00 | 34.47892   | -3.81974   | -.69616       |
| -1175.00 | 34.47892   | -3.81974   | -.69616       |
| -1150.00 | 34.47892   | -3.81974   | -.69616       |
| -1125.00 | 34.47892   | -3.81974   | -.69616       |
| -1100.00 | 34.47892   | -3.81974   | -.69616       |
| -1075.00 | 34.47892   | -3.81974   | -.69616       |
| -1050.00 | 34.47892   | -3.81974   | -.69616       |
| -1025.00 | 34.47892   | -3.81974   | -.69616       |
| -1000.00 | 34.58644   | -3.39803   | -.72150       |
| -975.00  | 34.56483   | -3.43329   | -.72077       |
| -950.00  | 34.53733   | -3.50123   | -.71771       |
| -925.00  | 34.50733   | -3.59941   | -.71228       |
| -900.00  | 34.47756   | -3.72460   | -.70460       |
| -875.00  | 34.44984   | -3.87256   | -.69496       |
| -850.00  | 34.42490   | -4.03793   | -.68382       |
| -825.00  | 34.40250   | -4.21414   | -.67179       |
| -800.00  | 34.46198   | -3.94278   | -.68802       |
| -775.00  | 34.42507   | -4.10970   | -.67781       |
| -750.00  | 34.38156   | -4.30081   | -.66631       |
| -725.00  | 34.33237   | -4.51125   | -.65387       |
| -700.00  | 34.27830   | -4.73488   | -.64086       |
| -675.00  | 34.27860   | -4.44543   | -.66126       |
| -650.00  | 34.21058   | -4.64109   | -.65124       |
| -625.00  | 34.13583   | -4.86098   | -.63985       |
| -600.00  | 34.05593   | -5.10078   | -.62725       |
| -575.00  | 33.97232   | -5.35457   | -.61368       |
| -550.00  | 33.95747   | -5.07095   | -.63026       |
| -525.00  | 33.86533   | -5.28489   | -.61990       |
| -500.00  | 33.76840   | -5.52065   | -.60792       |
| -475.00  | 33.66802   | -5.77332   | -.59447       |
| -450.00  | 33.56533   | -6.03609   | -.57973       |
| -425.00  | 33.52674   | -5.72958   | -.59425       |
| -400.00  | 33.41534   | -5.93593   | -.58357       |
| -375.00  | 33.29926   | -6.15699   | -.57130       |
| -350.00  | 33.17956   | -6.38672   | -.55754       |

|         |          |          |          |
|---------|----------|----------|----------|
| -325.00 | 33.05709 | -6.61704 | -54244   |
| -300.00 | 33.00925 | -6.14768 | -55929   |
| -275.00 | 32.87444 | -6.30345 | -54927   |
| -250.00 | 32.73381 | -6.46226 | -53800   |
| -225.00 | 32.58839 | -6.61775 | -52553   |
| -200.00 | 32.43914 | -6.76233 | -51199   |
| -175.00 | 32.37304 | -6.21965 | -52520   |
| -150.00 | 32.20744 | -6.28857 | -51792   |
| -125.00 | 32.03511 | -6.35397 | -50991   |
| -100.00 | 31.85725 | -6.41173 | -50120   |
| -75.00  | 31.67506 | -6.45740 | -49185   |
| -50.00  | 31.48966 | -6.48633 | -48194   |
| -25.00  | 31.30198 | -6.49385 | -47158   |
|         | 31.22661 | -5.80880 | -48201   |
|         | 31.02061 | -5.75371 | -48032   |
| 25.00   | 30.80734 | -5.69380 | -47901   |
| 50.00   | 30.58796 | -5.62780 | -47817   |
| 75.00   | 30.36367 | -5.55442 | -47792   |
| 100.00  | 30.13564 | -5.47246 | -47835   |
| 125.00  | 29.90497 | -5.38080 | -47957   |
| 150.00  | 29.67266 | -5.27841 | -48173   |
| 175.00  | 29.43956 | -5.16442 | -48495   |
| 200.00  | 29.20638 | -5.03811 | -48941   |
| 225.00  | 28.97364 | -4.89896 | -49531   |
| 250.00  | 28.74168 | -4.74665 | -50289   |
| 275.00  | 28.51074 | -4.58110 | -51241   |
| 300.00  | 28.28094 | -4.40246 | -52423   |
| 325.00  | 28.05239 | -4.21108 | -53873   |
| 350.00  | 27.82526 | -4.00758 | -55639   |
| 375.00  | 27.59991 | -3.79276 | -57774   |
| 400.00  | 27.37694 | -3.56760 | -60339   |
| 425.00  | 27.15735 | -3.33328 | -63400   |
| 450.00  | 26.94262 | -3.09108 | -67027   |
| 475.00  | 26.73477 | -2.84242 | -71286   |
| 500.00  | 26.53647 | -2.58880 | -76235   |
| 525.00  | 26.35102 | -2.33178 | -81915   |
| 550.00  | 26.18228 | -2.07295 | -88332   |
| 575.00  | 26.03459 | -1.81395 | -95451   |
| 600.00  | 25.91257 | -1.55638 | -1.03177 |
| 625.00  | 25.82083 | -1.30186 | -1.11347 |
| 650.00  | 25.76359 | -1.05196 | -1.19731 |
| 675.00  | 25.74438 | -.80824  | -1.28034 |
| 700.00  | 25.76568 | -.57217  | -1.35922 |
| 725.00  | 25.82862 | -.34521  | -1.43050 |
| 750.00  | 25.93295 | -.12872  | -1.49098 |
| 775.00  | 26.07697 | .07601   | -1.53797 |
| 800.00  | 26.25779 | .26775   | -1.56963 |
| 825.00  | 26.47158 | .44536   | -1.58495 |
| 850.00  | 26.71389 | .60783   | -1.58382 |
| 875.00  | 26.97998 | .75419   | -1.56686 |
| 900.00  | 27.26514 | .88363   | -1.53525 |
| 925.00  | 27.56487 | .99543   | -1.49057 |
| 950.00  | 27.87505 | 1.08898  | -1.43458 |
| 975.00  | 28.19202 | 1.16383  | -1.36912 |
| 1000.00 |          |          |          |

|         |          |         |          |
|---------|----------|---------|----------|
| 1025.00 | 28.51265 | 1.21963 | -1.29600 |
| 1050.00 | 28.83429 | 1.25619 | -1.21694 |
| 1075.00 | 29.15475 | 1.27347 | -1.13349 |
| 1100.00 | 29.47231 | 1.27157 | -1.04707 |
| 1125.00 | 29.78561 | 1.25076 | -95892   |
| 1150.00 | 30.09359 | 1.21147 | -87011   |
| 1175.00 | 30.39548 | 1.15431 | -78155   |
| 1200.00 | 30.69072 | 1.08005 | -69402   |
| 1225.00 | 30.97888 | .98966  | -60813   |
| 1250.00 | 31.25965 | .88430  | -52437   |
| 1275.00 | 31.53284 | .76534  | -44312   |
| 1300.00 | 31.79826 | .63436  | -36463   |
| 1325.00 | 32.05580 | .49322  | -28906   |
| 1350.00 | 32.30538 | .34400  | -21650   |
| 1375.00 | 32.54699 | .18912  | -14694   |
| 1400.00 | 32.78067 | .03128  | -08034   |
| 1425.00 | 33.00654 | -.12645 | -01662   |
| 1450.00 | 33.22483 | -.28067 | .04435   |
| 1475.00 | 33.43587 | -.42760 | .10271   |
| 1500.00 | 33.64011 | -.56316 | .15859   |
| 1525.00 | 33.83810 | -.68299 | .21214   |
| 1550.00 | 34.03043 | -.78256 | .26353   |
| 1575.00 | 34.21774 | -.85725 | .31293   |
| 1600.00 | 34.40061 | -.90257 | .36053   |
| 1625.00 | 34.57953 | -.91430 | .40656   |
| 1650.00 | 34.75480 | -.88873 | .45129   |
| 1675.00 | 34.92646 | -.82279 | .49506   |
| 1700.00 | 35.09430 | -.71428 | .53824   |
| 1725.00 | 35.25776 | -.56198 | .58129   |
| 1750.00 | 35.41600 | -.36571 | .62470   |
| 1775.00 | 35.56795 | -.12636 | .66901   |
| 1800.00 | 35.71233 | .15418  | .71477   |
| 1825.00 | 35.84782 | .47317  | .76255   |
| 1850.00 | 35.97311 | .82712  | .81289   |
| 1875.00 | 36.08706 | 1.21204 | .86629   |
| 1900.00 | 36.18871 | 1.62361 | .92322   |
| 1925.00 | 36.27742 | 2.05739 | .98407   |
| 1950.00 | 36.35285 | 2.50902 | 1.04915  |
| 1975.00 | 36.41496 | 2.97430 | 1.11872  |
| 2000.00 | 36.46397 | 3.44931 | 1.19295  |
| 2025.00 | 36.50023 | 3.93047 | 1.27198  |
| 2050.00 | 36.52418 | 4.41456 | 1.35587  |
| 2075.00 | 36.53618 | 4.89864 | 1.44470  |
| 2100.00 | 36.53640 | 5.38011 | 1.53851  |
| 2125.00 | 36.52473 | 5.85654 | 1.63742  |
| 2150.00 | 36.50074 | 6.32574 | 1.74158  |
| 2175.00 | 36.46365 | 6.78556 | 1.85123  |
| 2200.00 | 36.41234 | 7.23403 | 1.96667  |
| 2225.00 | 36.34551 | 7.66918 | 2.08827  |
| 2250.00 | 36.26175 | 8.08911 | 2.21645  |
| 2275.00 | 36.15969 | 8.49200 | 2.35163  |
| 2300.00 | 36.03822 | 8.87613 | 2.49416  |
| 2325.00 | 35.89657 | 9.23989 | 2.64426  |
| 2350.00 | 35.73457 | 9.58186 | 2.80195  |

|         |          |          |         |
|---------|----------|----------|---------|
| 2375.00 | 35.55272 | 9.90083  | 2.96693 |
| 2400.00 | 35.35236 | 10.19586 | 3.13847 |
| 2425.00 | 35.13578 | 10.46629 | 3.31531 |
| 2450.00 | 34.90633 | 10.71180 | 3.49546 |
| 2475.00 | 34.66844 | 10.93242 | 3.67610 |
| 2500.00 | 34.42772 | 11.12856 | 3.85346 |
| 2525.00 | 34.19083 | 11.30097 | 4.02273 |
| 2550.00 | 33.96544 | 11.45079 | 4.17808 |
| 2575.00 | 33.75994 | 11.57949 | 4.31287 |
| 2600.00 | 33.58307 | 11.68885 | 4.42006 |
| 2625.00 | 33.44341 | 11.78088 | 4.49282 |
| 2650.00 | 33.34870 | 11.85781 | 4.52543 |
| 2675.00 | 33.30517 | 11.92193 | 4.51421 |
| 2700.00 | 33.31679 | 11.97555 | 4.45834 |
| 2725.00 | 33.38474 | 12.02083 | 4.36035 |
| 2750.00 | 33.50712 | 12.05972 | 4.22604 |
| 2775.00 | 33.67901 | 12.09377 | 4.06377 |
| 2800.00 | 33.89283 | 12.12406 | 3.88339 |
| 2825.00 | 33.82295 | 12.34650 | 3.92673 |
| 2850.00 | 34.05833 | 12.36170 | 3.78486 |
| 2875.00 | 34.32481 | 12.37288 | 3.64615 |
| 2900.00 | 34.61314 | 12.38093 | 3.51491 |
| 2925.00 | 34.91408 | 12.38642 | 3.39380 |
| 2950.00 | 35.21879 | 12.38955 | 3.28421 |
| 2975.00 | 35.51905 | 12.39013 | 3.18666 |
| 3000.00 | 35.80741 | 12.38754 | 3.10109 |
| 3025.00 | 35.80135 | 12.72306 | 3.27852 |
| 3050.00 | 36.02739 | 12.73106 | 3.25771 |
| 3075.00 | 36.24107 | 12.73586 | 3.24202 |
| 3100.00 | 36.43967 | 12.73587 | 3.22945 |
| 3125.00 | 36.62080 | 12.72923 | 3.21832 |
| 3150.00 | 36.58416 | 13.02928 | 3.40890 |
| 3175.00 | 36.71295 | 13.04480 | 3.43024 |
| 3200.00 | 36.82752 | 13.05337 | 3.44825 |
| 3225.00 | 36.92765 | 13.05240 | 3.46113 |
| 3250.00 | 37.01318 | 13.03935 | 3.46756 |
| 3275.00 | 36.93267 | 13.22947 | 3.61049 |
| 3300.00 | 36.97881 | 13.23831 | 3.63212 |
| 3325.00 | 37.01476 | 13.23430 | 3.64550 |
| 3350.00 | 37.04158 | 13.21498 | 3.64924 |
| 3375.00 | 37.06020 | 13.17819 | 3.64248 |
| 3400.00 | 36.94730 | 13.22190 | 3.71595 |
| 3425.00 | 36.94286 | 13.20258 | 3.71704 |
| 3450.00 | 36.93530 | 13.16653 | 3.70746 |
| 3475.00 | 36.92597 | 13.11227 | 3.68664 |
| 3500.00 | 36.91593 | 13.03874 | 3.65459 |
| 3525.00 | 36.80669 | 12.96543 | 3.66759 |
| 3550.00 | 36.78914 | 12.92045 | 3.64808 |
| 3575.00 | 36.77417 | 12.86070 | 3.61966 |
| 3600.00 | 36.76253 | 12.78607 | 3.58276 |
| 3625.00 | 36.75459 | 12.69681 | 3.53831 |
| 3650.00 | 36.67435 | 12.53713 | 3.51171 |
| 3675.00 | 36.66478 | 12.49488 | 3.49053 |
| 3700.00 | 36.65882 | 12.44437 | 3.46484 |

|         |          |          |         |
|---------|----------|----------|---------|
| 3725.00 | 36.65658 | 12.38615 | 3.43524 |
| 3750.00 | 36.65790 | 12.32096 | 3.40251 |
| 3775.00 | 36.66238 | 12.24976 | 3.36753 |
| 3800.00 | 36.66947 | 12.17367 | 3.33130 |
| 3825.00 | 36.62451 | 11.95320 | 3.28659 |
| 3850.00 | 36.62451 | 11.95320 | 3.28659 |
| 3875.00 | 36.62451 | 11.95320 | 3.28659 |
| 3900.00 | 36.62451 | 11.95320 | 3.28659 |
| 3925.00 | 36.62451 | 11.95320 | 3.28659 |
| 3950.00 | 36.62451 | 11.95320 | 3.28659 |
| 3975.00 | 36.62451 | 11.95320 | 3.28659 |
| 4000.00 | 36.62451 | 11.95320 | 3.28659 |
| 4025.00 | 36.62451 | 11.95320 | 3.28659 |
| 4050.00 | 36.62451 | 11.95320 | 3.28659 |
| 4075.00 | 36.62451 | 11.95320 | 3.28659 |
| 4100.00 | 36.62451 | 11.95320 | 3.28659 |
| 4125.00 | 36.62451 | 11.95320 | 3.28659 |
| 4150.00 | 36.62451 | 11.95320 | 3.28659 |
| 4175.00 | 36.62451 | 11.95320 | 3.28659 |
| 4200.00 | 36.62451 | 11.95320 | 3.28659 |
| 4225.00 | 36.62451 | 11.95320 | 3.28659 |
| 4250.00 | 36.62451 | 11.95320 | 3.28659 |
| 4275.00 | 36.62451 | 11.95320 | 3.28659 |
| 4300.00 | 36.62451 | 11.95320 | 3.28659 |
| 4325.00 | 36.62451 | 11.95320 | 3.28659 |
| 4350.00 | 36.62451 | 11.95320 | 3.28659 |
| 4375.00 | 36.62451 | 11.95320 | 3.28659 |
| 4400.00 | 36.62451 | 11.95320 | 3.28659 |
| 4425.00 | 36.62451 | 11.95320 | 3.28659 |
| 4450.00 | 36.62451 | 11.95320 | 3.28659 |
| 4475.00 | 36.62451 | 11.95320 | 3.28659 |
| 4500.00 | 36.62451 | 11.95320 | 3.28659 |
| 4525.00 | 36.62451 | 11.95320 | 3.28659 |
| 4550.00 | 36.62451 | 11.95320 | 3.28659 |
| 4575.00 | 36.62451 | 11.95320 | 3.28659 |
| 4600.00 | 36.62451 | 11.95320 | 3.28659 |
| 4625.00 | 36.62451 | 11.95320 | 3.28659 |
| 4650.00 | 36.62451 | 11.95320 | 3.28659 |
| 4675.00 | 36.62451 | 11.95320 | 3.28659 |
| 4700.00 | 36.62451 | 11.95320 | 3.28659 |
| 4725.00 | 36.62451 | 11.95320 | 3.28659 |
| 4750.00 | 36.62451 | 11.95320 | 3.28659 |
| 4775.00 | 36.62451 | 11.95320 | 3.28659 |
| 4800.00 | 36.62451 | 11.95320 | 3.28659 |
| 4825.00 | 36.62451 | 11.95320 | 3.28659 |
| 4850.00 | 36.62451 | 11.95320 | 3.28659 |
| 4875.00 | 36.62451 | 11.95320 | 3.28659 |
| 4900.00 | 36.62451 | 11.95320 | 3.28659 |
| 4925.00 | 36.62451 | 11.95320 | 3.28659 |
| 4950.00 | 36.62451 | 11.95320 | 3.28659 |
| 4975.00 | 36.62451 | 11.95320 | 3.28659 |
| 5000.00 | 36.62451 | 11.95320 | 3.28659 |

If this is the hp 7550 plotter and you want auto feed,  
then set up the plotter, load a sheet and answer y:  
Do you want auto feed?  
Set up plotter, enter rotation (y/n) when ready

Hprime=86 to Hprime=70

Freq = 21.794 kHz      Receiver Distance = 3821.0 km  
 Zt = 15.00 km      Zr = 15.00 km      Gamma = 45.0 deg      Phi1 = 270.0 deg

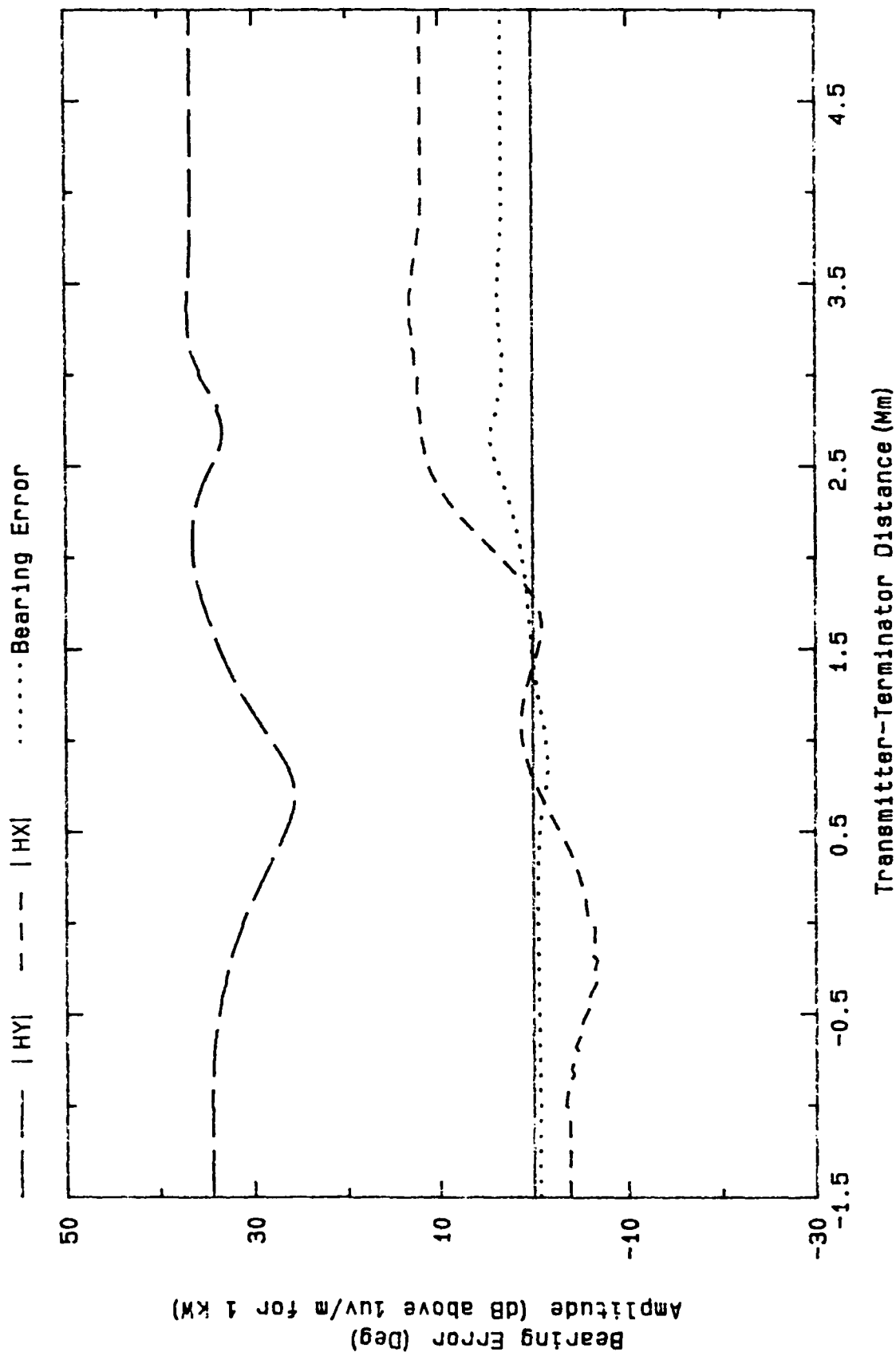


Figure 5. Plot output for moving terminator sample input.

#### IV. RESULTS

In the following section day and night comparisons are given between calculations and variations in the DOA at San Diego measured in reference 2 for the following VLF/LF transmitters: Annapolis, Lualualei, Cutler, Jim Creek and Silver Creek.

##### A. DOA RESULTS FOR ANNAPOLIS TO SAN DIEGO - DAY

Annapolis transmits at 21.4 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north =  $249^\circ$ ,

codip =  $23^\circ$ ,

$|\vec{B}|$  = magnitude of the earth's magnetic induction vector =  $0.537 \times 10^{-4}$  w-/m<sup>2</sup>.

$\sigma$  = ground conductivity =  $10^{-2}$  S/M.

$\epsilon$  = earth's dielectric constant = 15.

Figure 6 shows measured histograms for two days in April 1987 when daylight prevailed over the entire path. The horizontal scale is such that the true bearing should be  $45^\circ$  with values greater than  $45^\circ$  corresponding to signals arriving from south of the true DOA and values less than  $45^\circ$  corresponding to signals arriving from north of the true DOA. The theoretical spread, discussed subsequently, is indicated by the arrows on the top and although it encompasses the region when most observations occurred it does underestimate the observed spread indicating that perhaps some off path ground or ionospheric scatter is playing a role. The theoretical spread is less than  $2^\circ$ . To arrive at the theoretical spread, waveguide calculations were performed for

exponential profiles characterized in the notation of Wait and Spies (ref 10), by:

$$\beta = 0.3 \text{ km}^{-1}, 0.5 \text{ km}^{-1} \left\{ \begin{array}{l} h' = 70 \text{ km} \\ h' = 72 \text{ km} . \\ h' = 74 \text{ km} \end{array} \right. \quad (18)$$

On the basis of a previous study with exponential profiles (ref. 11) these profiles appear to be reasonable bounds for daytime propagation. The DOA for these profiles at the Annapolis-San Diego range (taken to be 3705 km) was then used to determine the spread. Clearly this is simply one of many procedures for determining the spread but, unless noted otherwise, it is the method used for spread comparisons throughout this section.

An illustrative example of mode sum behavior as a function of range is shown in Figure 7. Shown are mode sum plots for the scaled transverse and longitudinal magnetic intensities  $H_y$  and  $H_x$  respectively. Also shown is DOA (or bearing) error. The plot is for the  $\beta = 0.3 \text{ km}^{-1}$ ,  $h' = 74 \text{ km}$  profile and shows that even under daytime conditions large errors are possible ( $\approx 50^\circ$ ) at ranges  $\lesssim 1 \text{ Mm}$ . Examination of such curves for the six profiles considered showed DOA errors less than about  $3^\circ$  at ranges greater than about 1.5 Mm.

#### B. DOA RESULTS FOR ANNAPOLIS TO SAN DIEGO - NIGHT

Figure 8 shows measured histograms for two days in April when nighttime prevailed over the entire path. To arrive at the theoretical spread, waveguide calculations were performed for the following exponential profiles:

$$\beta = 0.4 \text{ km}^{-1}, 0.5 \text{ km}^{-1}, 0.7 \text{ km}^{-1} \left\{ \begin{array}{l} h' = 86 \text{ km} \\ h' = 87 \text{ km} \\ h' = 88 \text{ km} \end{array} \right. \quad (19)$$

Again they were chosen on the basis of the study of exponential profiles given in reference 11. The theoretical spread of about  $12^\circ$  is in reasonable agreement with the observed spreads though the calculations indicate arrivals from the south of the true DOA whereas the measurements indicate substantial numbers of arrivals from the north.

An example of mode sum behavior as a function of range is shown in Figure 9. The possibility of DOA errors in excess of  $70^\circ$  at ranges  $< 2$  Mm is clearly evident. Examination of mode sum plots and DOA's for the nine cases considered indicates that errors  $\approx 30^\circ$  are quite possible at select ranges in excess of about 2.5 Mm.

#### C. DOA RESULTS FOR LUALUALEI TO SAN DIEGO - DAY

Lualualei transmits at 23.4 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north =  $59^\circ$

codip =  $40^\circ$

$|\vec{B}| = 0.413 \times 10^{-4} \text{ w/m}^2$

$\sigma = 4 \text{ S/M}$

$\epsilon = 81.$

Figures 10 and 11 show daytime histograms of the DOA's measured during April of 1987. The true bearing should be  $45^\circ$  with values greater than  $45^\circ$  corresponding to signals arriving from north of the true DOA and values less than  $45^\circ$  corresponding to signals arriving from south of the true DOA. The theoretical spread of about  $2^\circ$  calculated for the transmitter receiver separation of 4211 km using the profiles specified in Equations (18) is in quite good agreement with the 4/10, 4/11 and 4/12 data. The 4/1 data indicates a somewhat larger spread with the preponderance of measurements indicating arrivals from more southerly directions than predicted.

Of the six profiles used to determine the spread the only one which indicated an appreciable effect was the  $\beta = 0.5 \text{ km}^{-1}$ ,  $h' = 74 \text{ km}$  case shown in Figure 12. In that instance it will be seen that a deep null in HY occurs close to the receiving site. The spread indicated on Figures 10 and 11 could clearly be increased by allowing for a reception range about the receiving site and/or a more densely selected set of profiles. This points out the subjective nature of the comparisons.

#### D. DOA RESULTS FOR LUALUALEI TO SAN DIEGO - NIGHT

Figures 13 and 14 show nighttime histograms of the DOA's for the four days in April. The profiles specified in Equations (19) were used to determine the theoretical spreads. The lower spread was calculated as described for the previous cases. The small spread is singular among all of the nighttime cases considered. It reflects in some measure the smooth propagation characteristics of easterly propagation. If a loose tolerance of  $\pm 200 \text{ km}$  in range about the receiving site is permitted then the theoretical spread is given by the curve marked "calculated spread\*". The reason for the difference in the spread is evident from Figure 15 which shows the mode sum and DOA error for

the  $\beta = 0.7 \text{ km}^{-1}$ ,  $h' = 86 \text{ km}$  profile. The error peak which occurs at about 4400 km is responsible for the augmented spread.

#### E. DOA RESULTS FOR CUTLER TO SAN DIEGO - DAY

Cutler transmits at 24.0 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north =  $245.5^\circ$

codip =  $19.3^\circ$

$|\vec{B}| = 0.553 \times 10^{-4} \text{ w/m}^2$

$\sigma = 10^{-2} \text{ S/m}$

$\epsilon = 15.$

Figure 16 shows daytime histograms of the DOA's measured during two days in March 1987. The true bearing should be  $45^\circ$  with values greater than  $45^\circ$  corresponding to signals arriving from south of the true DOA and values less than  $45^\circ$  corresponding to signals arriving from north of the true DOA. The theoretical spread, calculated for a transmitter-receiver distance of 4454 km, is somewhat less than  $2^\circ$  and appears to be consistent with the bulk of the measurements. An example of the mode sum and DOA plots for this case is shown in Figure 17.

#### F. DOA RESULTS FOR CUTLER TO SAN DIEGO - NIGHT

Figure 18 shows nighttime histograms of the DOA 's for three days in March of 1987. The profiles specified in Equations (19) were used to determine the theoretical spreads. The rather large calculated spread in excess of  $30^\circ$

results from a null in  $|HY|$  close to the receiving site (4454 km) for the  $\beta = 0.5 \text{ km}^{-1}$ ,  $h' = 88 \text{ km}$  profile. This is shown in Figure 19. The theoretical spread is larger than indicated by the measurements. The theoretical result predicts all arrivals from south of the true bearing while the measurements show a substantial number of arrivals from the north.

#### G. DOA RESULTS FOR JIM CREEK TO SAN DIEGO - DAY

Jim Creek transmits at 24.8 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculation are:

azimuth from magnetic north =  $149^\circ$

codip =  $25^\circ$

$|\vec{B}| = .518 \times 10^{-4} \text{ w/m}^2$

$\sigma = 10^{-2} \text{ S/M}$

$\epsilon = 15.$

Figure 20 shows daytime histograms of the DOA's measured during three days in April 1987. The true bearing should be  $45^\circ$  with values greater than  $45^\circ$  corresponding to signals arriving from east of the true DOA and values less than  $45^\circ$  corresponding to signals arriving from west of the true DOA. The calculated spread for a transmitter receiver distance of 1767 km is about  $1^\circ$ . Though it underestimates the total measured spread, the latter is quite peaked indicating a spread for the bulk of the measurements of about  $1^\circ$ . An example of the mode sum and DOA plots for this case is shown in Figure 21.

#### H. DOA RESULTS FOR JIM CREEK TO SAN DIEGO - NIGHT

Figures 22 and 23 show nighttime histograms of the DOA's for five days in April 1987 and one day in December 1986. The profiles specified in Equation (19) were used to determine the theoretical spread which is over  $40^\circ$ . The histograms range from spreads of about  $20^\circ$  to about  $40^\circ$ . Figure 24 is an example of the bearing error behavior with range. This path has been cited as having the most extreme behavior (ref. 2). The reason for this is probably the relatively short path length (1767 km) rather than anything peculiar about the north south path. It is clear from the nighttime mode sum plots (e.g., Figures 9, 15, 19 and 24) that the most severe problems, except for isolated instances, occur for ranges  $< 2000$  km.

#### I. DOA RESULTS FOR SILVER CREEK TO SAN DIEGO - DAY

Silver Creek transmits at 48.5 kHz. It is the sole LF frequency considered in this study. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north =  $227.7^\circ$

codip =  $24.9^\circ$

$|\vec{B}| = 0.523 \times 10^{-4} \text{ w/m}^2$

$\sigma = 10^{-2} \text{ s/m}$

$\epsilon = 15.$

At this LF frequency the study reported in reference 11 indicates that the following daytime profiles cover the range of interest

$$\beta = 0.3 \text{ km}^{-1}, 0.5 \text{ km} \left\{ \begin{array}{l} h' = 70 \text{ km} \\ h' = 73 \text{ km} \\ h' = 75 \text{ km} \end{array} \right. \quad (20)$$

Figures 25, 26 and 27 show daytime histograms for six days of measurement in November 1986 and one day in December 1986. Values greater than  $45^\circ$  correspond to signals arriving from south of the true bearing and values less than  $45^\circ$  correspond to signals arriving from north of the true bearing. The theoretical spread of about  $2^\circ$  calculated on the basis of the above profiles at a range of 1989 km is consistent with the observations. The calculated result indicates arrivals from the north whereas the measurements indicate arrivals from both north and south of the true bearing. A sample mode sum and DOA plot for this case is given in Figure 28.

#### J. DOA RESULTS FOR SILVER CREEK TO SAN DIEGO - NIGHT

Figures 29, 30 and 31 show nighttime histograms for the seven days of measurements. Under nighttime conditions at this LF frequency the following six profiles have been used.

$$\beta = 0.7 \text{ km}^{-1}, 0.8 \text{ km}^{-1}, 0.9 \text{ km}^{-1}, 1.0 \text{ km}^{-1}, 1.1 \text{ km}^{-1}, 1.2 \text{ km}^{-1} \left\} h = 88 \text{ km}. (21)$$

Again they were chosen on the basis of the study of exponential profiles given in reference 11.

The theoretical spread based on these profiles indicates a preponderance of arrivals from the north with the spread being over  $50^\circ$ . The measurements indicate spreads ranging between about  $20^\circ$  and  $30^\circ$  with substantial arrivals

from both the North and South. The reason for the large calculated spread is the deep null in  $|HY|$  at about 2 Mm shown in Figure 32. Failure of the measurements to show such an effect could indicate that either the profiles were inadequate or that too few modes were used. With respect to the latter, in all cases the modal search rectangle was  $60^\circ$  to  $90^\circ$  for the real part of the eigenangle and 0 to  $-4^\circ$  for the imaginary part. Examination of the mode set in this instance indicates that the dominant mode would be at least 30 dB higher than the first neglected mode at the receiving site so that profile inadequacy seems the more likely explanation.

## V. CONCLUSIONS

A modification of an earlier program has been used to calculate DOA errors due to geomagnetic field effects at San Diego for the following VLF/LF transmitters: Annapolis (21.4 kHz), Lualualei (23.4 kHz), Cutler (24 kHz), Jim Creek (24.8 kHz) and Silver Creek (48.5 kHz). Calculated spreads of the DOA have been based on a selection of best fit exponential profiles determined in a previous study (ref. 11). This is subjective in the sense that it is just one of many procedures that could be used to determine the DOA spread. The calculations have been compared with corresponding variations in the DOA reported in reference 2. Calculated daytime spreads were about  $2^\circ$ . Measured daytime spreads were somewhat larger than this, though the bulk of the measurements usually is confined to a range of several degrees. In agreement with measurements and expectations, the nighttime calculated DOA spreads were much greater than the daytime spreads. A quantitative comparison between calculated and measured nighttime spreads is shown below:

|              | Calculated<br>Nighttime Spread | Measured<br>Nighttime Spread             |
|--------------|--------------------------------|------------------------------------------|
| Annapolis    | $\approx 11^\circ$             | $\approx 25^\circ$                       |
| Lualualei    | $\approx 2^\circ$              | $\approx 8^\circ$                        |
| Cutler       | $\approx 32^\circ$             | $\approx 20^\circ$                       |
| Jim Creek    | $\approx 42^\circ$             | $\approx 22^\circ$ to $\approx 42^\circ$ |
| Silver Creek | $\approx 53^\circ$             | $\approx 33^\circ$ to $47^\circ$         |

In addition, the nighttime calculations for Annapolis and Cutler yield an excessive number (relative to measurement) of arrivals from the south, the calculations for Jim Creek indicate an excessive number from the east and the

calculations for Silver Creek indicate an excessive number of arrivals from the north.

Generally there is no obvious trend in DOA variation with frequency in the VLF band, though on the basis of the calculations the nighttime DOA variation is expected to be more severe for the LF frequency than for the VLF frequencies at ranges > 5000 km. Calculations and measurements indicate that the nighttime westerly paths are subject to more DOA variation than the single easterly path considered. This is believed to be due to geomagnetic field effects and not to conductivity differences for the easterly and westerly paths (ref. 12). Reference 2 singles out Jim Creek as a path of excessive DOA variation. On the basis of the calculations it is believed that this is because of the relatively short path (1767 km) and not because of peculiarities associated with north-south propagation.

## REFERENCES

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2. Stang, R.T. and W.E. Davis, VLF/LF signal direction-of-arrival variation (an overview) and data books I through VI, Naval Ocean Systems Center Technical Report 1236, Sept. 1988.
3. Pappert, R.A. and L.R. Shockey, Simplified VLF/LF mode conversion program with allowance for elevated arbitrarily oriented electric dipole antennas, Naval Electronics Laboratory Center Interim Report No. 771, prepared for the Defense Nuclear Agency, October 1976.
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5. Ferguson, J.A. and F.P. Snyder, Approximate VLF/LF waveguide mode conversion model: Computer applications: FASTMC and BUMP, Naval Ocean Systems Center Technical Document 400, November 1980.
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9. Born, M. and E. Wolf, Principles of Optics, 2nd edition, The Macmillan Co., New York, 1964.
10. Wait, J.R. and K.P. Spies, Characteristics of the earth-ionosphere waveguide for VLF radio waves, NBS Tech. Note No. 300, Dec. 1964.
11. Morfitt, D.G., Ferguson, J.A. and F.P. Snyder, Electromagnetic wave propagation panel on medium, long and very long wave propagation (at frequencies less than 3000 kHz). AGARD Conference Proceedings No. 305, Numerical modeling at the propagation medium at ELF/VLF/LF, pp 32-1 to 33-14. Published February 1982.
12. Pappert, R.A. and L.R. Hitney, Empirical modeling of nighttime easterly and westerly VLF propagation in the Earth-ionosphere waveguide, Radio Sci., vol 23 (4). pp 599-611, 1988.

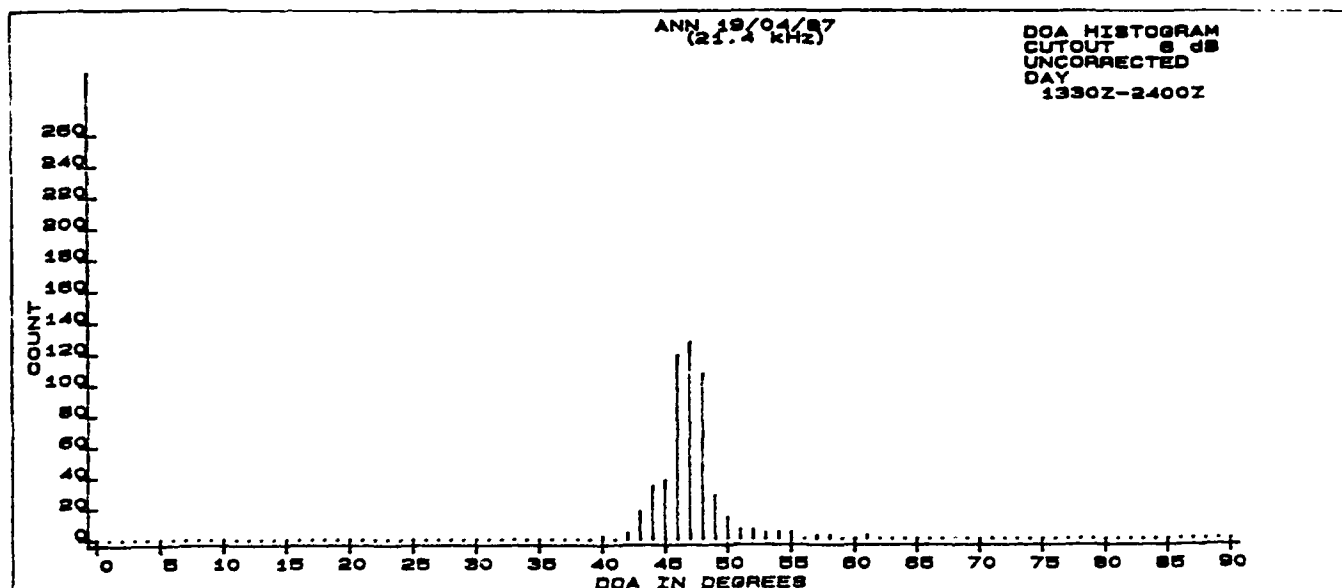
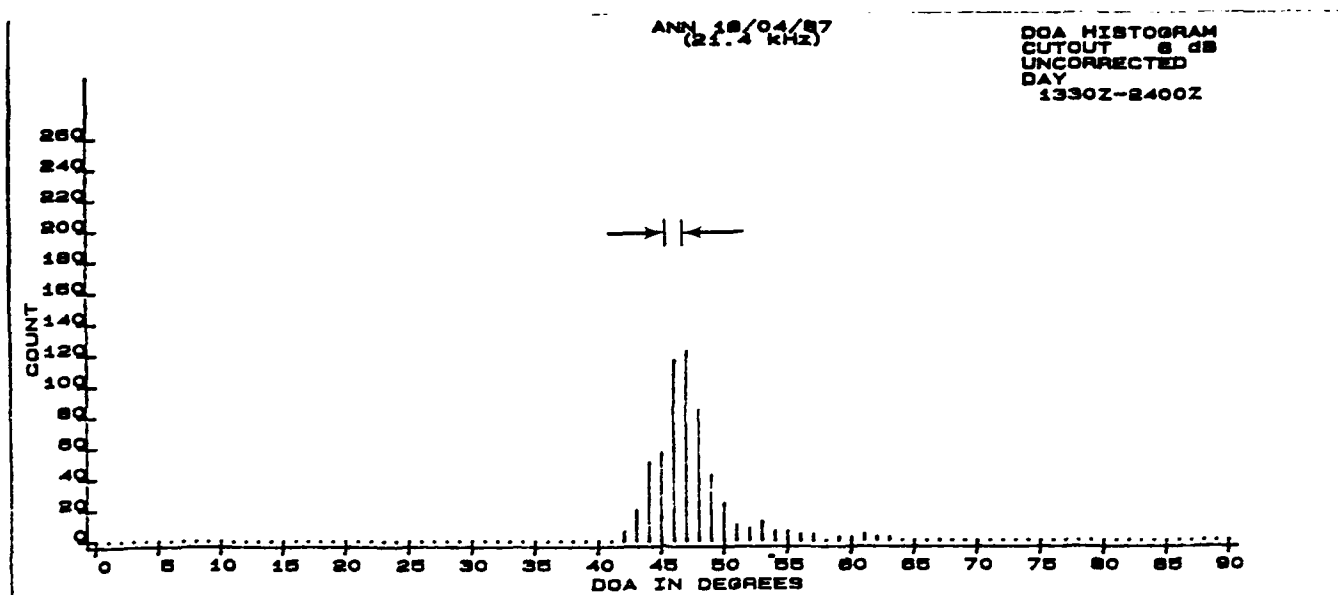


Figure 6. Histograms for Annapolis to San Diego - Day.

Annapolis to San Diego  $\beta = .3, h_{\text{prime}} = 74.0$

Freq = 21.400 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

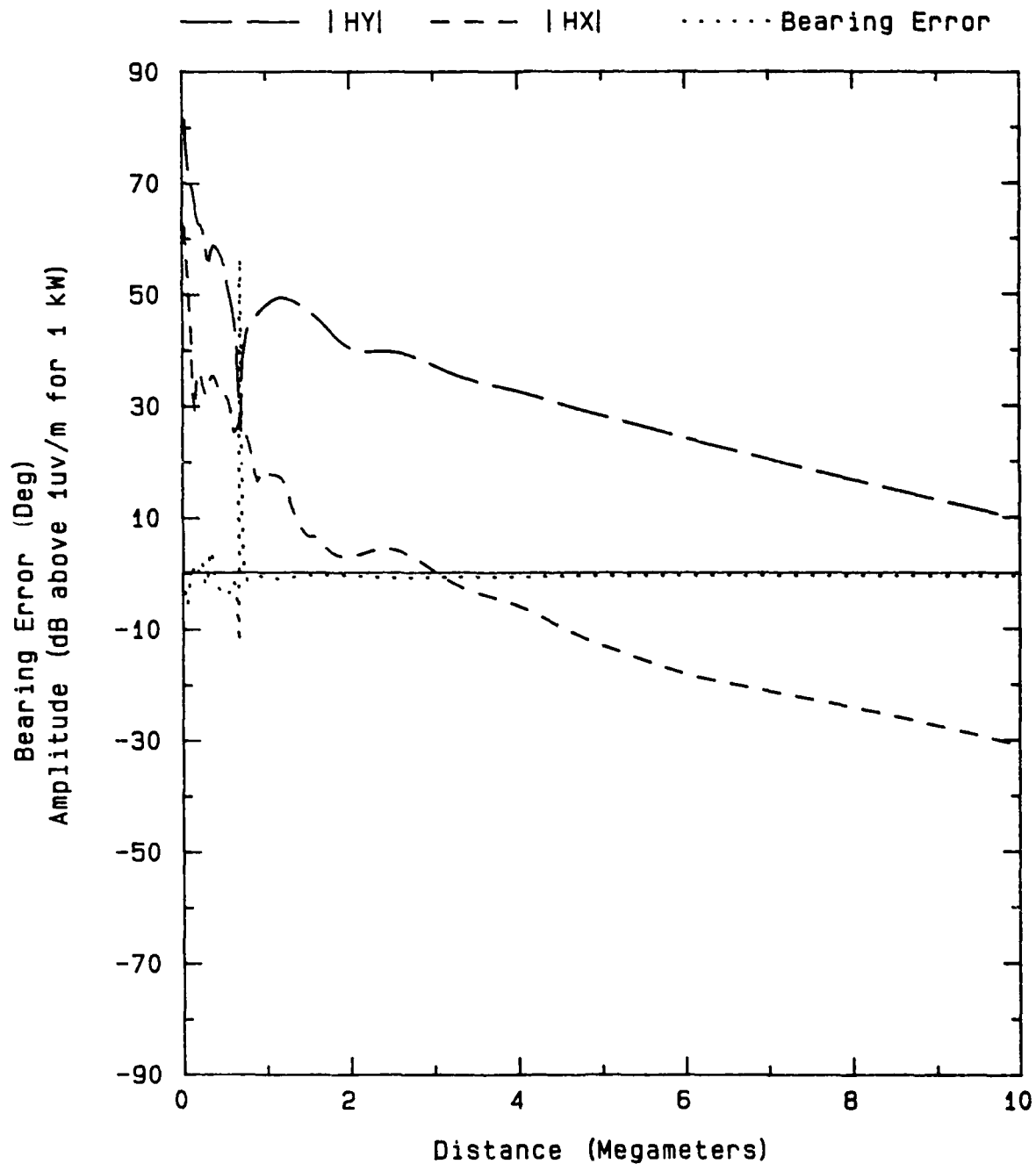


Figure 7. Sample range plot for Annapolis to San Diego - Day.

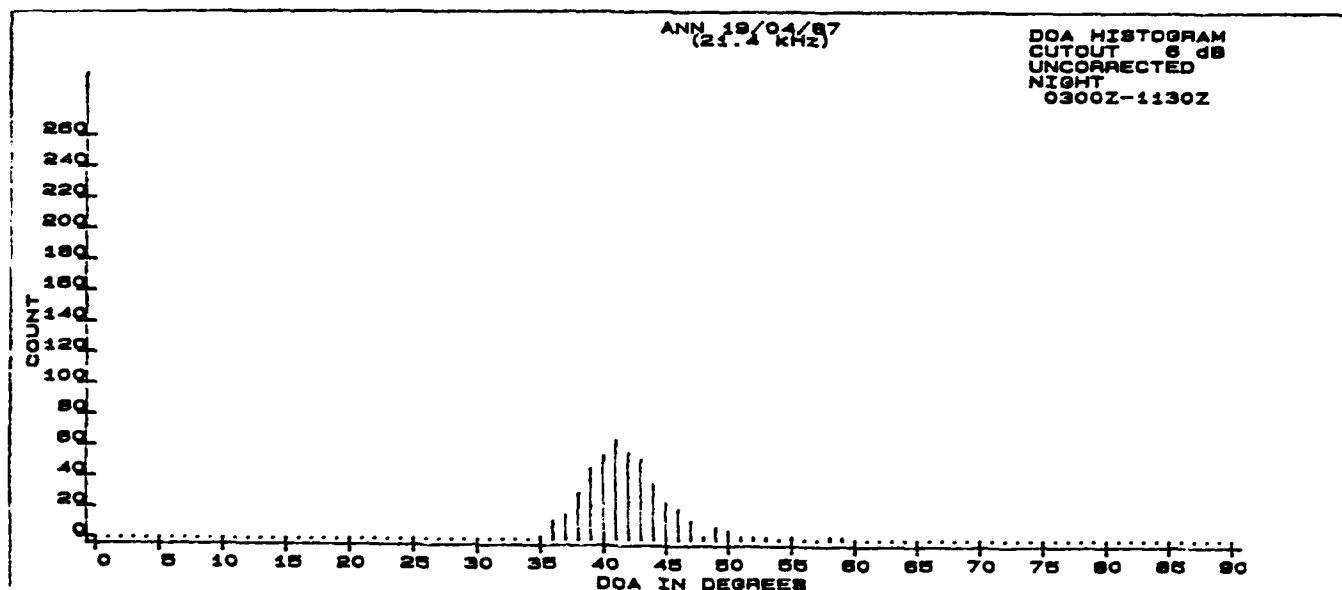
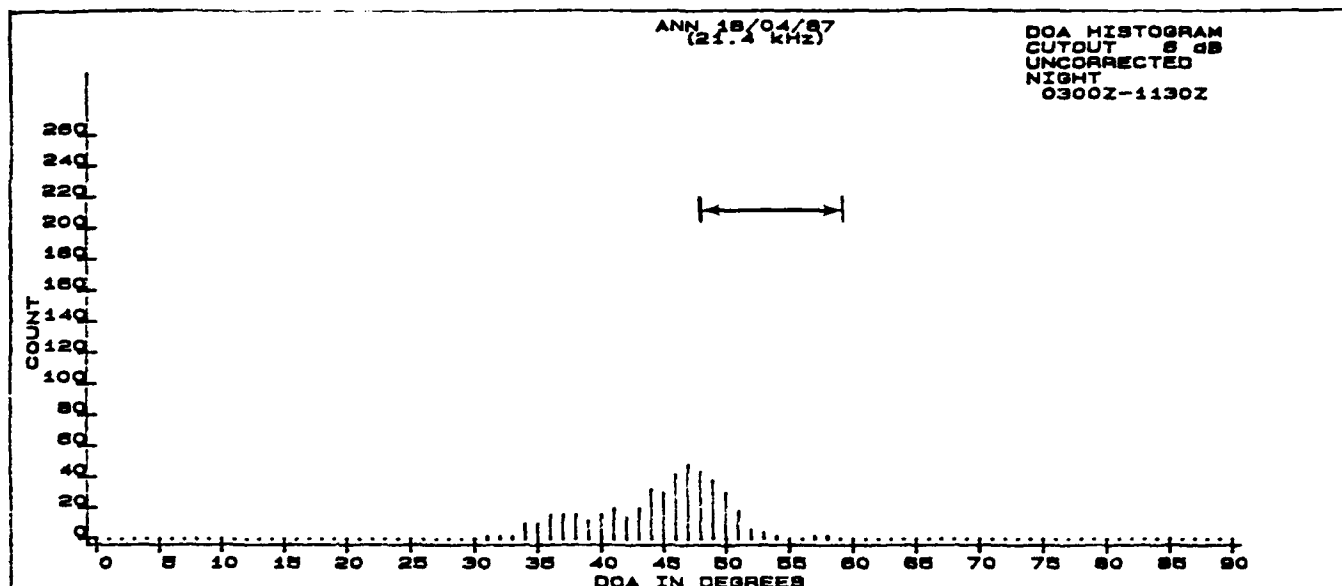


Figure 8. Histograms for Annapolis to San Diego - Night.

Annapolis to San Diego  $\beta = .4$ ,  $h' = 86.0$

Freq = 21.400 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

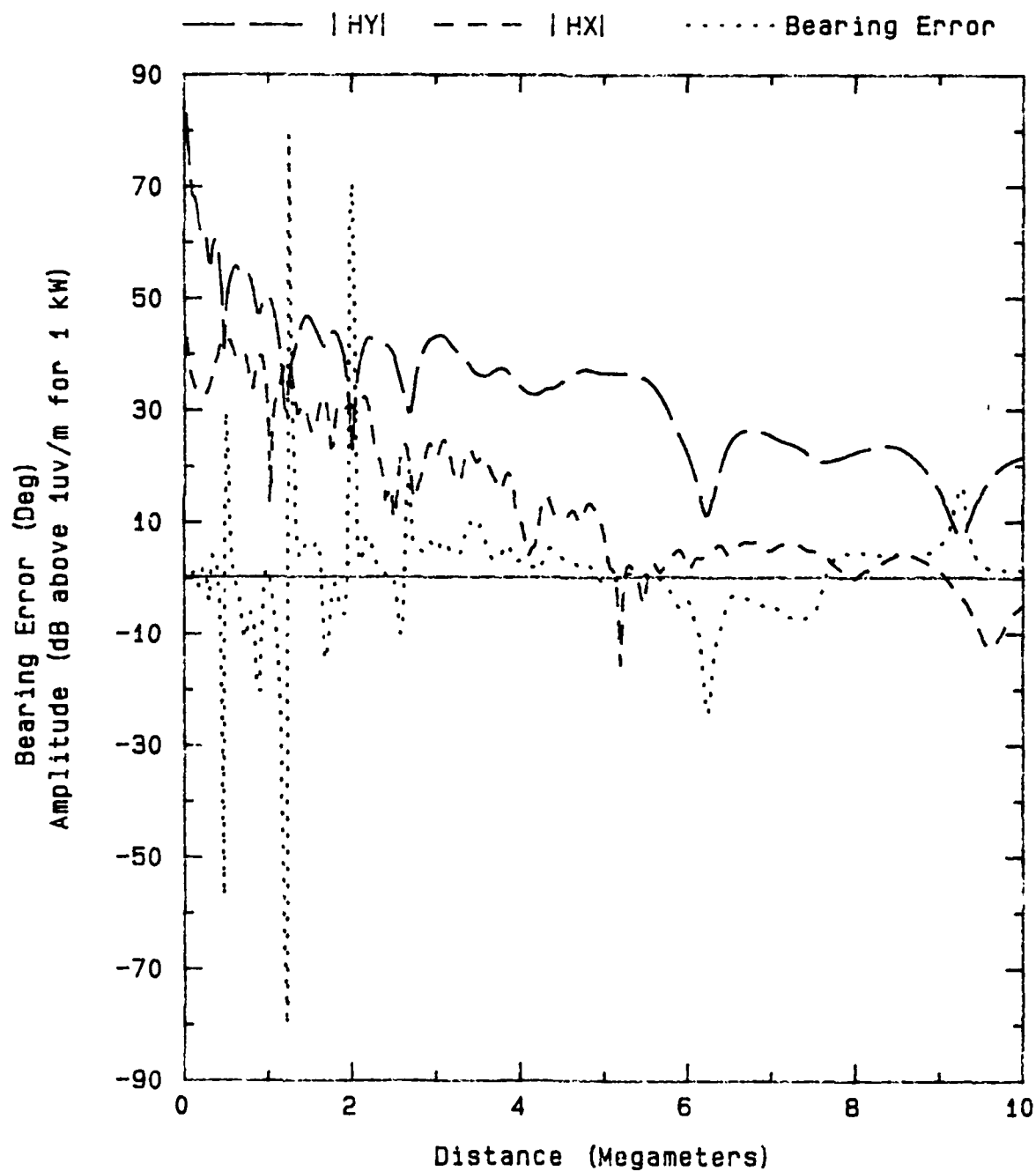


Figure 9. Sample range plot for Annapolis to San Diego - Night.

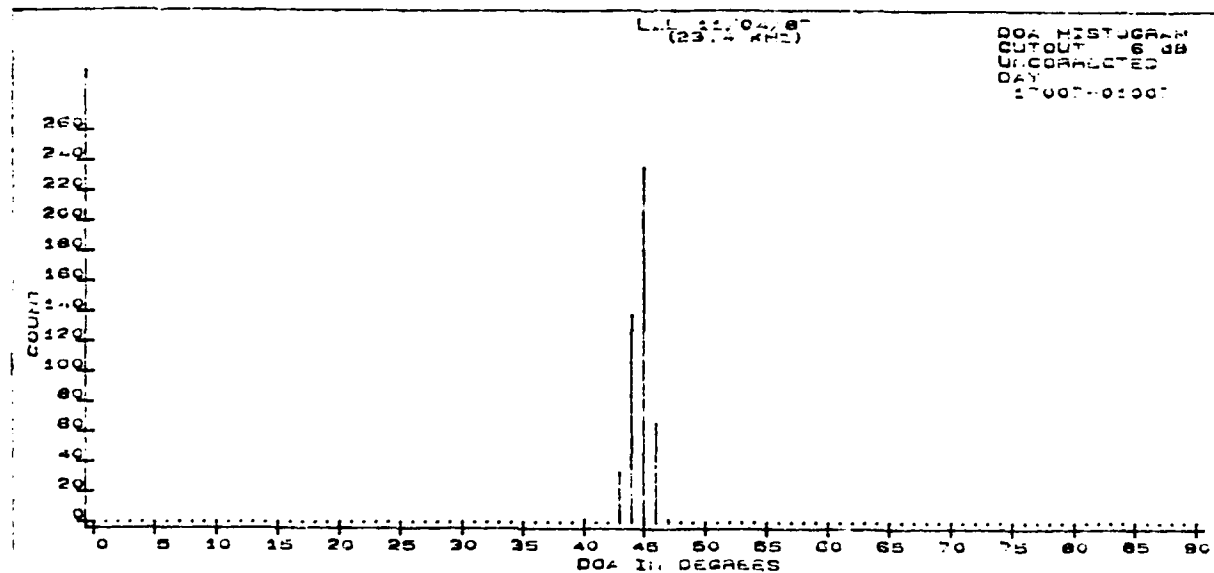
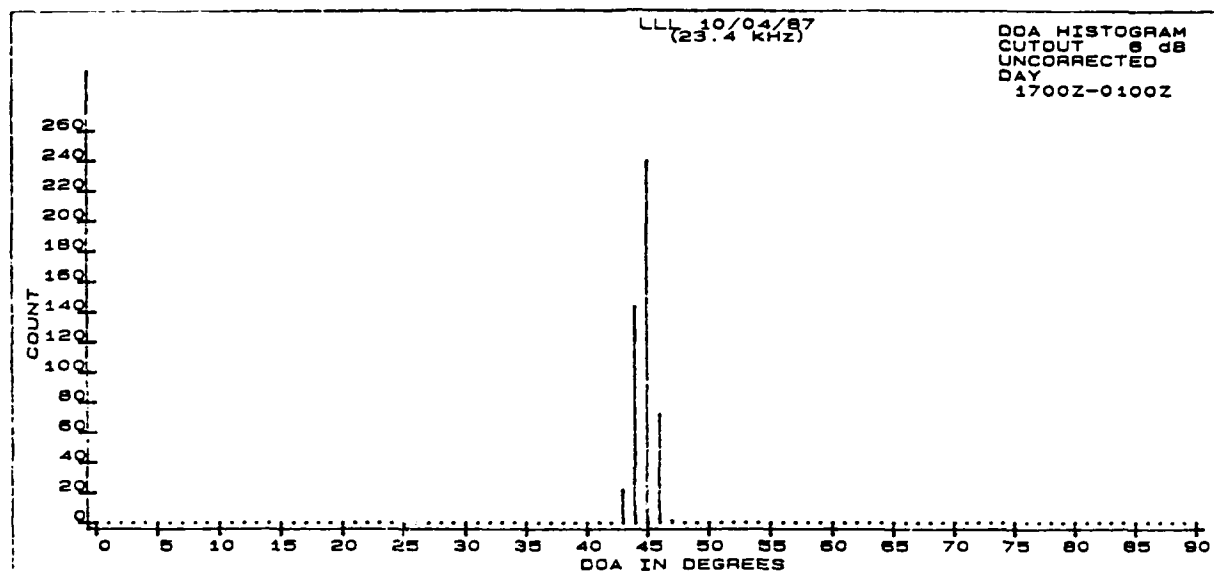
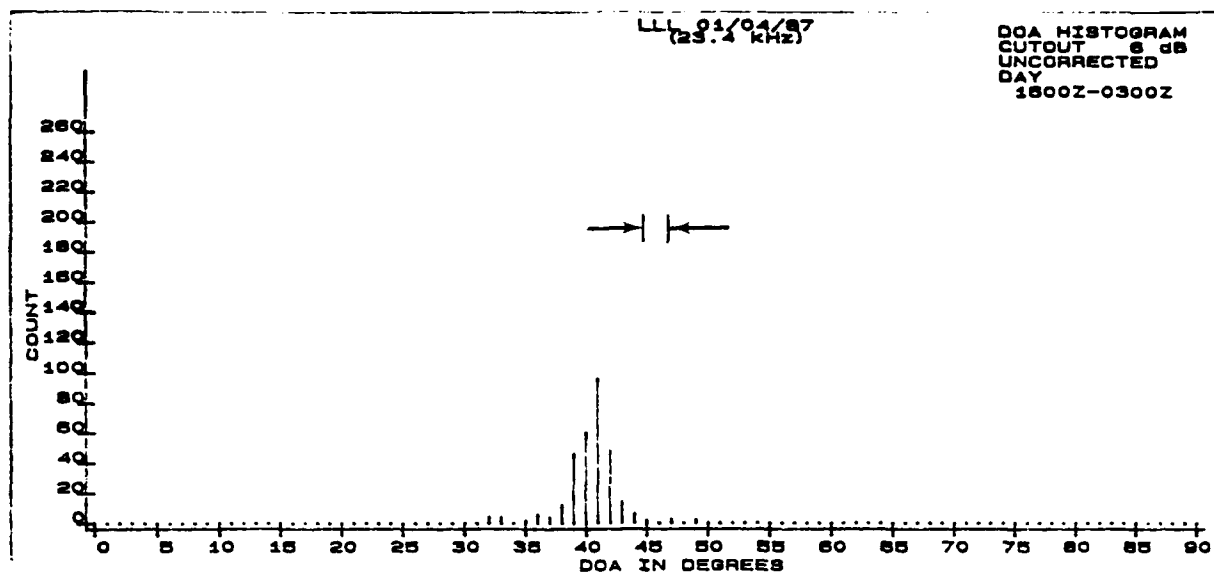


Figure 10. Histograms for Lualualei to San Diego - Day.

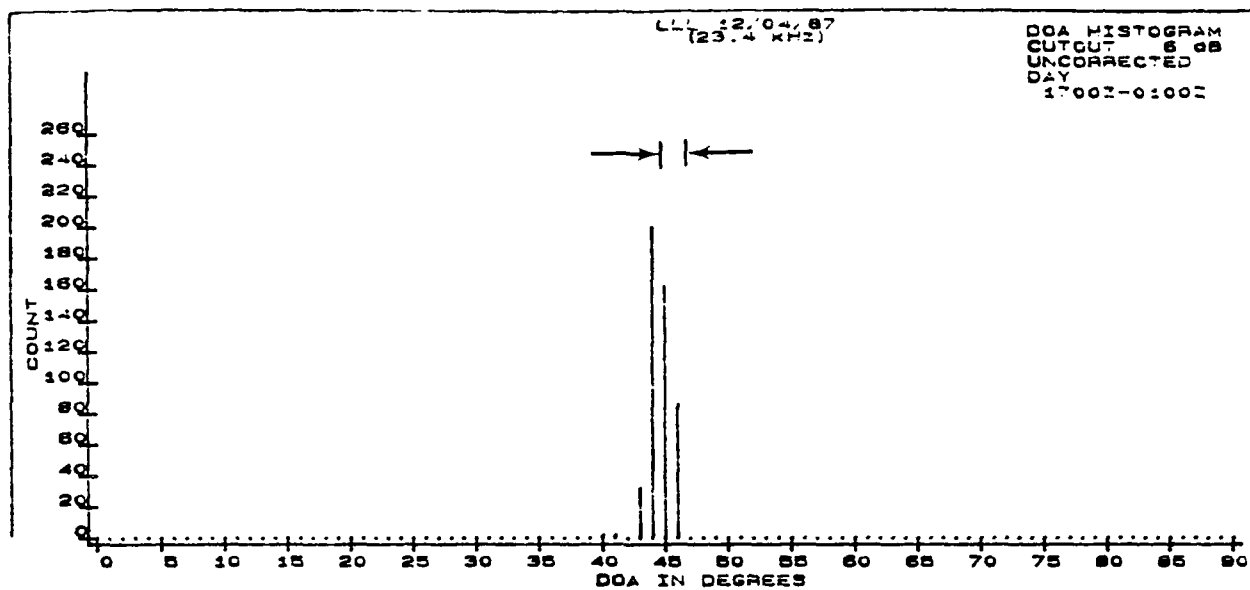


Figure 11. Histograms for Lualualei to San Diego - Day.

Lualualei to San Diego  $\beta = .5$ ,  $h_{\text{prime}} = 74.0$

Freq = 23.400 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

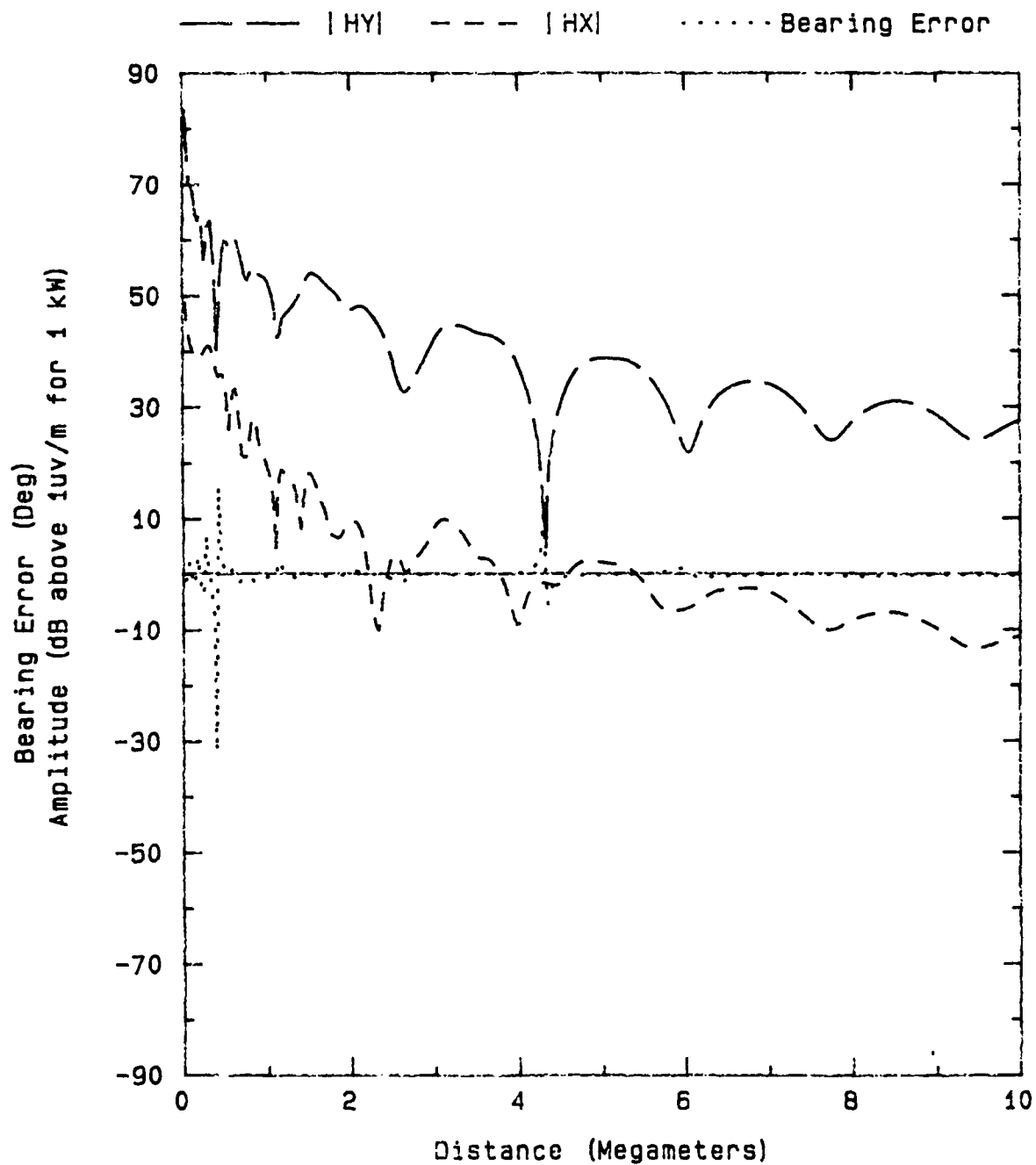


Figure 12. Sample range plot for Lualualei to San Diego - Day.

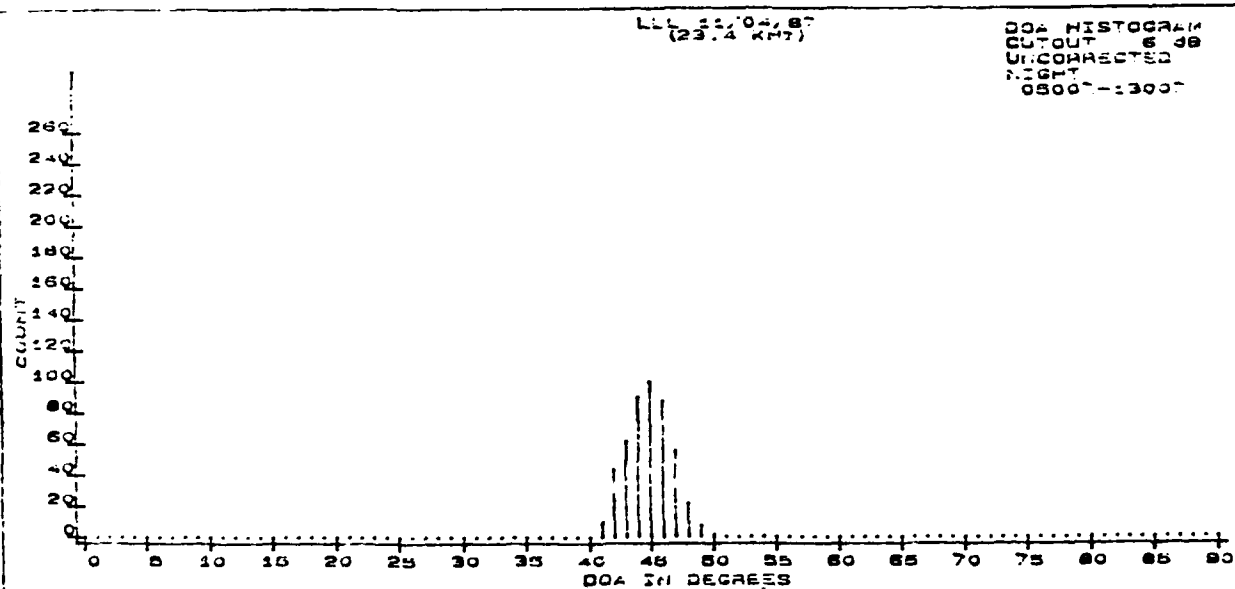
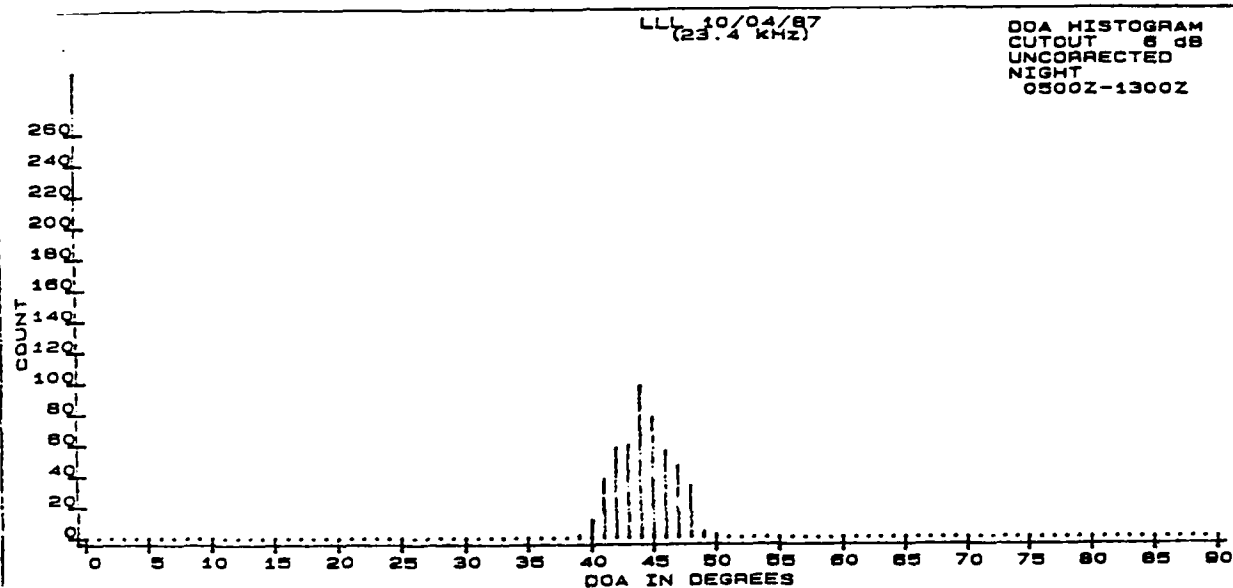
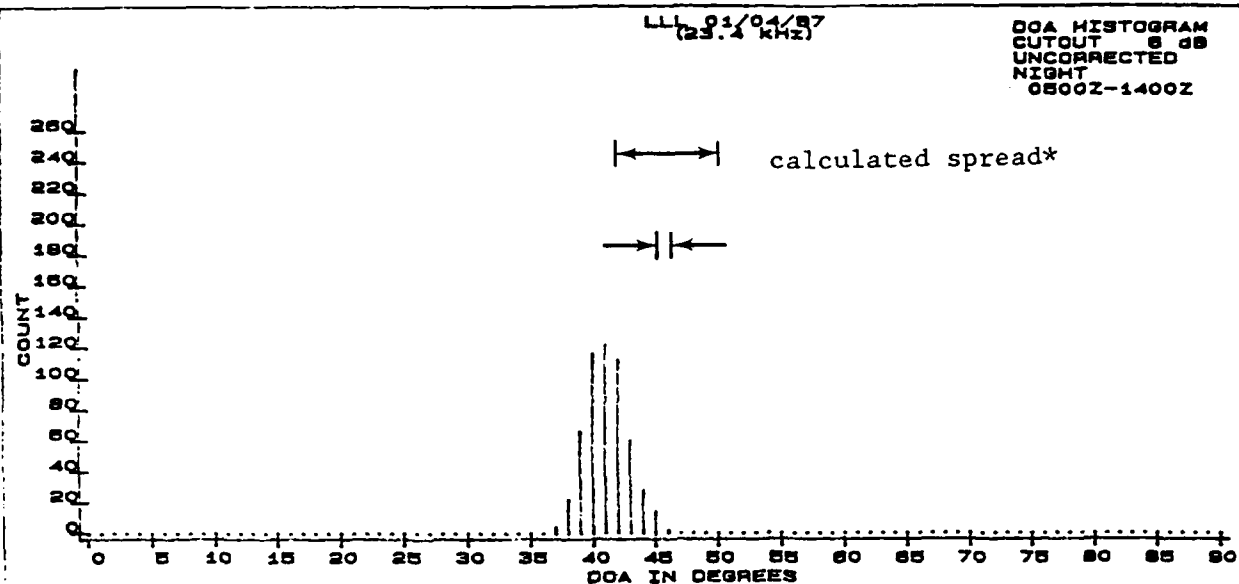


Figure 13. Histograms for Lualualei to San Diego - Night.

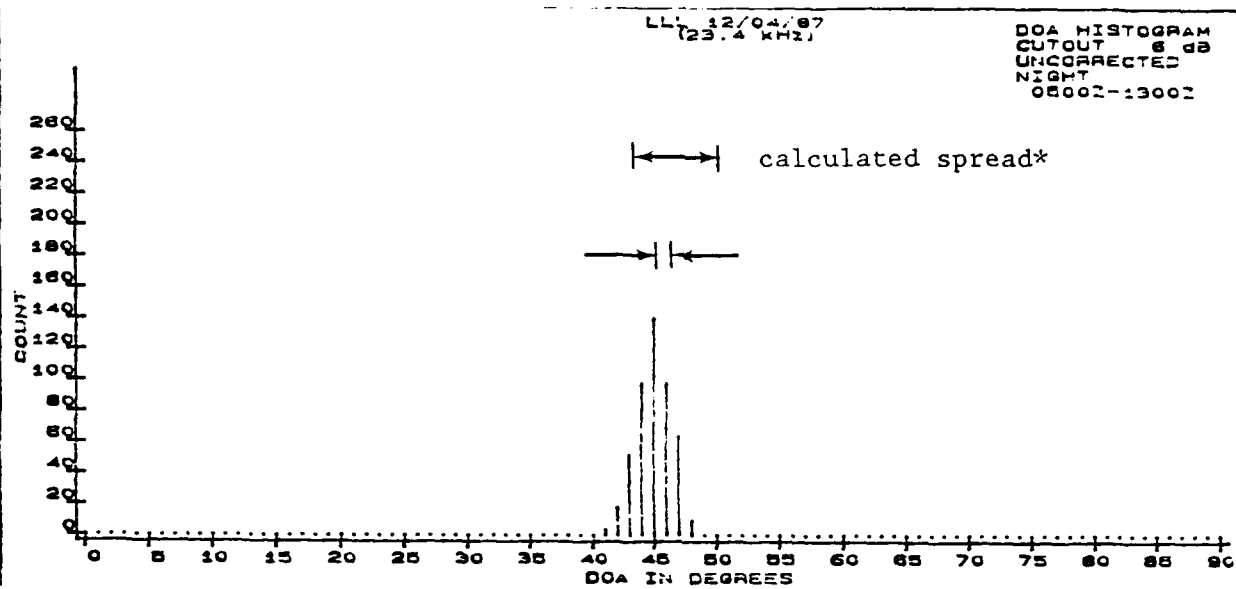


Figure 14. Histograms for Lualualei to San Diego - Night.

Lualualei to San Diego  $\beta = .7, h_{\text{prime}} = 86.0$

Freq = 23.400 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

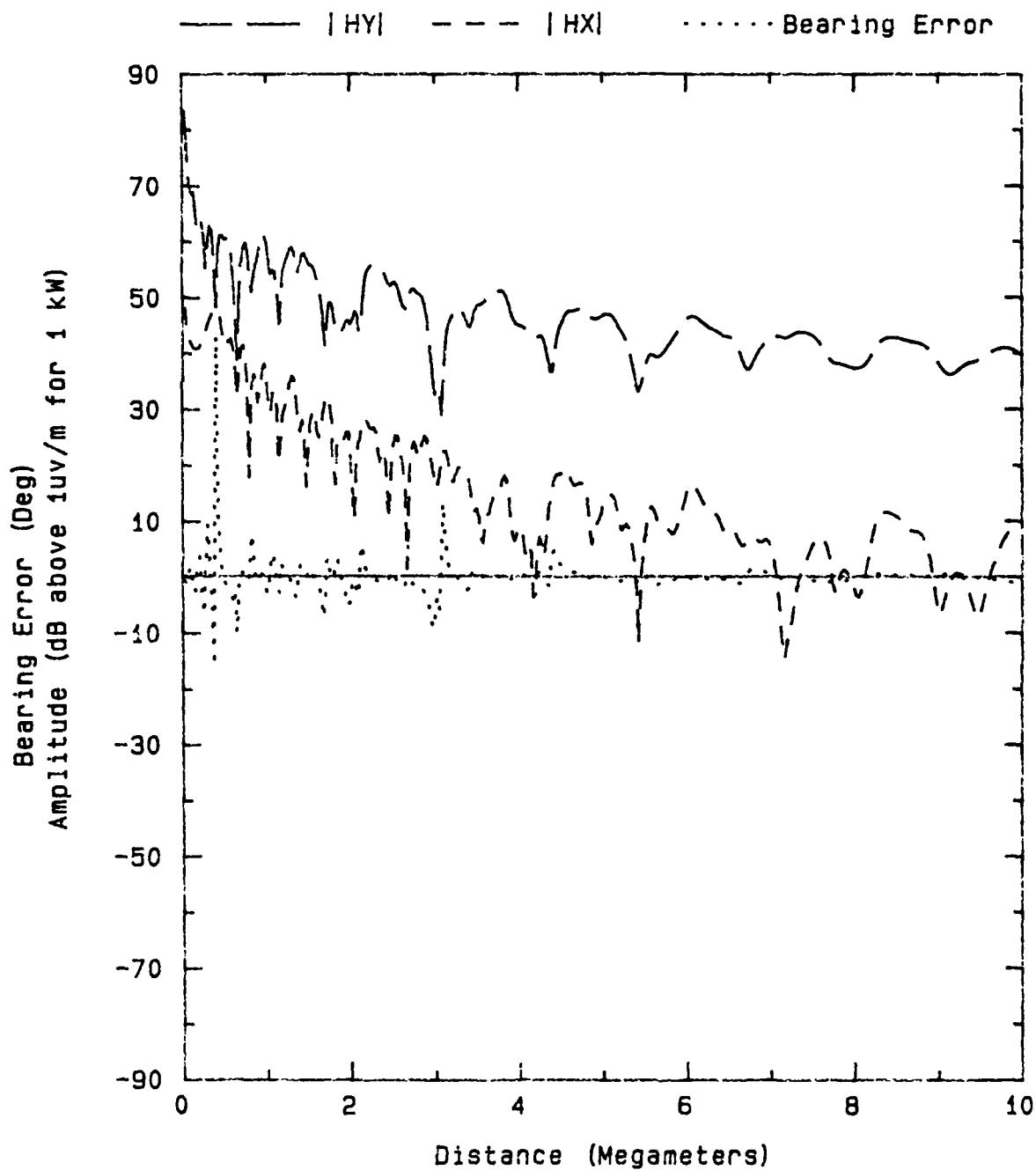


Figure 15. Sample range plot for Lualualei to San Diego - Night.

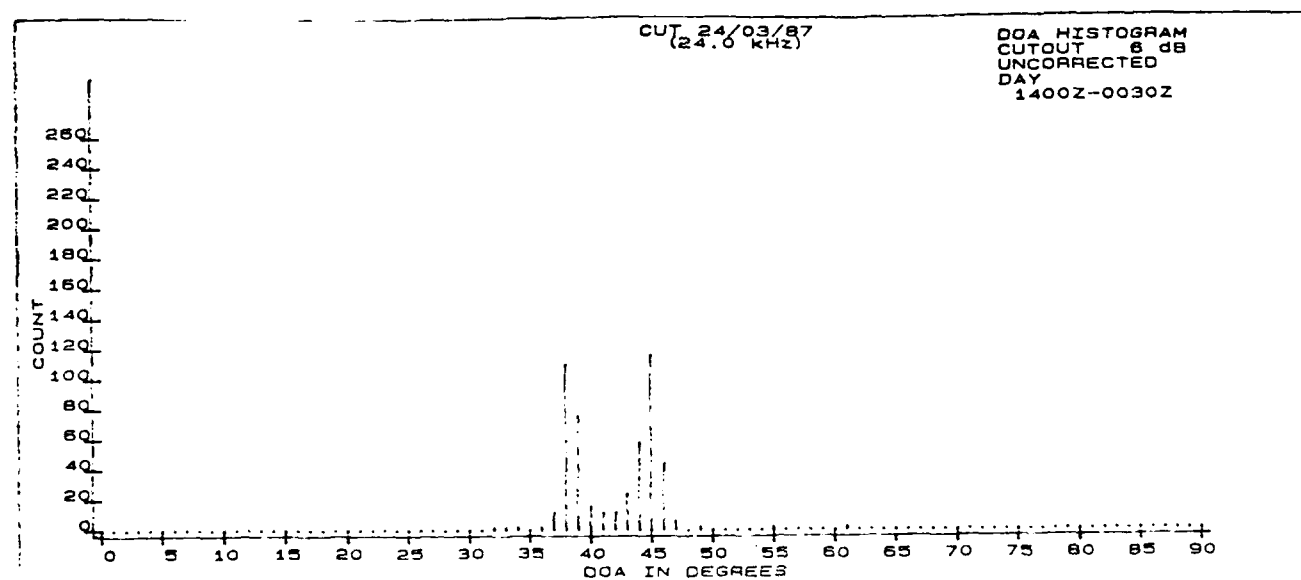
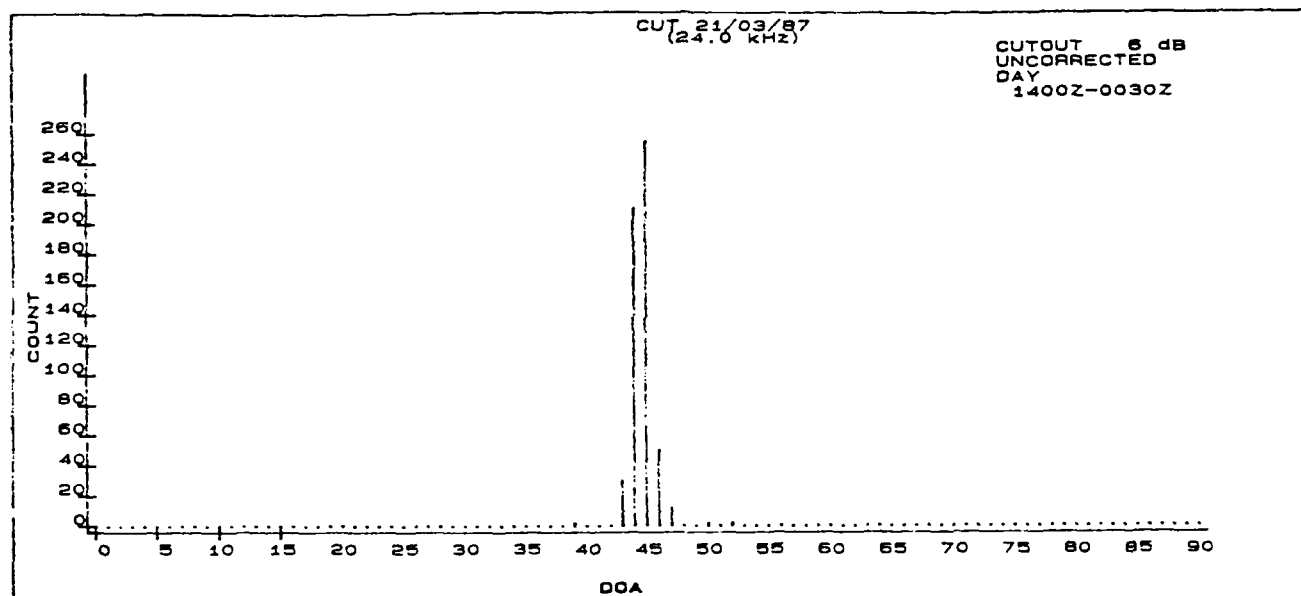
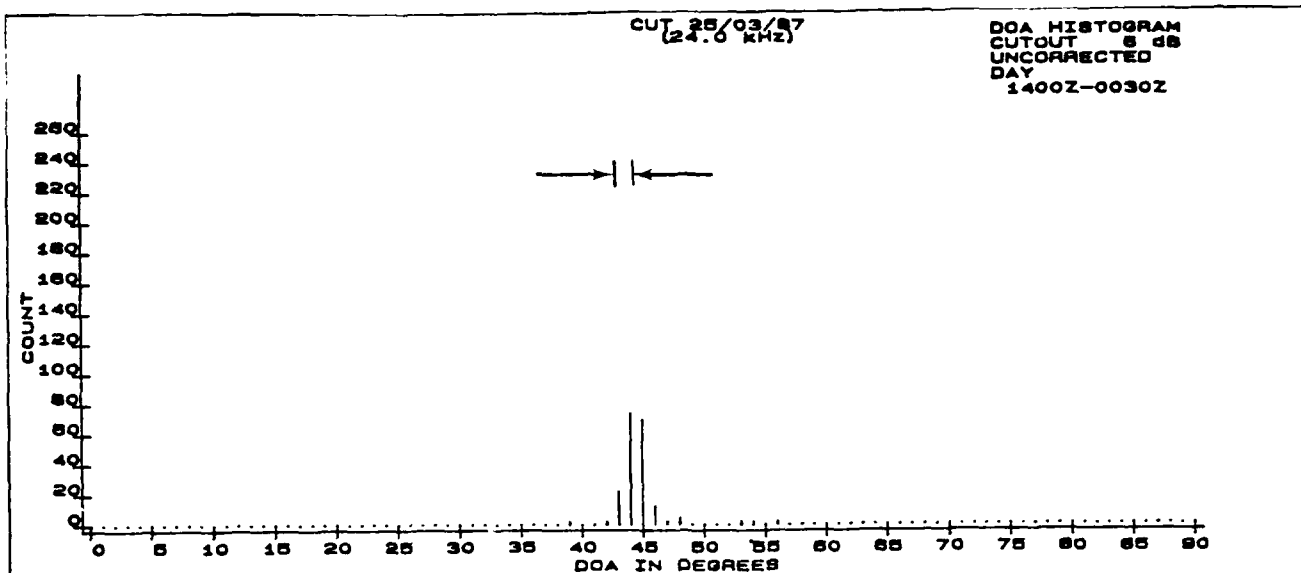


Figure 16. Histograms for Cutler to San Diego - Day.

Cutler to San Diego  $\beta = .5, h_{\text{prime}} = 74.0$

Freq = 24.000 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

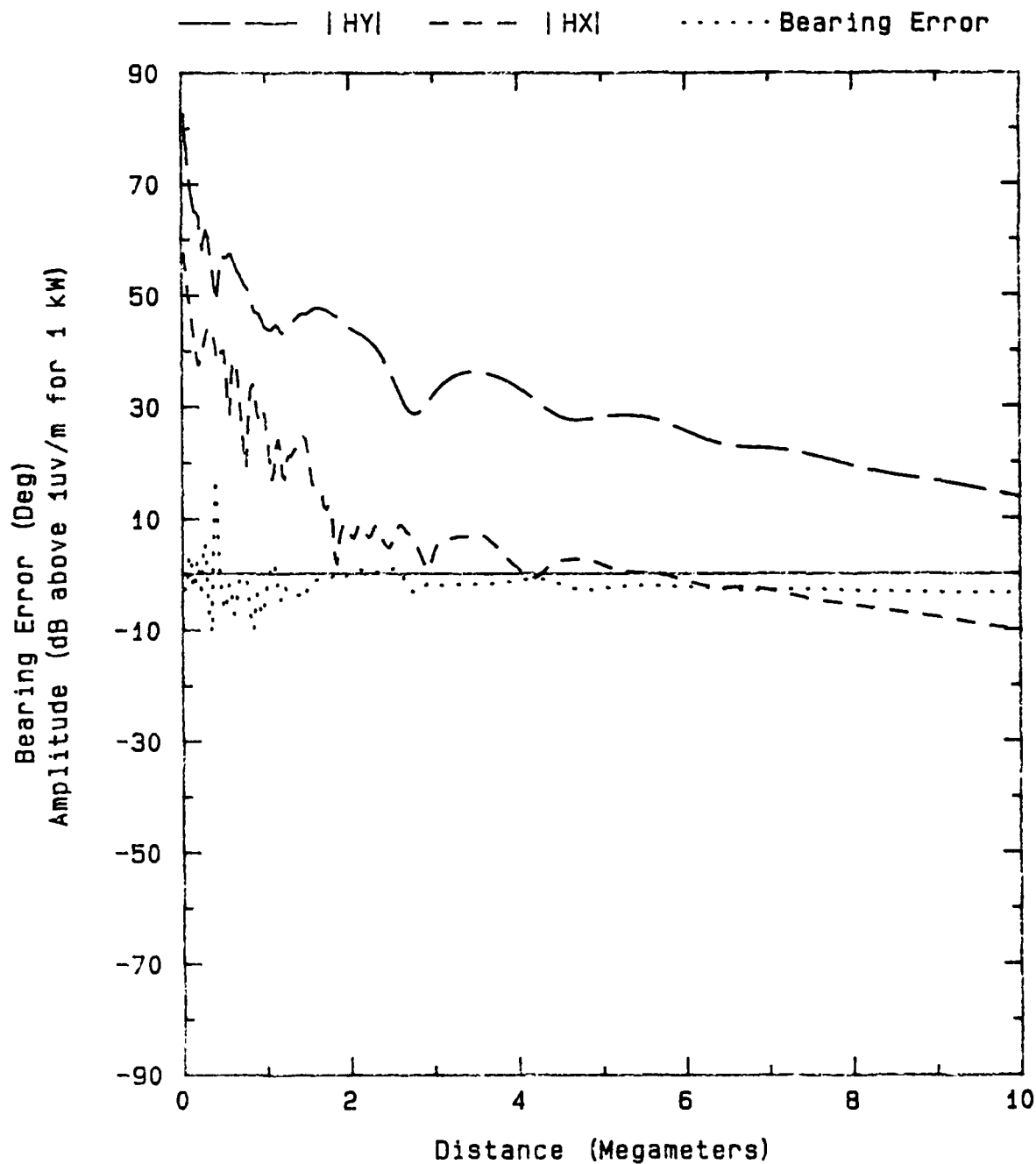


Figure 17. Sample range plot for Cutler to San Diego - Day.

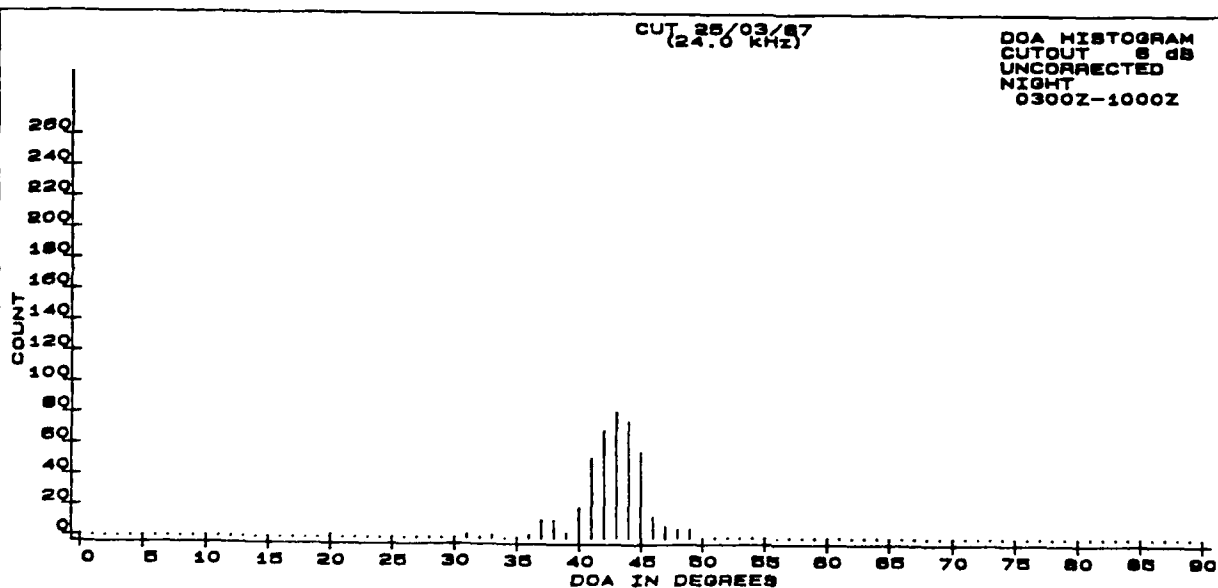
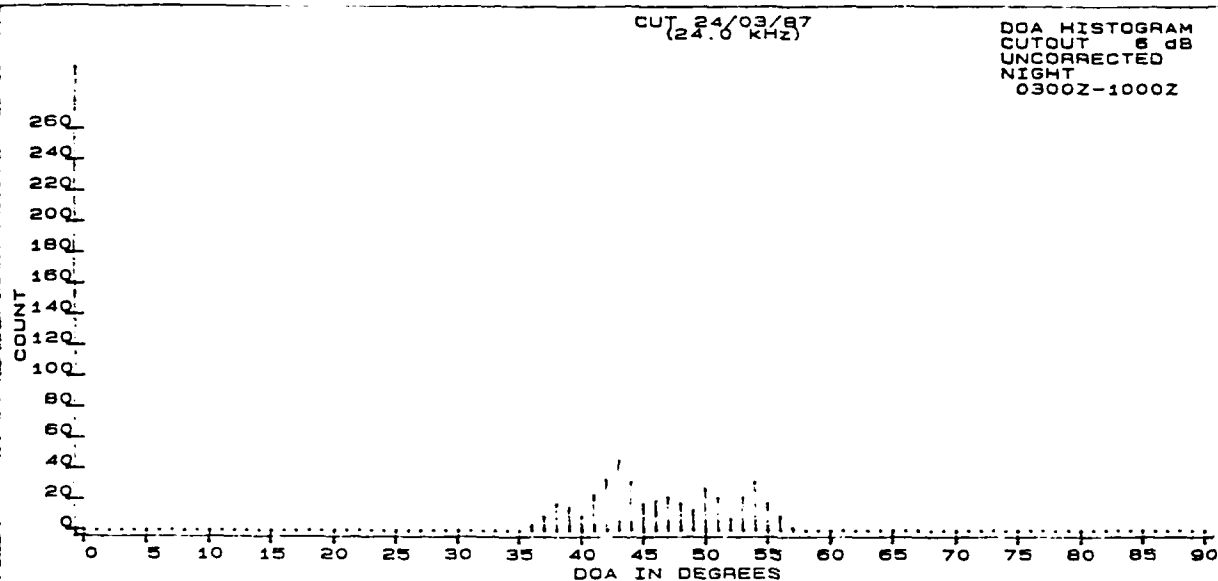
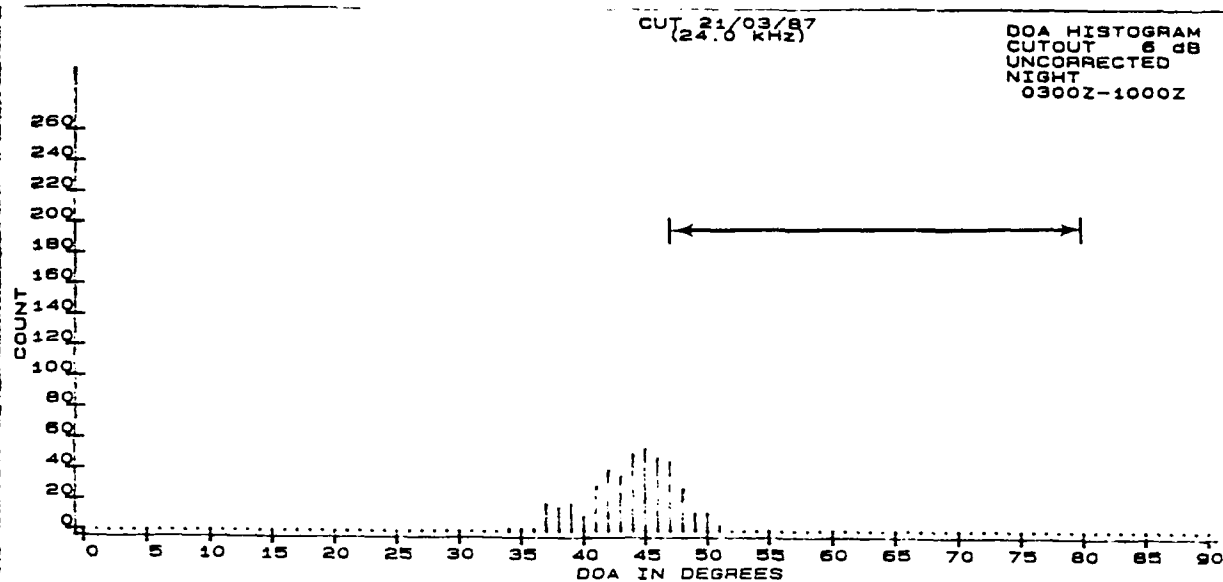


Figure 18. Histograms for Cutler to San Diego - Night.

Cutler to San Diego  $\beta = .5, h_{\text{prime}} = 88.0$

Freq = 24.000 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

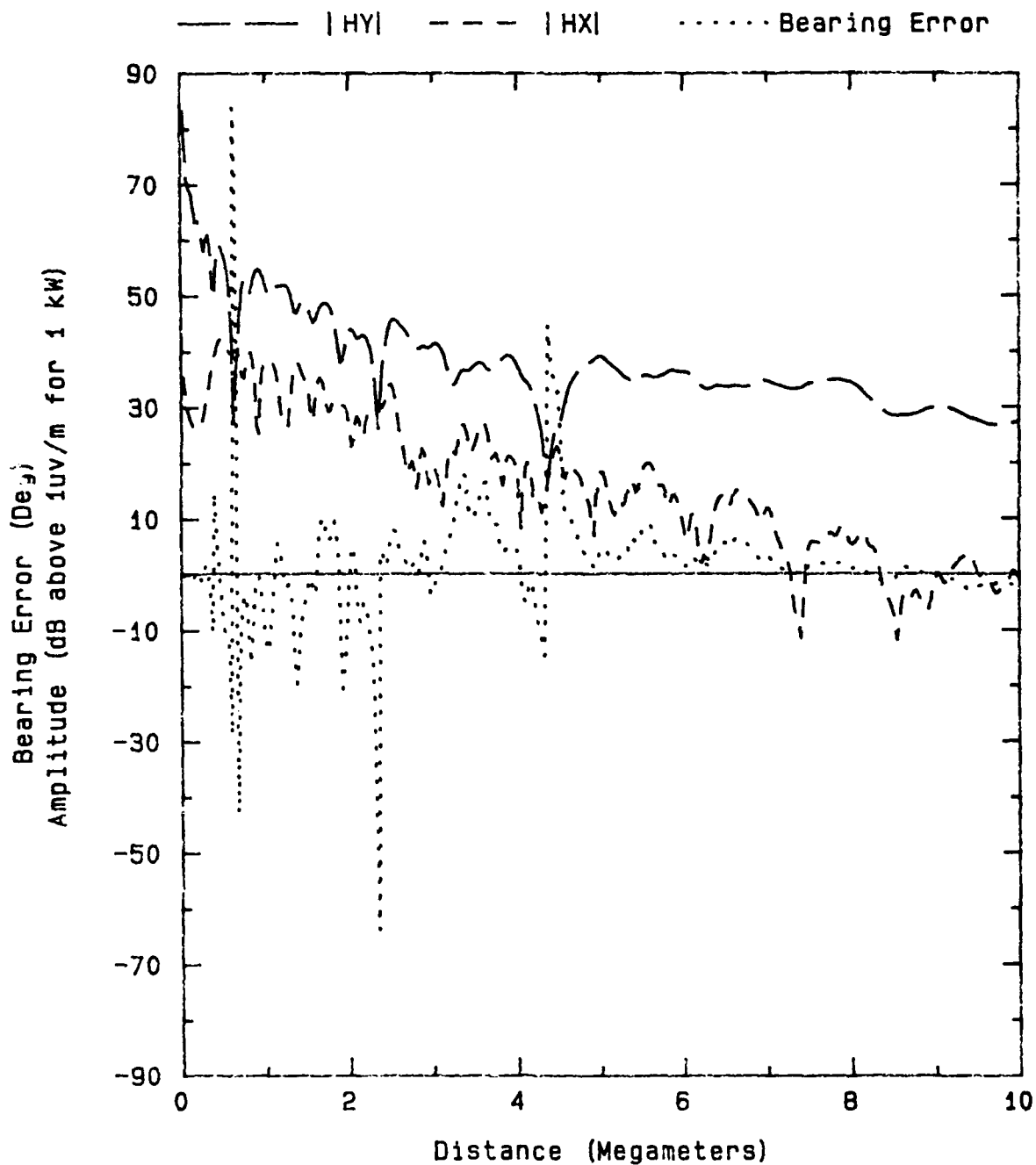


Figure 19. Sample range plot for Cutler to San Diego - Night.

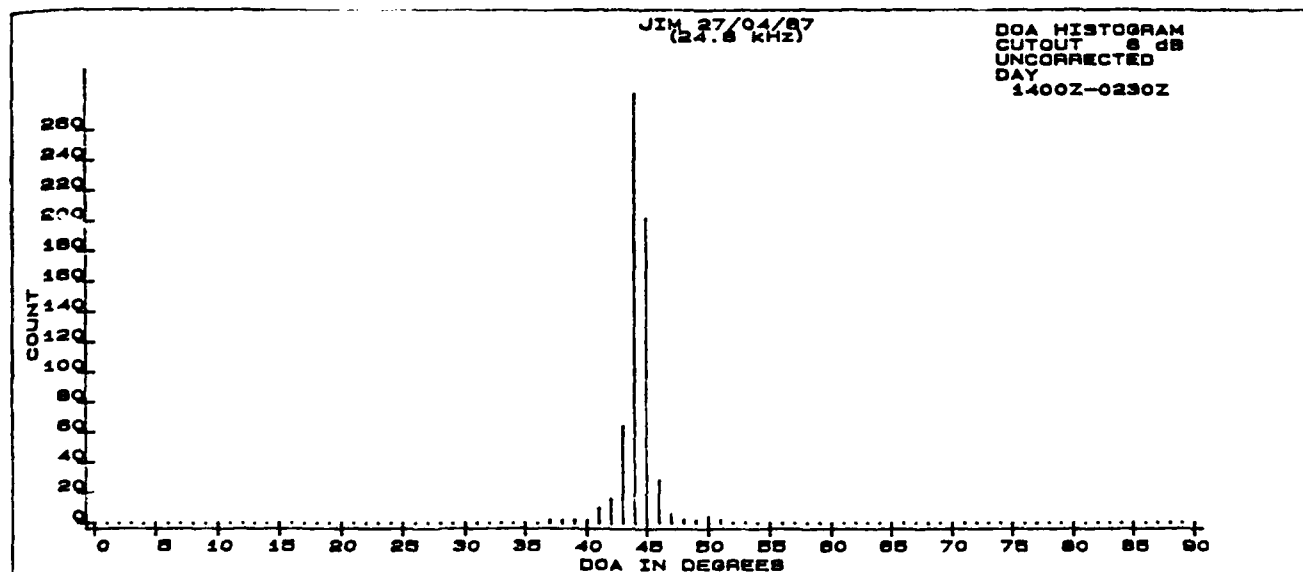
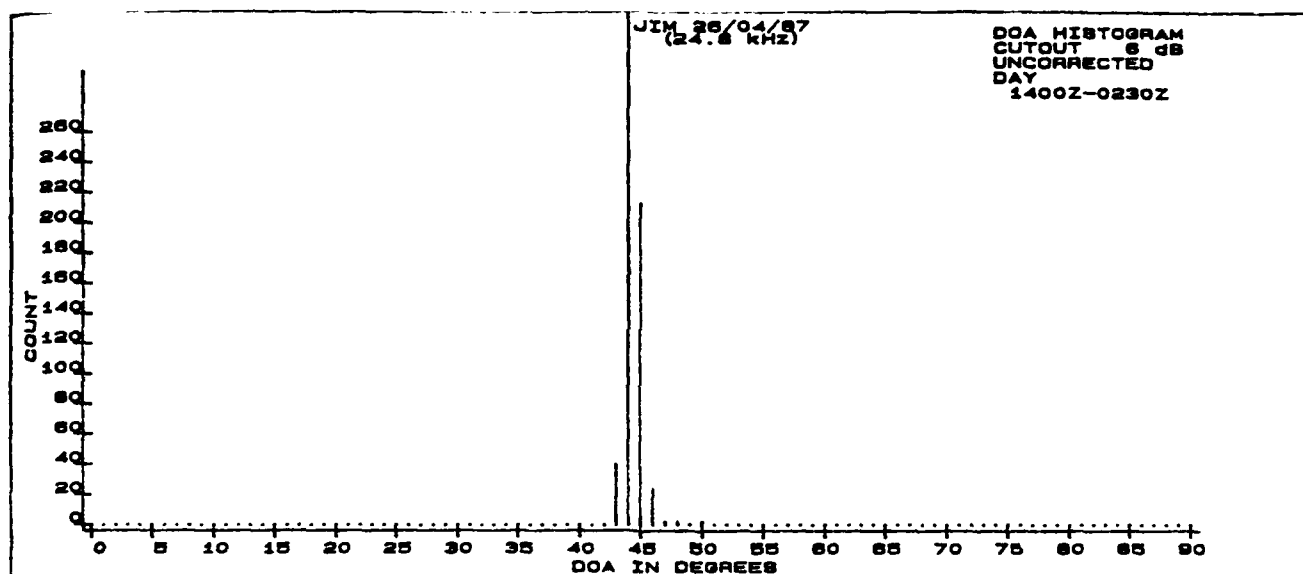
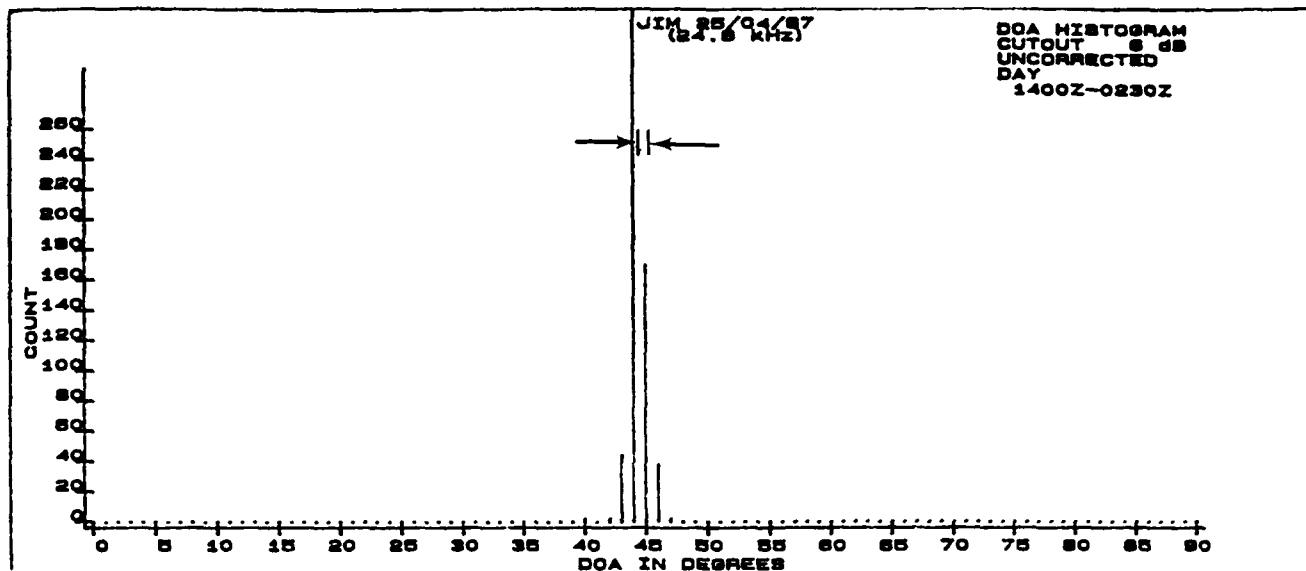


Figure 20. Histograms for Jim Creek to San Diego - Day.

Jim Creek to San Diego  $\beta = .5$ ,  $h' = 74.0$

Freq = 24.800 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

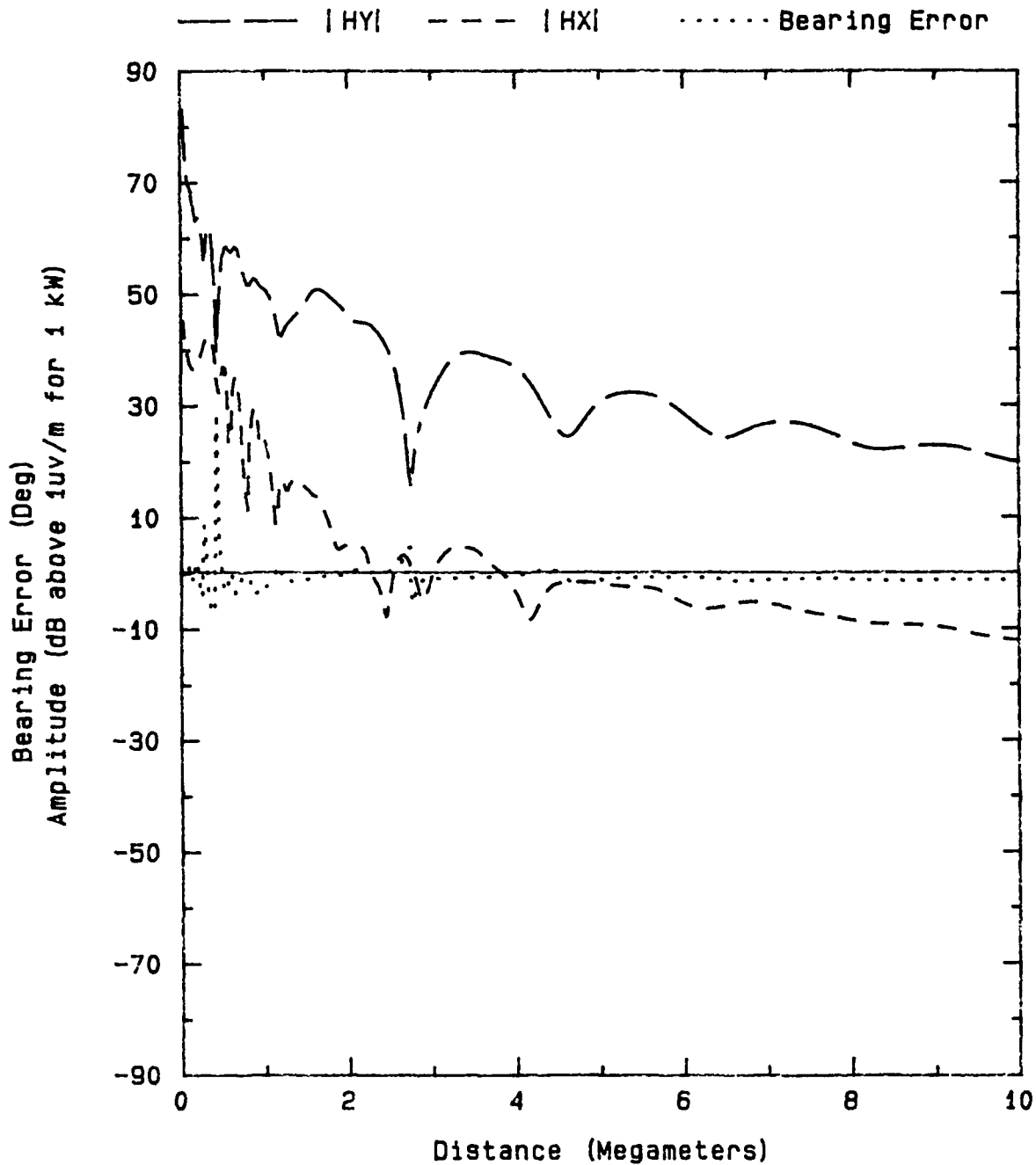


Figure 21. Sample range plot for Jim Creek to San Diego - Day.

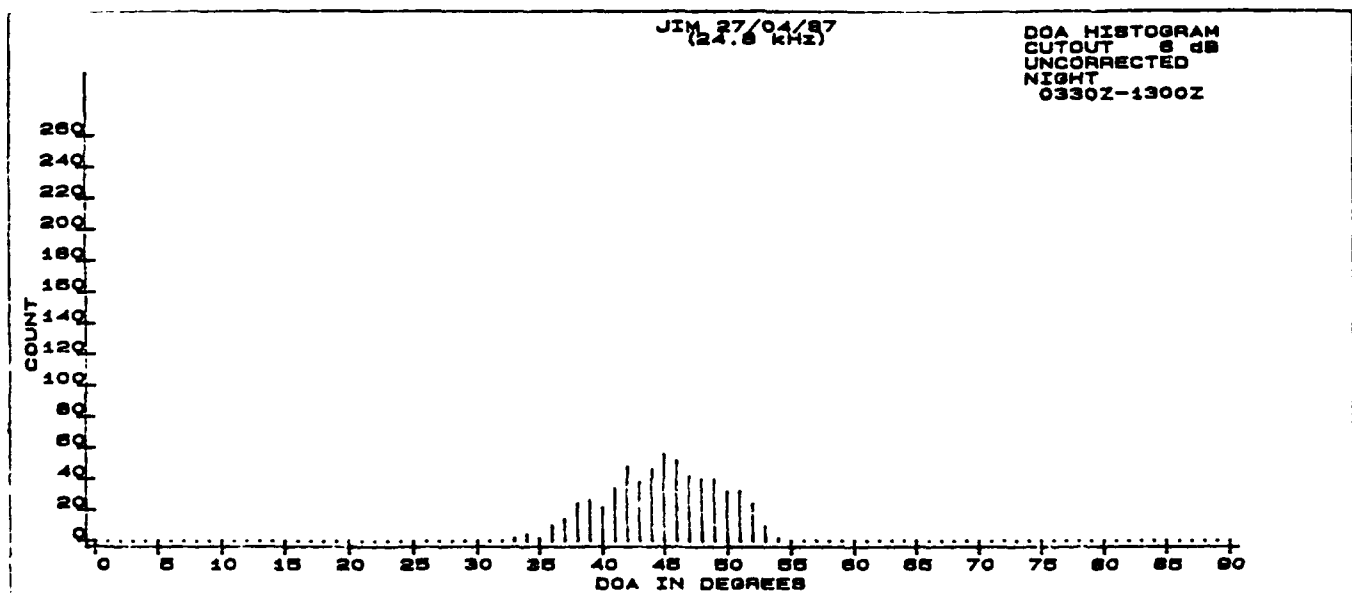
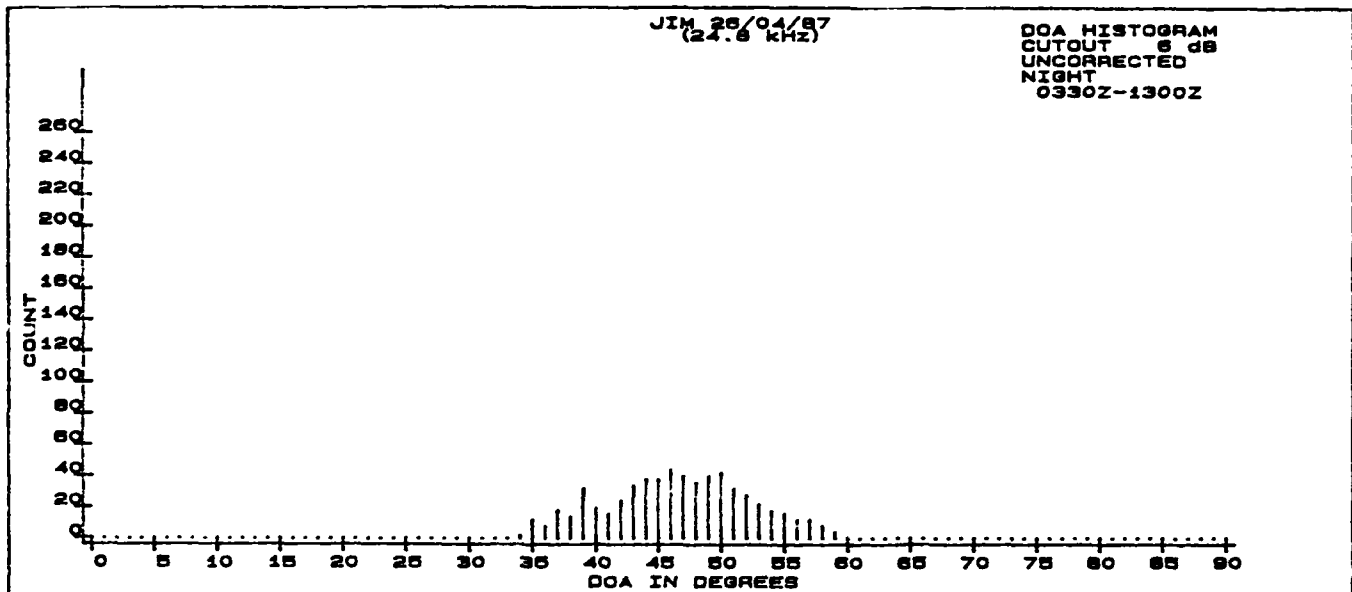
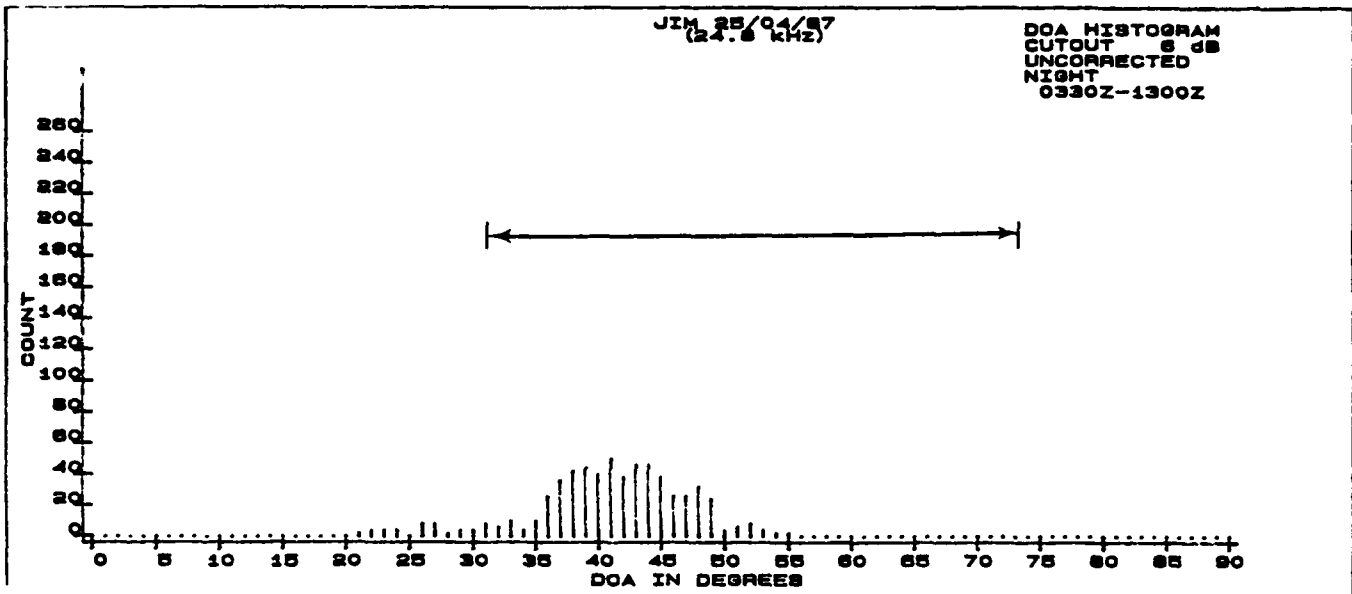


Figure 22. Histograms for Jim Creek to San Diego - Night.

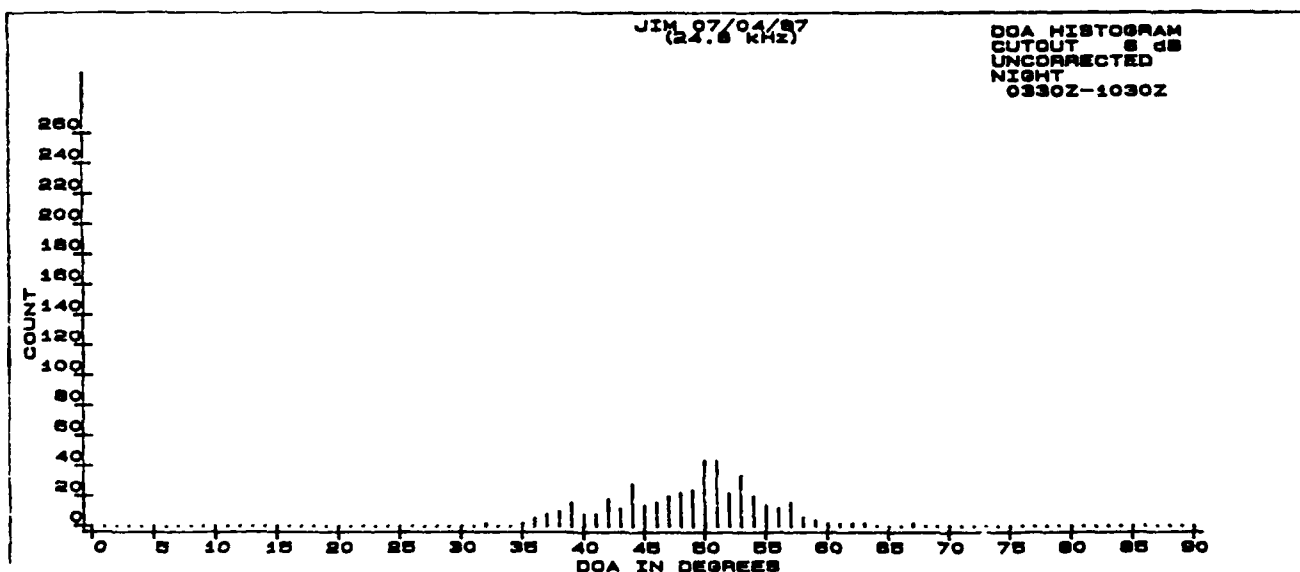
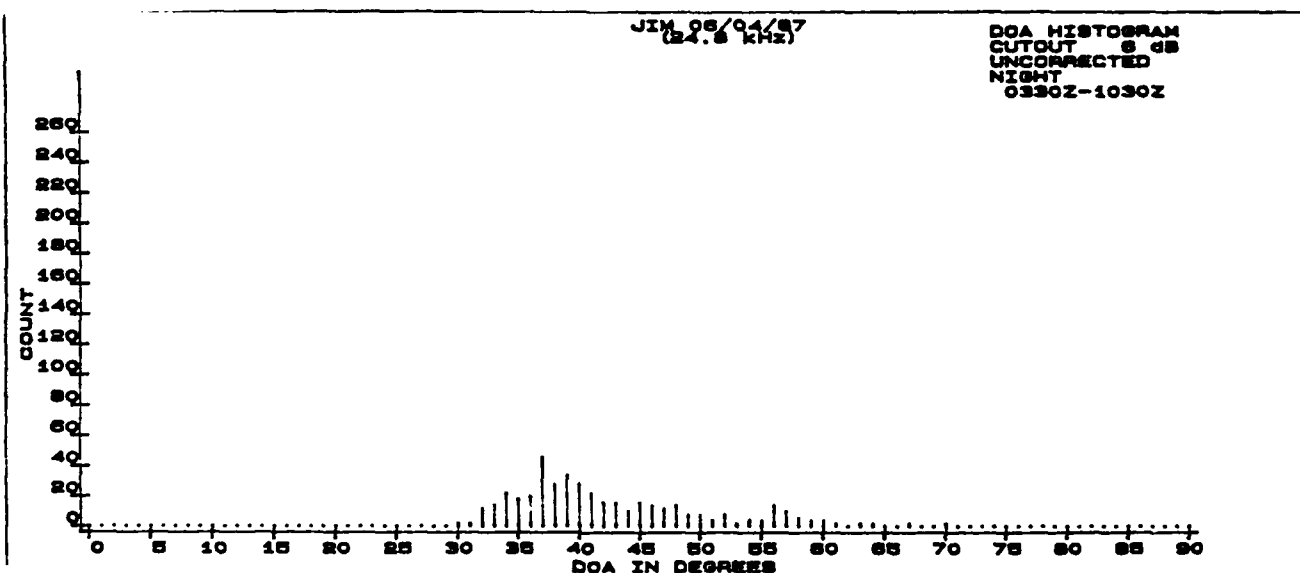
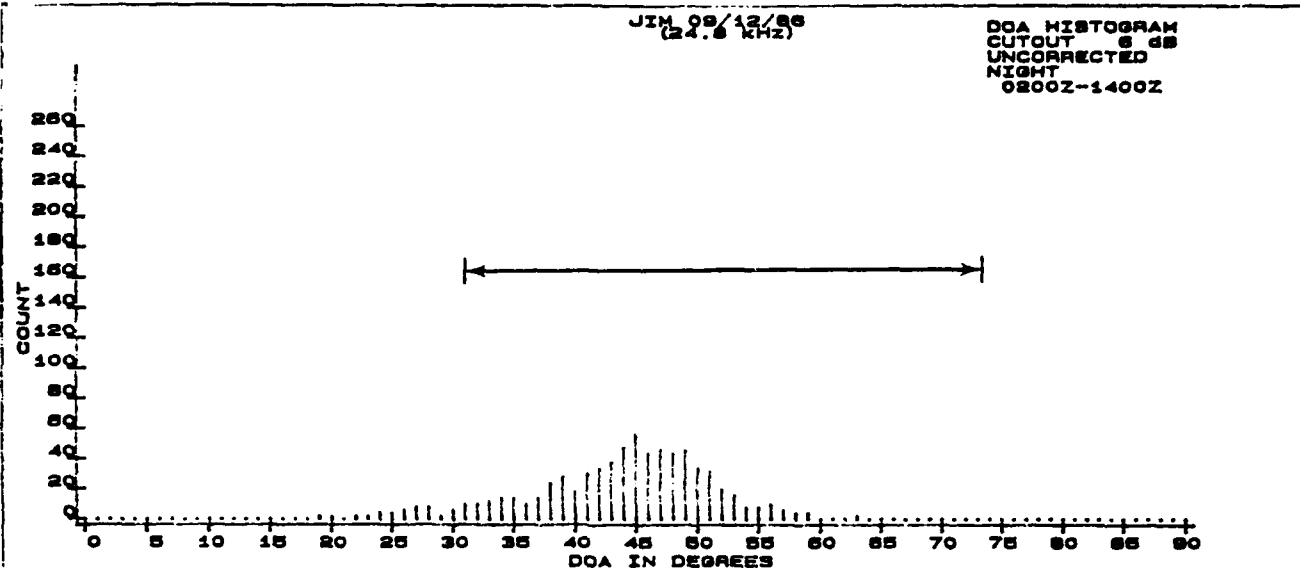


Figure 23. Histograms for Jim Creek to San Diego - Night.

Jim Creek to San Diego  $\beta = .5, h_{\text{prime}} = 88.0$

Freq = 24.800 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

— — — |HY|    - - - |HX|    ..... Bearing Error

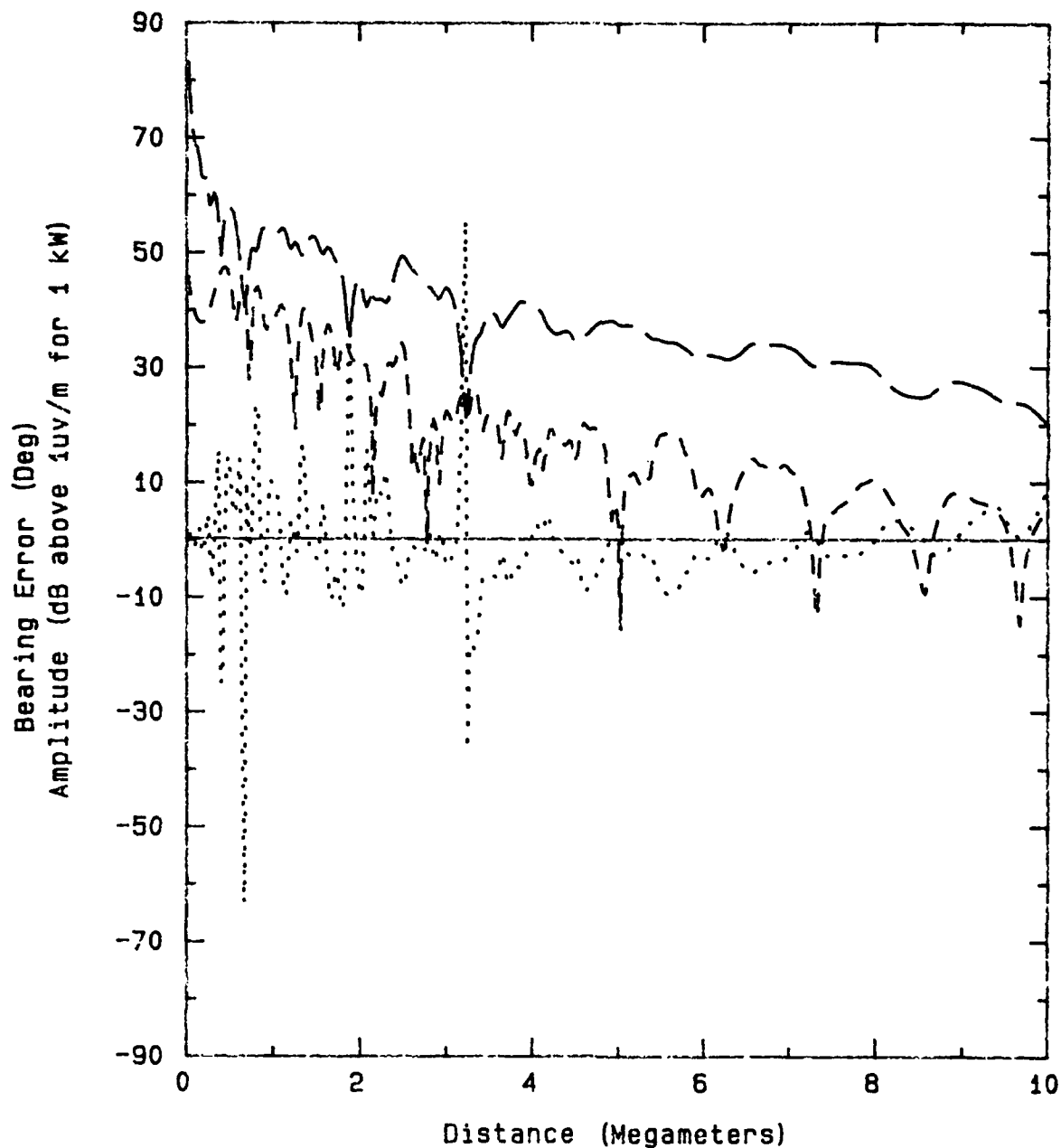


Figure 24. Sample range plot for Jim Creek to San Diego - Night.

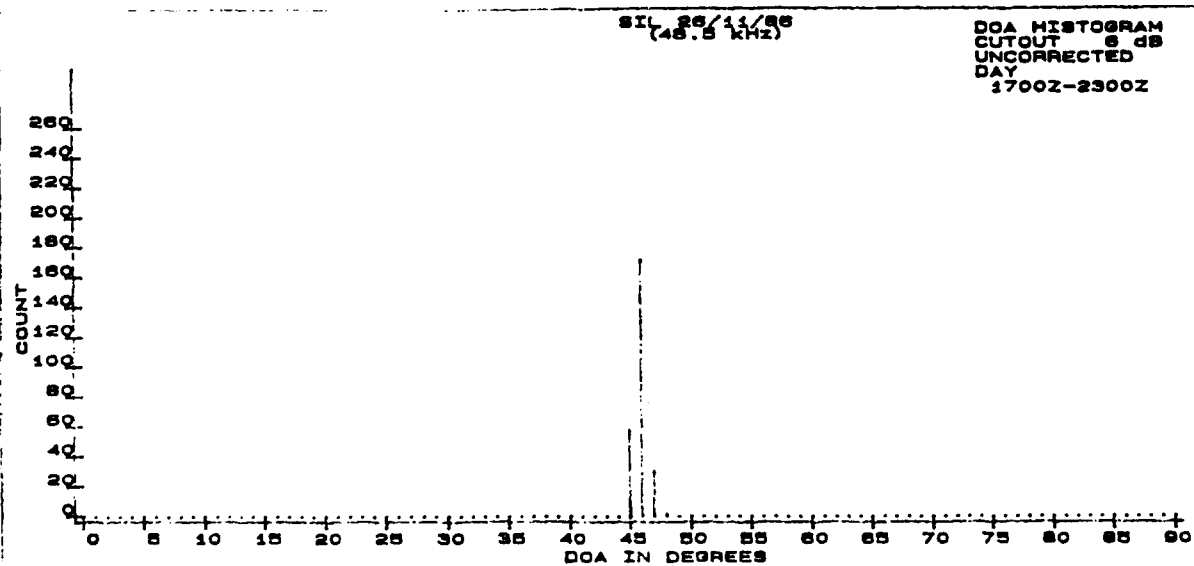
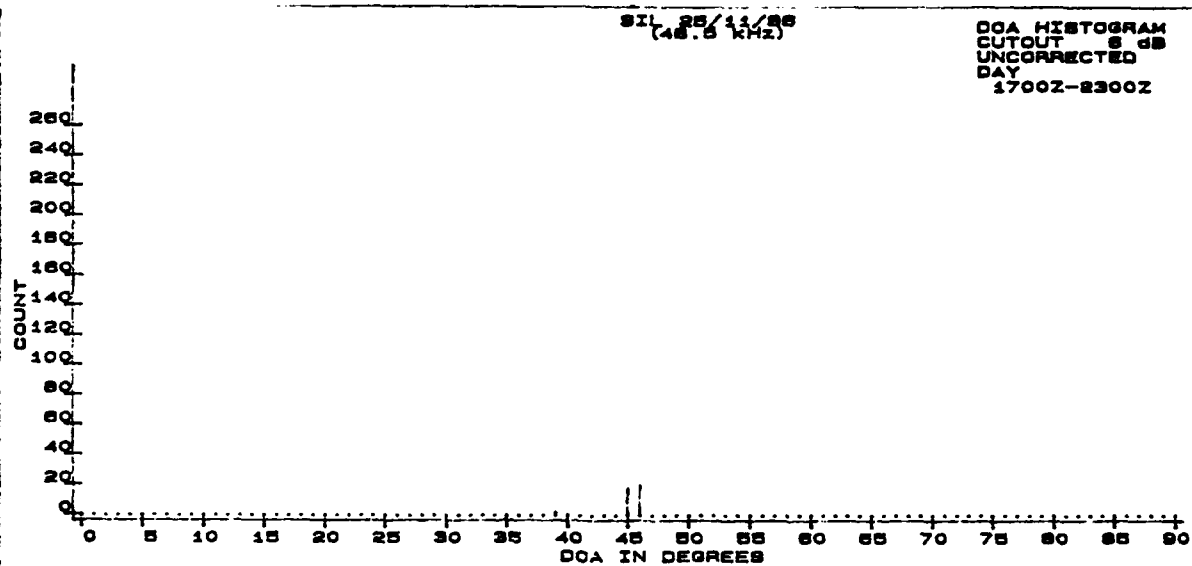
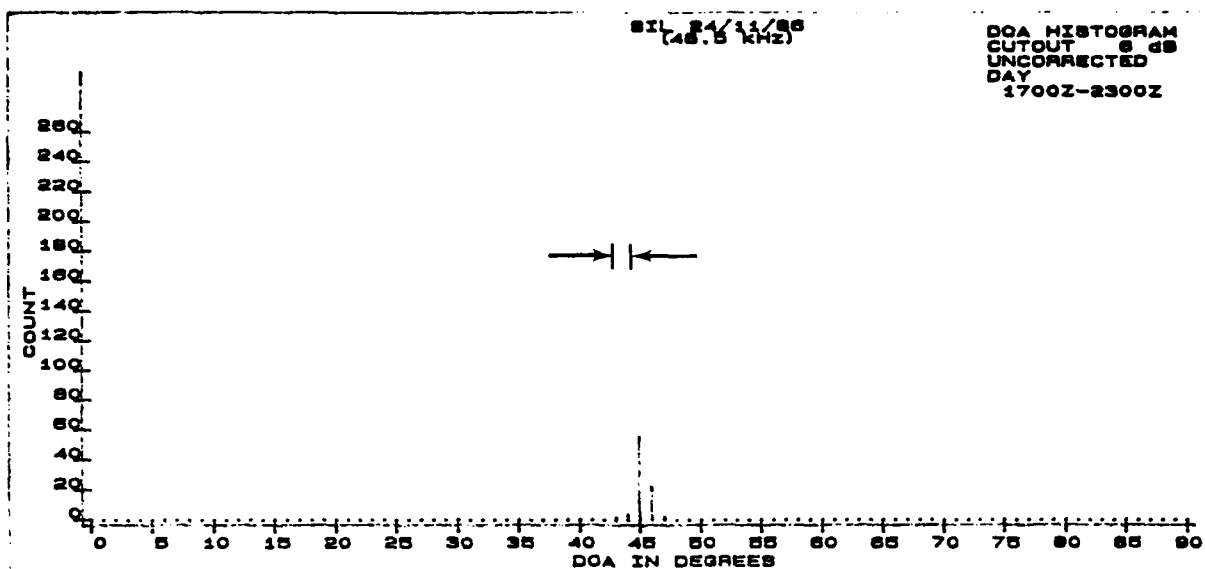


Figure 25. Histograms for Silver Creek to San Diego - Day.

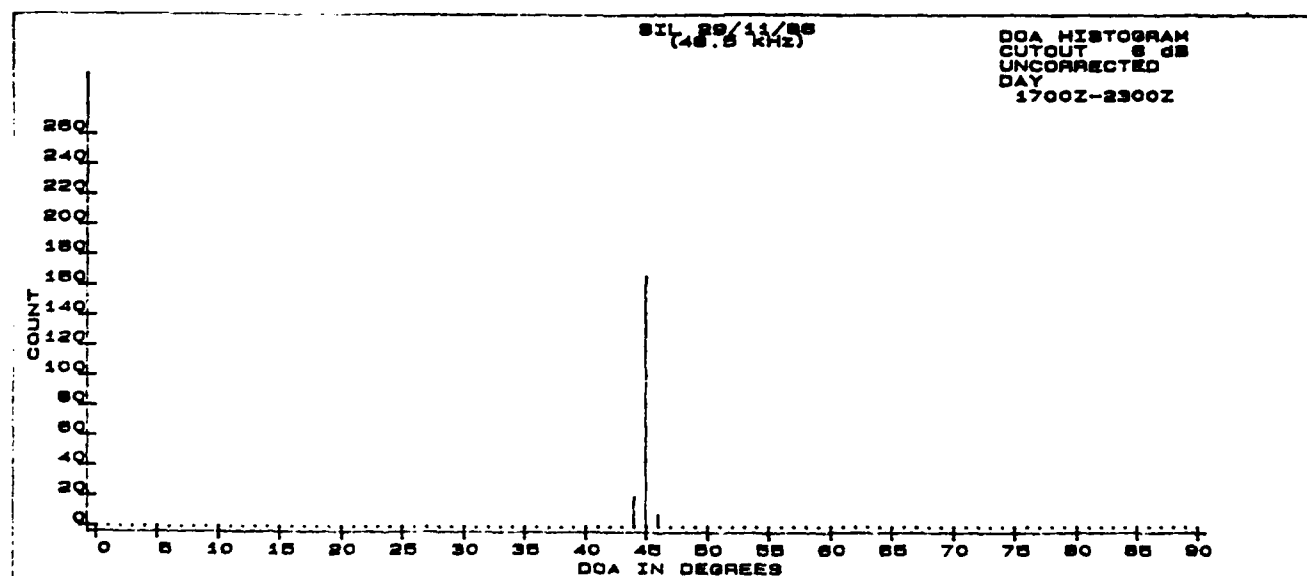
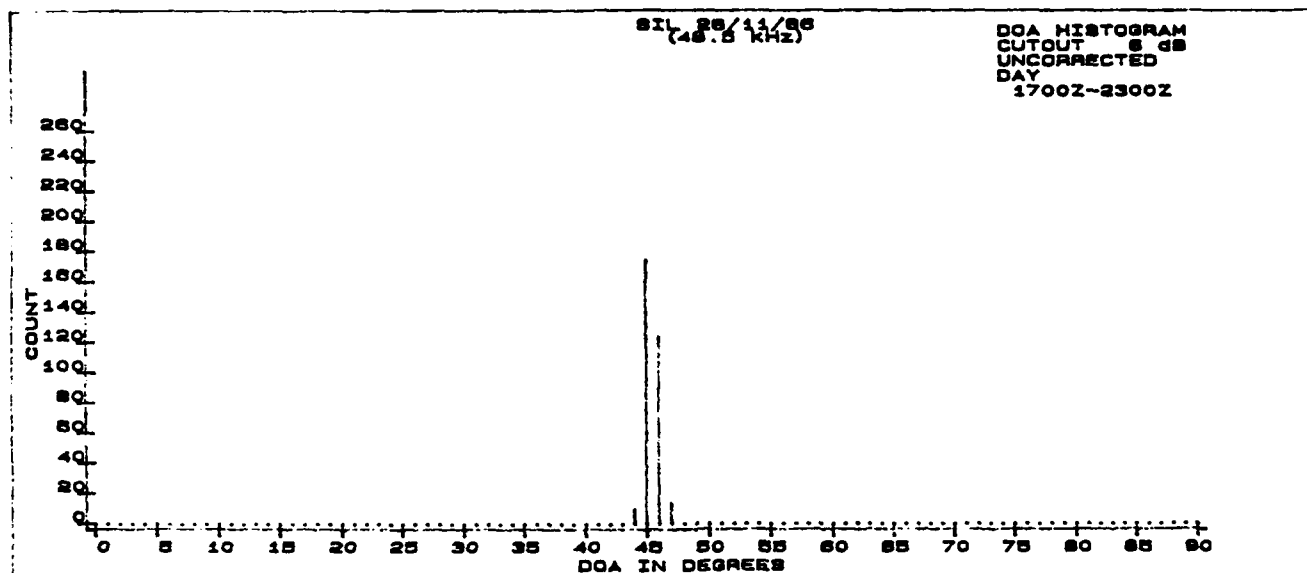
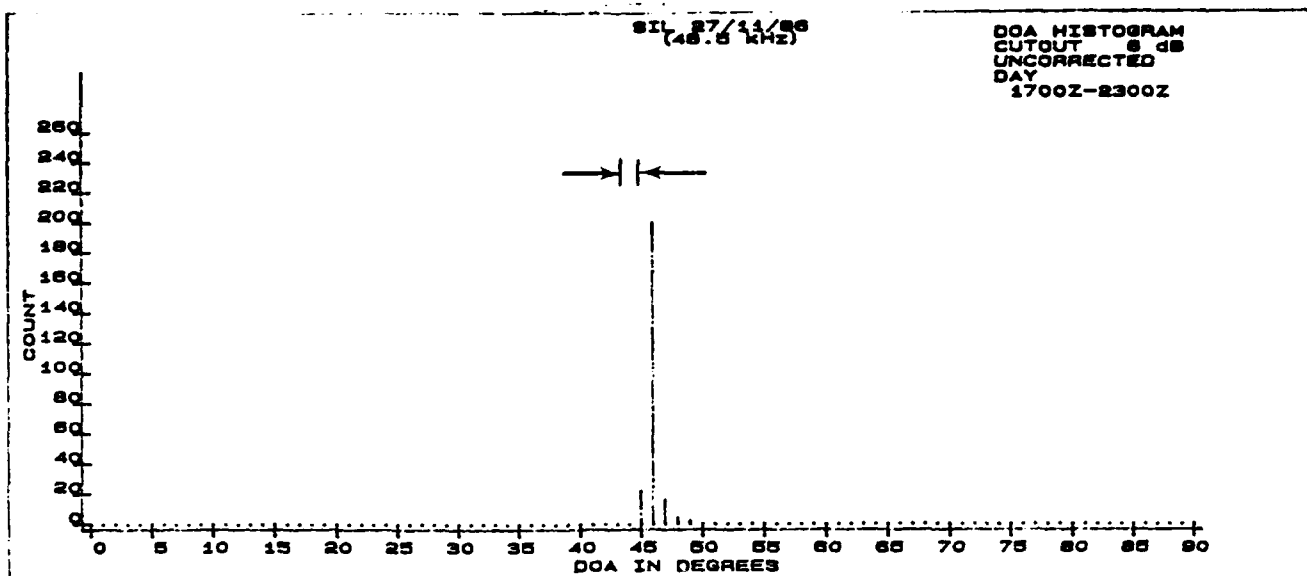


Figure 26. Histograms for Silver Creek to San Diego - Day.

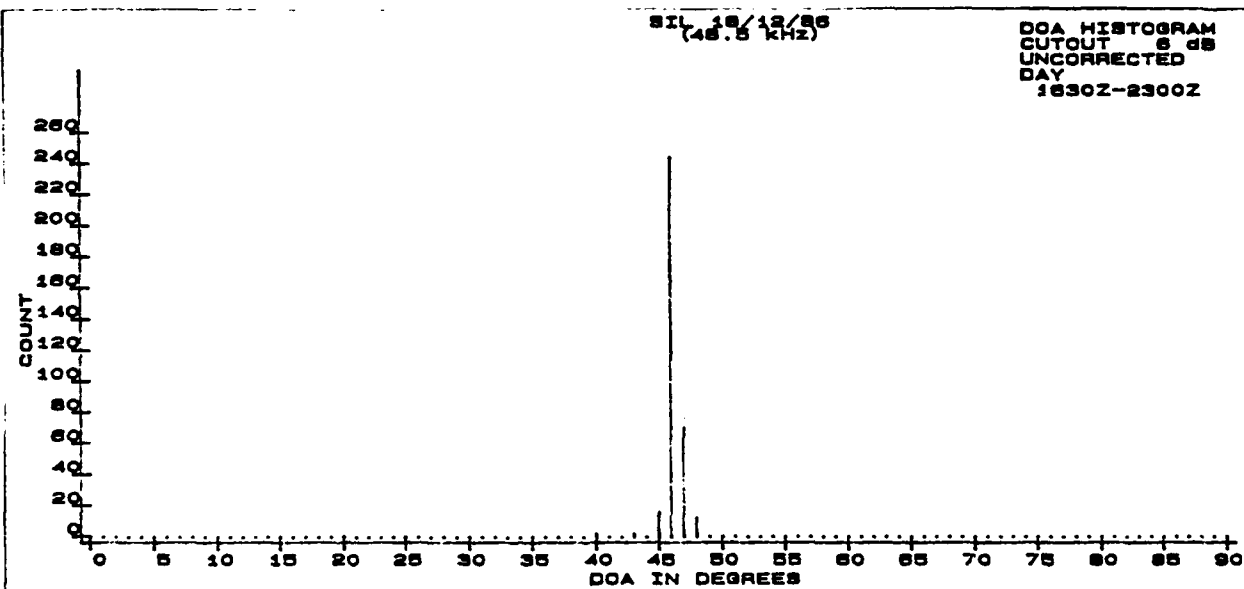
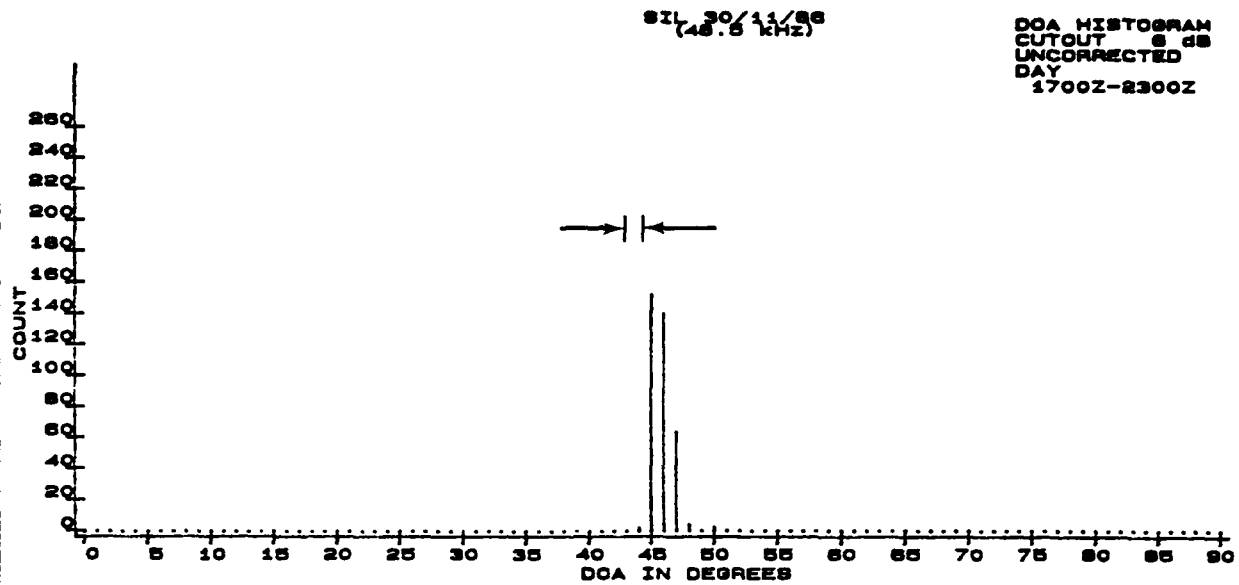


Figure 27. Histograms for Silver Creek to San Diego - Day.

Silver Creek to San Diego  $\beta = .5, h_{\text{prime}} = 75.0$

Freq = 48.500 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

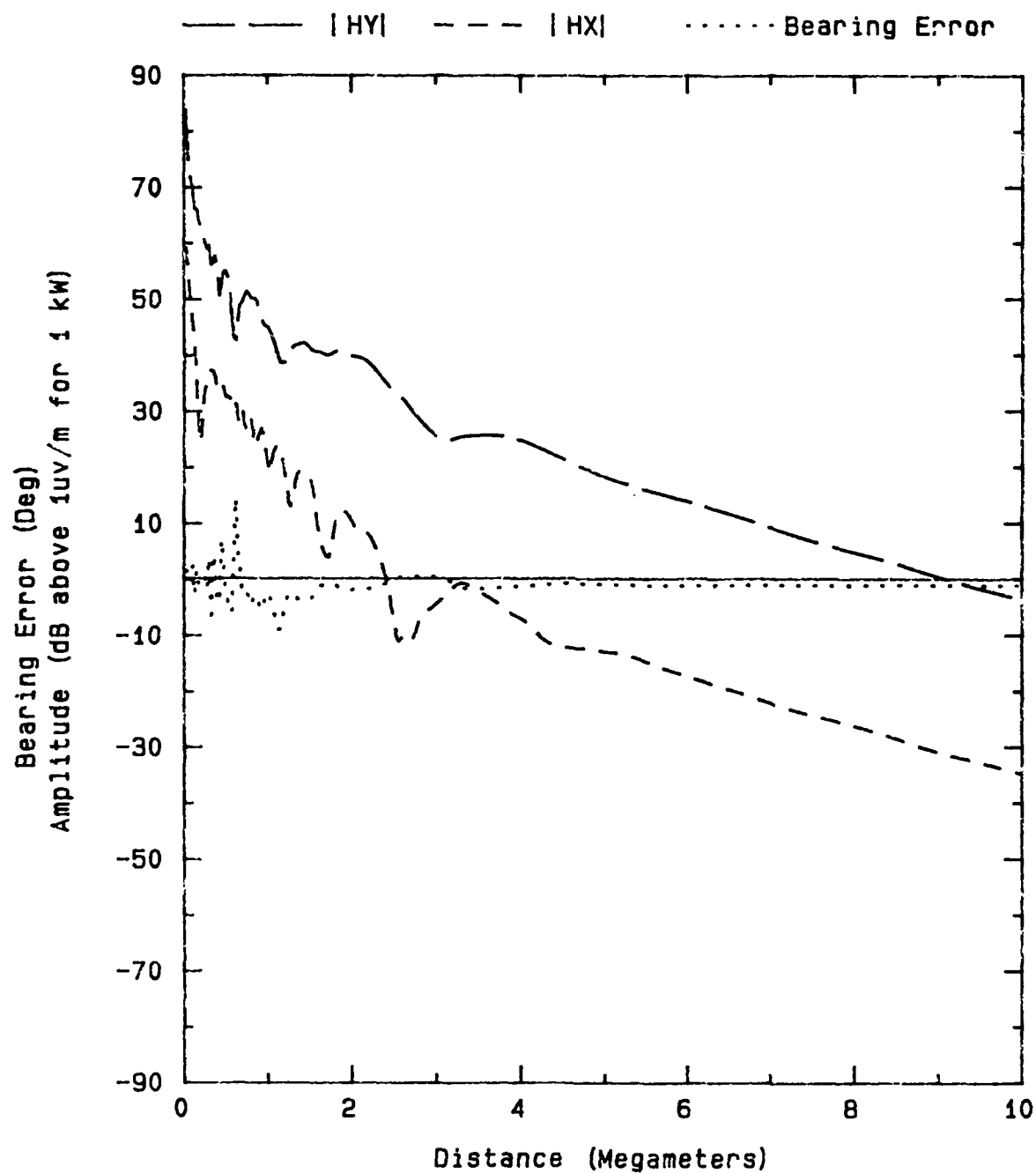


Figure 28. Sample range plot for Silver Creek to San Diego - Day.

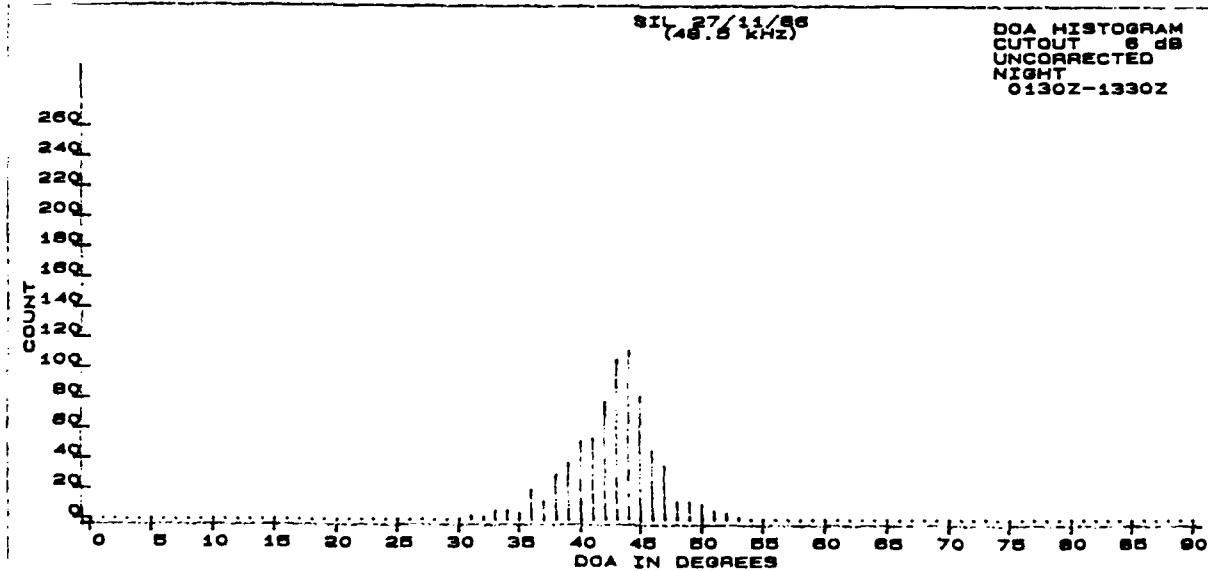
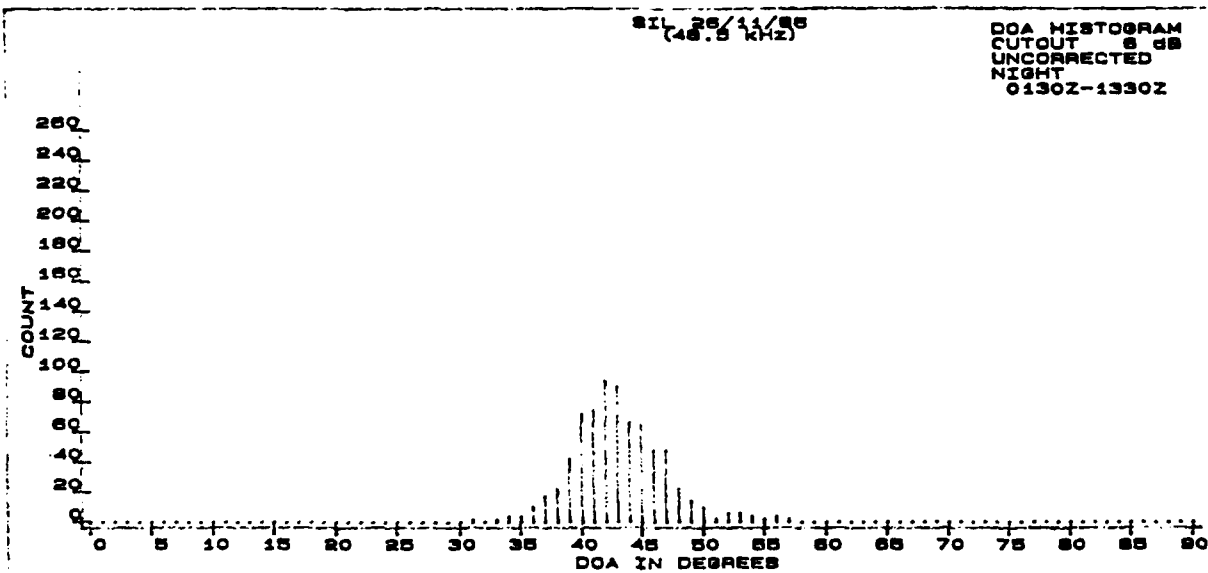
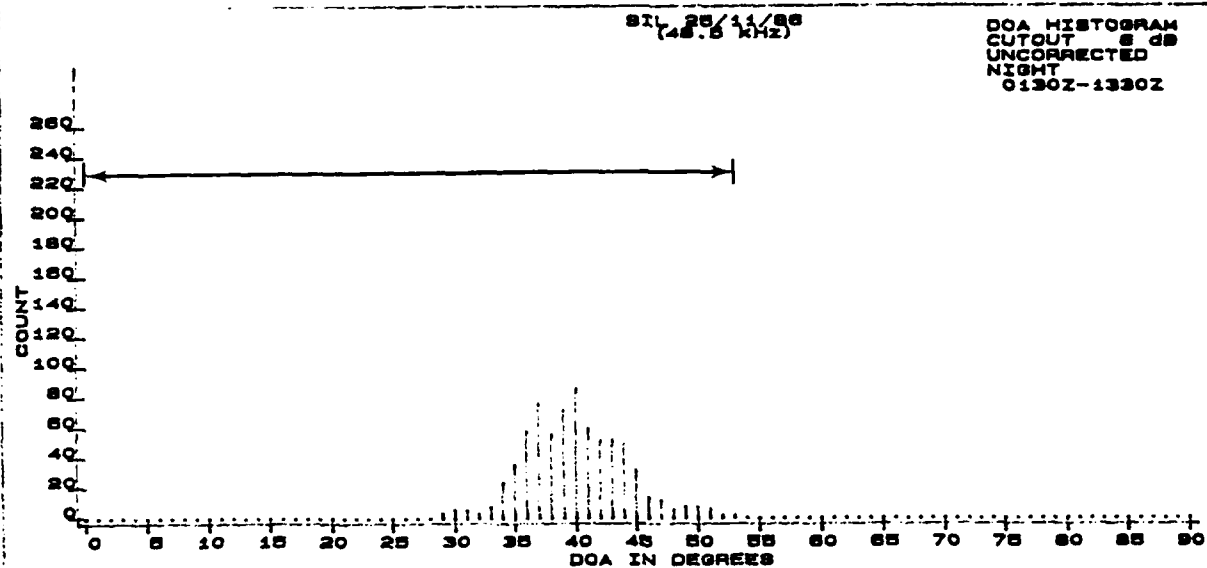


Figure 29. Histograms for Silver Creek to San Diego - Night.

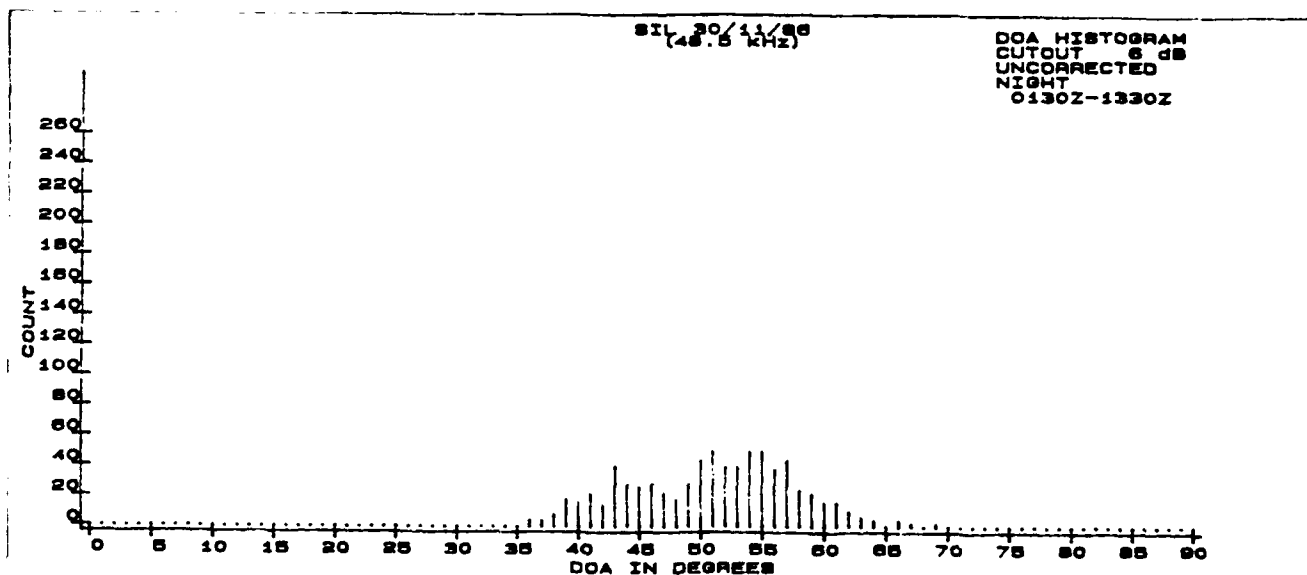
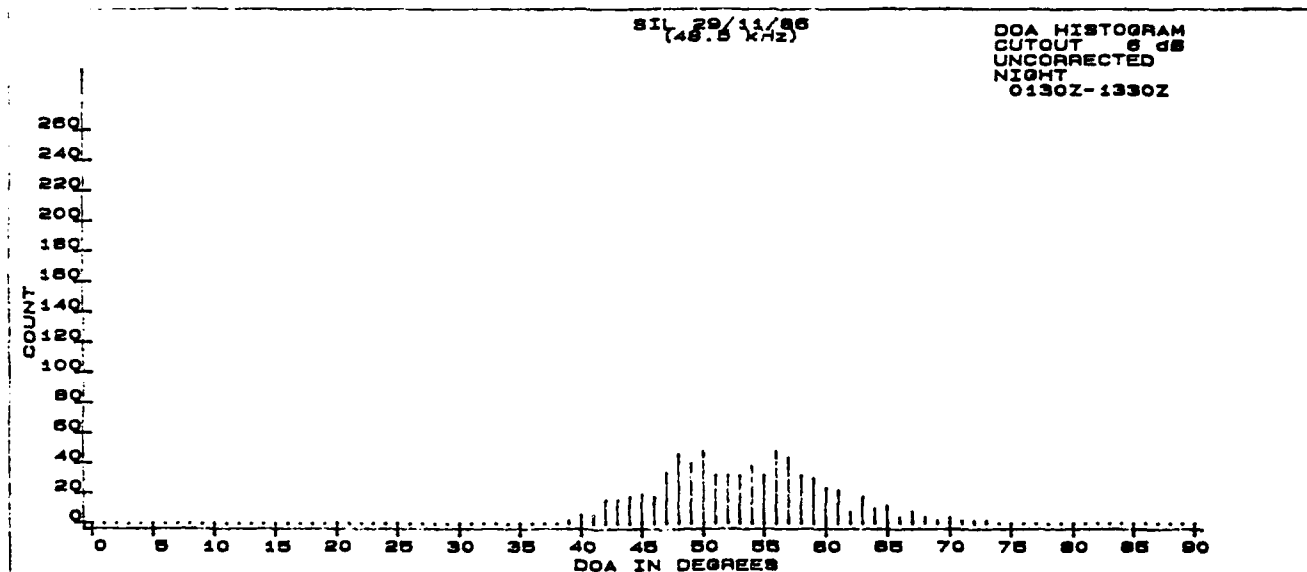
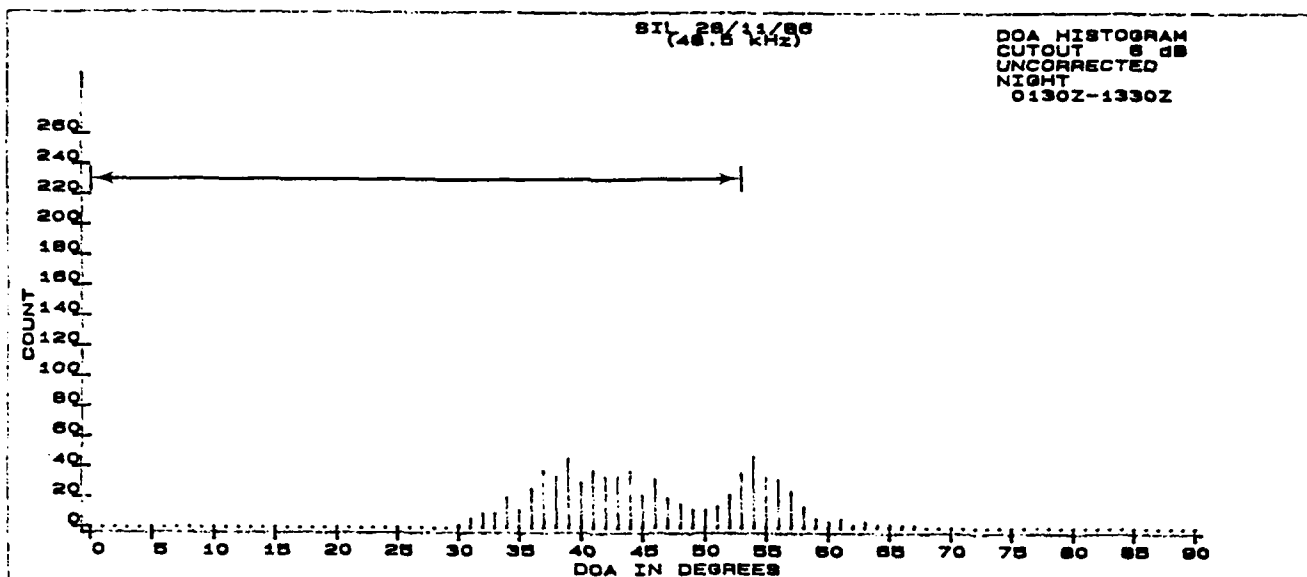


Figure 30. Histograms for Silver Creek to San Diego - Night.

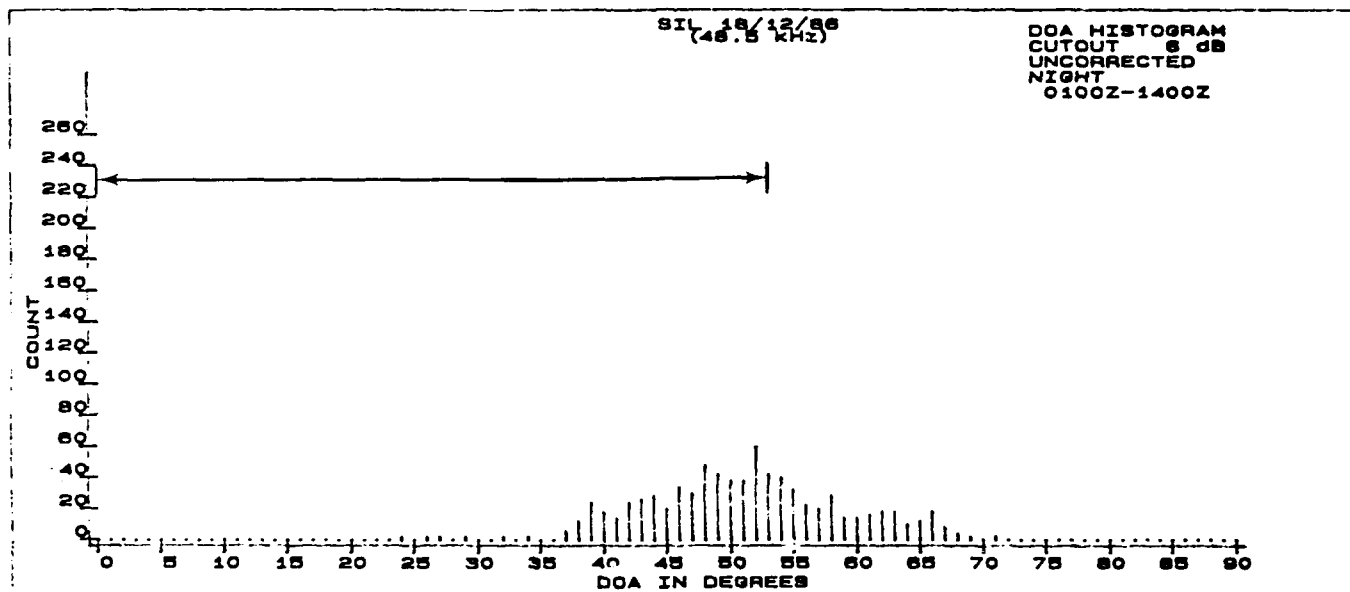


Figure 31. Histograms for Silver Creek to San Diego - Night.

Silver Creek to San Diego  $\beta=1.1, h_{\text{prime}}=88.0$

Freq = 48.500 kHz

$Z_t = 0.00$  km  $Z_r = 0.00$  km

$\Gamma = 0.0$  deg  $\Phi = 0.0$  deg

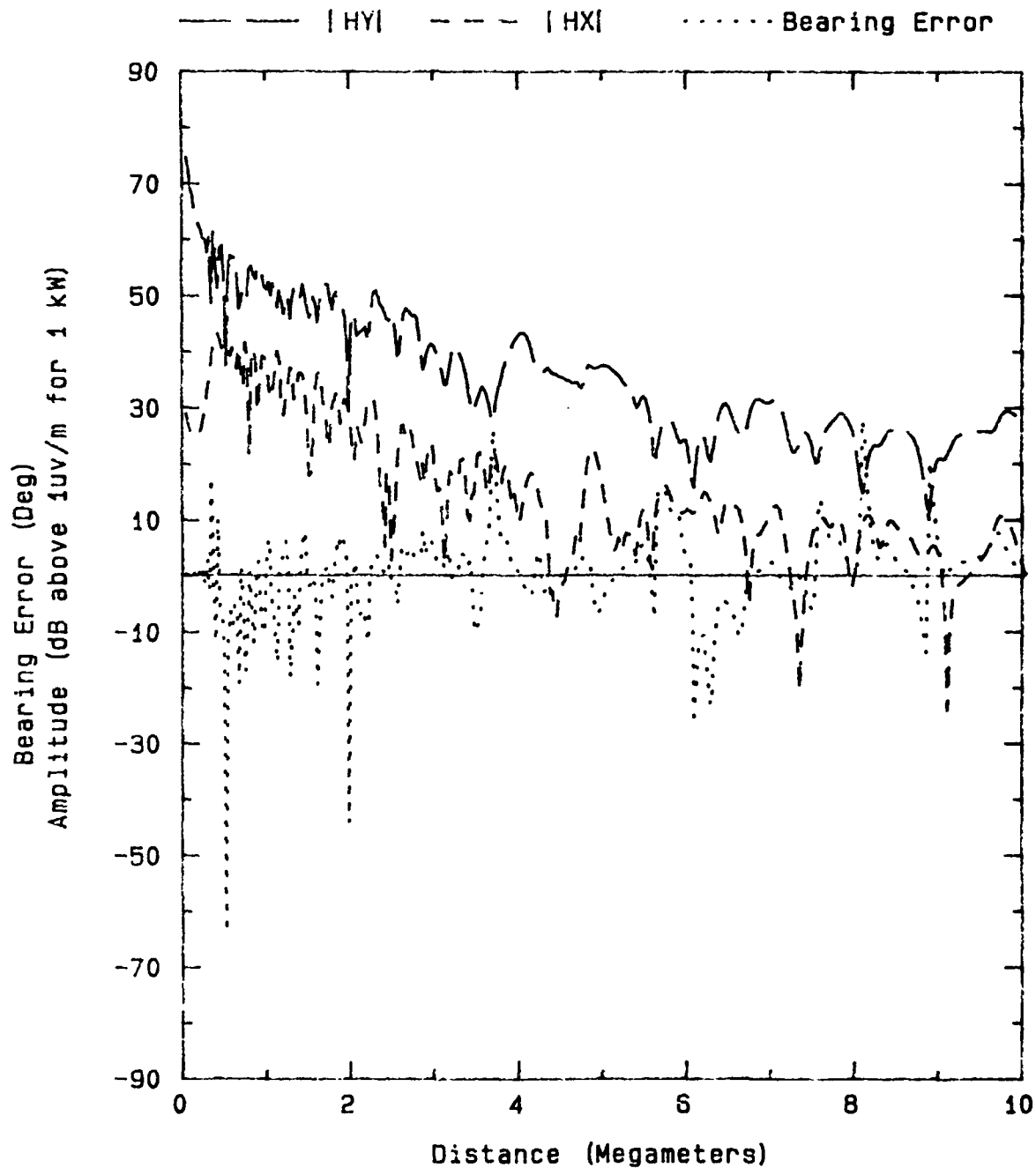


Figure 32. Sample range plot for Silver Creek to San Diego - Night.

## APPENDIX A: PROGRAM LISTING

```

parameter (maxmds=30)
IMPLICIT REAL *8(A-H,O-Z)
COMMON/HGTEMP/FF1(25,maxmds),FF3(25,maxmds)
COMMON/TERM/NT,NTR
COMMON/CAP/CAPI(25,maxmds,maxmds),TNORM(25,maxmds,maxmds)
COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$      XTRA(3,3,25,maxmds),TOPHT(25),
$      XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$      SIGMA(25),NRSLAB,NRMODE(25),NTMAX
COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
$      NTHSQ(25),KVRAOT,KVRATT,
$      AVRKOT,AVRKT,CONST,OMEGA,WAVENO
COMMON/MCPLOT/R(400),DBY(400),DBX(400),ANGCHI(400),
$      IDPLOT,ISUB
COMMON/XPLOT/XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
common/pltflg/iplflg
DIMENSION Z(2)
character*4 bcd(20)
character*68 idplot
REAL*4 R,DBY,dbx,angchi
REAL*4 XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
COMPLEX*16 FF1,FF3
COMPLEX*16 THETA,A,S,C,FOFR,IM,CAPI,TNORM
complex*16 temp
COMPLEX*16 XTRA,NTHSQ,T1,T2,T3,T4
REAL*8 KVRAOT,KVRATT
data IM/(0.0D0,1.0D0)/
NAMELIST/DATUM/      RHOMAX,
&  RHOMIN,DELTAX,NRSLAB,NTMAX,XVAL,
$  DELRHO,IFIRST,LAST,IPLTOP,iplflg,
$  XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY,
$  GAMMA,PHI,ZT,ZR,IPRNTA
$  ,INTFLG
DATA TWOPI/6.283185D0/,VELITE/2.997928D5/,ALPHA/3.14D-4/,
$  DEGRAD/1.745329D-2/
DATA LAST/0/,IPRNTA/0/

C
  INTFLG=0
  iplflg=0
10  continue
  READ(5,DATUM)
  print datum
  write(*,'(//)')
  GAMMA = GAMMA*DEGRAD
  PHI = PHI*DEGRAD
  SINGAM = DSIN(GAMMA)
  COSGAM = DCOS(GAMMA)
  SINPHI = DSIN(PHI)
  COSPHI = DCOS(PHI)
  read(5,'(a68)') idplot
  write(*,'(1x,a68,/)' ) idplot
  DO M=1,NRSLAB
    nrmode(m)=1
    read(5,1020) rr,ff,aa,cc,bb,ss,ee,topht(m)
    print 1022,m,rr,ff,aa,cc,bb,ss,ee,topht(m)
    PRINT 102
    if(m .gt. 1 .and. ff .ne. freq ) then

```

```

        print *, 'Check input records - mis-match on freq'
        stop
    endif
    freq=ff
    sigma(m)=ss
    epsr(m)=ee
205    k=nrmode(m)
    read(5,1023) indx1,temp,ipoll,t1,t2
    if(indx1 .gt. 0) then
        read(5,1023) indx2,theta(m,k),ipol2,t3,t4
c        get ey/hy
        if(ipoll .eq. 1) then
            fofr(m,k)=t3/t1
        else
            fofr(m,k)=t2/(t3*t4)
        end if
        PRINT 103, THETA(M,K), T1, T2, T3, T4, FOFR(M,K), TOPHT(M)
        S(M,K) = zsin(THETA(M,K)*DEGRAD)
        C(M,K) = zcos(THETA(M,K)*DEGRAD)
        XTRA(1,1,M,K) = T1*S(M,K)**2
        XTRA(1,2,M,K) = T1*S(M,K)
        XTRA(1,3,M,K) = -T3*S(M,K)
        XTRA(2,1,M,K) = -T1*S(M,K)
        XTRA(2,2,M,K) = -T1
        XTRA(2,3,M,K) = T3
        XTRA(3,1,M,K) = -T3*T4*S(M,K)
        XTRA(3,2,M,K) = -T3*T4
        XTRA(3,3,M,K) = T2
        nrmode(m)=nrmode(m)+1
        go to 205
    endif
    nrmode(m)=nrmode(m)-1
enddo
NT = 1
WAVE NO = TWO PI*1000.0*FREQ/VELITE
CONST = 0.03248*WAVE NO/DSQRT(FREQ)
OMEGA = TWO PI*FREQ*1000.
KVRAOT = DEXP(DLOG(WAVE NO/ALPHA)/3.)
KVRATT = KVRAOT**2
AVRKOT = 1./KVRAOT
AVRKTT = AVRKOT**2*0.5
DO 130 L=1,NRSLAB
130    NTHSQ(L) = 1.+ALPHA*TOPHT(L)
    IFLG = 0
    DO 135 M=1,NRSLAB
        IF(M .NE. 1) IFLG=1
135    CALL HTINTL(CAPI, TNORM, IFLG, M, INTFLG)
        Z(1) = ZT
        Z(2) = ZR
        CALL HTGAIN(Z)
        DO 136 M=1,NRSLAB
            DO 136 K=1,NRMODE(m)
                XTRA(1,1,M,K) = XTRA(1,1,M,K)*FF1(M,K)**2
                XTRA(1,2,M,K) = XTRA(1,2,M,K)*FF1(M,K)**2
                XTRA(1,3,M,K) = XTRA(1,3,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
                XTRA(2,1,M,K) = XTRA(2,1,M,K)*FF1(M,K)**2
                XTRA(2,2,M,K) = XTRA(2,2,M,K)*FF1(M,K)**2
                XTRA(2,3,M,K) = XTRA(2,3,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)

```

```

XTRA(3,1,M,K) = XTRA(3,1,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
XTRA(3,2,M,K) = XTRA(3,2,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
XTRA(3,3,M,K) = XTRA(3,3,M,K)*FF3(M,K)**2/(FOFR(M,K)**2)
136 CONTINUE
    if(nrslab .eq. 1) then
        do j=1,nrmode(1)
            do k=1,nrmode(1)
                a(1,k,j)=(0.,0)
                if(k .eq. j) a(1,k,j)=(1.0,0.0)
            enddo
        enddo
        ntr=1
        go to 405
    endif
118 IF(XVAL(2) .GE. 0.) GO TO 111
    DO 112 L=1,NRSLAB
    DO 112 J=1,NRMODE(1)
    DO 112 K=1,NRMODE(1)
112 A(L,K,J) = 0.0
    DO 113 L=2,NRSLAB
    IF(XVAL(L) .GE. 0.) GO TO 114
113 CONTINUE
    NTR = nrslab
    GO TO 117
114 NTR = L-1
117 CONTINUE
    DO 116 J=1,NRMODE(ntr)
    DO 116 K=1,NRMODE(ntr)
116 IF(K .EQ. J) A(NTR,K,J)=(1.0,0.0)
    DO 401 M=ntr,nrslab
401 CALL MCSTEP(M)
    IF(IPRNTA .EQ. 0) GO TO 91
    PRINT 905
    DO 451 L=ntr,nrslab
    PRINT 900,L
    DO 451 J=1,NRMODE(1)
    DO 451 K=1,NRMODE(1)
    PRINT 901,J,K,A(L,J,K)
451 CONTINUE
91 IF(IPLTOP .EQ. 1) CALL MCFLD
    IF(IPLTOP .EQ. 2) CALL MCFLD2
    NT = NT+1
    DO 106 ME=2,nrslab
106 XVAL(ME) = XVAL(ME)+DELTAX
    IF(XVAL(NTR) .GE. 0. .AND. NT .LE. NTMAX) GO TO 118
    IF(NT .LE. NTMAX) GO TO 91
    IF(LAST .EQ. 0) GO TO 10
    stop
111 NTR = 1
    DO 120 L = 1,NRSLAB
    DO 120 K = 1, NRMODE(1)
    DO 120 J = 1, NRMODE(1)
    A(L,K,J) = 0.0
    IF(1 .eq. 1 .and. K .EQ. J) A(1,j,k) = (1.0,0.0)
120 CONTINUE
C THE LOOP 400 DETERMINES(A)
C IN SUCCESSIVE SLABS.
DO 400 M = 1,NRSLAB

```

```

      CALL MCSTEP(M)
      IF(NRSLAB .LE. 1) stop
400  CONTINUE
405  continue
      IF(IPRNTA .EQ. 0) GO TO 90
      PRINT 905
      DO 450 L=1,NRSLAB
      PRINT 900,L
      DO 450 J=1,NRMODE(1)
      DO 450 K=1,NRMODE(1)
      PRINT 901,J,K,A(L,J,K)
450  CONTINUE
90   IF(IPLTOP .EQ. 1) CALL MCFLD
      IF(IPLTOP .EQ. 2) CALL MCFLD2
      NT = NT + 1
      DO 105 ME = 2,nrslab
      XVAL(ME) = XVAL(ME) + DELTAX
105  CONTINUE
      IF(NT .LE. NTMAX) GO TO 90
      IF(LAST .EQ. 0) GO TO 10
      stop
102  FORMAT(5X,'THETA',15X,'T1',20X,'T2',20X,'T3',20X,'T4',20X,'FOFR',
$ 10X,'TOPHT')
103  FORMAT(' ',2F7.3,2X, 5(2D10.3,2X),F4.1)
201  FORMAT(20A4)
202  FORMAT(' ',20A4)
900  FORMAT(1H ,14X,
$ 'A - TOTAL CONVERSION COEFFICIENTS',6X,'SLAB NUMBER = ',I2,/)
901  FORMAT(14X,' J =',I2,5X,' K =', I2,5X,' A=',(E15.5,E15.5),/)
905  FORMAT(1H1)
1020 format(1x,f7.0,3(2x,f8.0),2(2x,e10.0),2(2x,e5.0))
1022 format(/,' Slab ',i2,' R',f7.3,' F',f8.4,' A',f8.3,' C',f8.3,' M',
$ f6.3,' S',1pe10.3,' E',0pf5.1,' T',f5.1)
1023 format(i1,2f9.0,i1,4e15.0)
      END

```

```

      SUBROUTINE HTINTL(CAPI,NORM,IFLG,M,INTFLG)
C  CALCULATE NORMALIZATION INTEGRALS AND INTEGRALS OF HEIGHT GAINS IN
C  ADJACENT SLABS.
      parameter (maxmds=30)
      IMPLICIT REAL *8(A-H,O-Z)
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$          XTRA(3,3,25,maxmds),TOPHT(25),
$          XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$          SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
$          NTHSQ(25),KVRAOT,KVRATT,
$          AVRKOT,AVRKT,CONST,OMEGA,WAVENO
      COMPLEX*16 NTHSQ
      COMPLEX*16 PTHA,H1TA,H2TA,H1PRTA,H2PRTA,HYTHA(maxmds),
$          EYTHA(maxmds),HYTHPA(maxmds),EYTHPA(maxmds)
      COMPLEX*16 THETA,FOFR,A,S,C,SSQ,CSQ,IM,NGSQ,
&          SQROOT,RTIORT,P0,PTH,H10,H20,H1PRM0,H2PRM0,CAPH10,CAPH20,
&          A1ST,A2ND,A3RD,A4TH,DEN12,DEN34,DENMF,NURMF,
&          H1T,H2T,H1PRMT,H2PRMT,HYTH(maxmds),EYTH(maxmds),HYTHPR(maxmds),
$          EYTHPR(maxmds),
&          HYOPR(maxmds),EYOPR(maxmds),EY0(maxmds),MULT,FAC1,FAC2,
$          NORM(25,maxmds,maxmds),PS(maxmds),
$          CAPI(25,maxmds,maxmds),PHYTH(maxmds),PHYTHP(maxmds),
$          PEYTH(maxmds),PEYTHP(maxmds),PEY0(maxmds),
&          PEYOPR(maxmds),PHYOPR(maxmds),XTRA
      REAL*8 KVRAOT,KVRATT
      DATA EPSLN0/8.85434D-12/
      data IM/(0.D0,1.D0)/
C
C
      DO 100 K = 1, NRMODE(m)
      SSQ = S(M,K)**2
      CSQ = C(M,K)**2
c      NGSQ = (EPSLN0(M) - IM*SIGMA(M)/OMEGA)/EPSLN0
      ngsq=epsr(m)-(im*sigma(m))/(omega*epsln0)
      SQROOT = zsqrt(NGSQ - SSQ)
      RSQR = SQROOT
      IF(RSQR .LT. 0.) SQROOT=-SQROOT
      RTIORT = 1./NGSQ*SQROOT
      P0 = KVRATT*CSQ
      PTH = KVRATT*(NTHSQ(M)-SSQ)
      CALL MDHNKL(P0,H10,H20,H1PRM0,H2PRM0)
      CAPH10 = H1PRM0 + AVRKT*H10
      CAPH20 = H2PRM0 + AVRKT*H20
      A1ST = CAPH20 - IM*RTIORT*KVRAOT*H20
      A2ND = CAPH10 - IM*RTIORT*KVRAOT*H10
      A3RD = H2PRM0 - IM*KVRAOT*SQROOT*H20
      A4TH = H1PRM0 - IM*KVRAOT*SQROOT*H10
      DEN12 = H20*A2ND - H10*A1ST
      DEN34 = H20*A4TH - H10*A3RD
      CALL MDHNKL(PTH,H1T,H2T,H1PRMT,H2PRMT)
      HYTH(K) = (H2T*A2ND - H1T*A1ST)/DEN12
      EYTH(K) = (H2T*A4TH - H1T*A3RD)/DEN34*FOFR(M,K)
      HYTHPR(K) = (H2PRMT*A2ND - H1PRMT*A1ST)/DEN12
      EYTHPR(K) = (H2PRMT*A4TH - H1PRMT*A3RD)/DEN34*FOFR(M,K)
      HYOPR(K) = (H2PRM0*A2ND - H1PRM0*A1ST)/DEN12
      EYOPR(K) = (H2PRM0*A4TH - H1PRM0*A3RD)/DEN34*FOFR(M,K)
      IF(IFLG .EQ. 0) GO TO 100

```

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PTHA = KVRATT*(NTHSQ(M-1)-SSQ)
CALL MDHNKL(PTHA,H1TA,H2TA,H1PRTA,H2PRTA)
HYTHA(K) = (H2TA*A2ND-H1TA*A1ST)/DEN12
EYTHA(K) = (H2TA*A4TH-H1TA*A3RD)/DEN34*FOFR(M,K)
HYTHPA(K) = (H2PRTA*A2ND-H1PRTA *A1ST)/DEN12
EYTHPA(K) = (H2PRTA*A4TH-H1PRTA*A3RD)/DEN34*FOFR(M,K)
100 EYO(K) = FOFR(M,K)
IF(INTFLG .EQ. 1) PRINT 906,M
DO 240 J = 1,NRMODE(m)
DO 240 K = 1,NRMODE(m)
IF(J .EQ. K) GO TO 120
MULT = AVRKOT/((S(M,J) - S(M,K))*WAVENO)
FAC1 = EYTH(K)*EYTHPR(J) - EYTH(J)*EYTHPR(K) + HYTH(K)*HYTHPR(J)
$ -HYTH(J)*HYTHPR(K)
FAC2 = -EYO(K)*EYOPR(J) + EYO(J)*EYOPR(K) - HYOPR(J) + HYOPR(K)
NORM(M,J,K) = MULT*(FAC1+FAC2)
IF(INTFLG .EQ. 1) PRINT 908,M,J,K,NORM(M,J,K)
GO TO 240
120 MULT = 2.0*S(M,J)*KVRATOT/WAVENO
PTH = KVRATT*(NTHSQ(M)-S(M,J)**2)
PO = KVRATT*C(M,J)**2
FAC1 = EYTHPR(J)**2 + HYTHPR(J)**2 + PTH*(EYTH(J)**2 + HYTH(J)**2)
FAC2 = -EYOPR(J)**2 - HYOPR(J)**2 - PO*(EYO(J)**2 + 1.0)
NORM(M,J,K) = MULT*(FAC1+FAC2)
IF(INTFLG .EQ. 1) PRINT 908,M,J,K,NORM(M,J,K)
240 CONTINUE
IF (IFLG .EQ. 0) GO TO 500
DO 400 K = 1, NRMODE(m)
DO 400 J = 1, NRMODE(m-1)
MULT = AVRKOT/((PS(J) - S(M,K))*WAVENO)
FAC1 = EYTHA(K)*PEYTHP(J)-PEYTH(J)*EYTHPA(K)
$+HYTHA(K)*PHYTHP(J)-PHYTH(J)*HYTHPA(K)
FAC2 = -EYO(K)*PEYOPR(J) + PEYO(J)*EYOPR(K) -PHYOPR(J) + HYOPR(K)
CAPI(M,K,J) = MULT*(FAC1+FAC2)
IF(INTFLG .EQ. 1) PRINT 910,M,K,J,CAPI(M,K,J)
400 CONTINUE
500 DO 600 J = 1, NRMODE(m)
PS(J) = S(M,J)
PHYTH(J) = HYTH(J)
PHYTHP(J) = HYTHPR(J)
PEYTH(J) = EYTH(J)
PEYTHP(J) = EYTHPR(J)
PHYOPR(J) = HYOPR(J)
PEYO(J) = EYO(J)
PEYOPR(J) = EYOPR(J)
600 CONTINUE
720 CONTINUE
RETURN
906 FORMAT('0',20X,'INTEGRALS IN SLAB',I3,/)
908 FORMAT(21X,'NORM(',I1,',',I1,',',I1,') =',2D13.6)
910 FORMAT(21X,'CAPI(',I1,',',I1,',',I1,') =',2D13.6)
END

```

```

      SUBROUTINE HTGAIN(Z)
C   COMPUTE EZ,EX,EY HEIGHT GAINS FOR TRANSMITTER AND RECEIVER.
      parameter (maxmds=30)
      IMPLICIT COMPLEX*16(A-H,O-Z)
      COMMON/HGTEMP/FF1(25,maxmds),FF3(25,maxmds)
      COMMON/HTGN/F(4,25,maxmds,2)
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$           XTRA(3,3,25,maxmds),TOPHT(25),
$           XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$           SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
$           NTHSQ(25),KVRAOT,KVRATT,
$           AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      COMPLEX*16 zsqr
      REAL*8 DEXP
      COMPLEX*16 NGSQ,IM,NTHSQ
      REAL*8 XVAL,FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr,SIGMA
      REAL*8 KVRAOT,KVRATT,AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      REAL*8 Z(2),EPSLN0,ALPHA,FAC1
      REAL*8 RSQR
      REAL*8 TOPHT
      data IM/(0.D0,1.D0)/
      data EPSLN0/8.85434D-12/,ALPHA/3.14D-4/
C
      DO 100 M=1,NRSLAB
C   NGSQ = (EPSLN(M) - IM*SIGMA(M)/OMEGA)/EPSLN0
      ngsq=epsr(m) - (im*sigma(m))/(omega*epsln0)
      DO 100 K=1,NRMODE(m)
      SSQ = S(M,K)**2
      SQROOT = zsqr(NGSQ-SSQ)
      CSQ = C(M,K)**2
      RSQR = SQROOT
      IF(RSQR .LT. 0.) SQROOT=-SQROOT
      DO 100 IZ=1,2
      Q = KVRATT*(CSQ+ALPHA*Z(IZ))
      Q0 = KVRATT*CSQ
      CALL MDHNKL(Q0,H10,H20,H1PRM0,H2PRM0)
      CALL MDHNKL(Q,H1,H2,H1PRM,H2PRM)
      CAPH10 = H1PRM0+AVRKTT*H10
      CAPH20 = H2PRM0+AVRKTT*H20
      FAC2 = IM*KVRAOT*SQROOT
      FAC3 = FAC2/NGSQ
      F1 = -(CAPH20-FAC3*H20)
      F2 = CAPH10-FAC3*H10
      F3 = -(H2PRM0-FAC2*H20)
      F4 = H1PRM0-FAC2*H10
      FAC1 = DEXP(ALPHA/2.*Z(IZ))
      F(1,M,K,IZ) = FAC1*(F1*H1+F2*H2)
      F(2,M,K,IZ) = ALPHA/(IM*2.*WAVENO)*F(1,M,K,IZ)+1./IM*AVRKOT*FAC1*
$ (F1*H1PRM+F2*H2PRM)
      F(3,M,K,IZ) = F3*H1+F4*H2
      f(4,m,k,iz) = -im*avrkot*(f3*h1prm+f4*h2prm)
      FF1(M,K) = F1*H10+F2*H20
      FF3(M,K) = F3*H10+F4*H20
      F(1,M,K,IZ) = F(1,M,K,IZ)/FF1(M,K)
      F(2,M,K,IZ) = F(2,M,K,IZ)/FF1(M,K)
      F(3,M,K,IZ) = F(3,M,K,IZ)*FOFR(M,K)/FF3(M,K)
      F(4,M,K,IZ) = F(4,M,K,IZ)*FOFR(M,K)/FF3(M,K)

```

100 CONTINUE  
RETURN  
END

```

SUBROUTINE MCSTEP(M)
C COMPUTE GENERALIZED MODE CONVERSION COEFFICIENTS.
  parameter (maxmds=30)
  IMPLICIT REAL *8(A-H,O-Z)
  COMMON/TERM/NT,NTR
  COMMON/CAP/CAPI(25,maxmds,maxmds),TNORM(25,maxmds,maxmds)
  COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$      XTRA(3,3,25,maxmds),TOPHT(25),
$      XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$      SIGMA(25),NRSLAB,NRMODE(25),NTMAX
  COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
$      NTHSQ(25),KVRAOT,KVRATT,
$      AVRKOT,AVRKT,CONST,OMEGA,WAVENO
  COMPLEX*16 zexp
  COMPLEX*16 NTHSQ
  COMPLEX*16 THETA,FOFR,A,S,C,TNORM,CAPI,
$      IM,B(maxmds),ANS(maxmds),TS(maxmds,maxmds),XTRA
  REAL*8 KVRAOT,KVRATT
  REAL*4 ERR
  data IM/(0.D0,1.D0)/

C
C
  MP = M-1
  IF(M .EQ. NTR) RETURN
  DO N=1,maxmds
    B(N) = (0.,0.)
  enddo
  IF(MP .ne. NTR) then
    DO K=1,NRMODE(ntr)
      DO L=1,NRMODE(m)
        DO J=1,NRMODE(m)
          TS(L,J) = TNORM(M,L,J)
        enddo
      enddo
      do l=1,nrmode(m)
        do j=1,nrmode(mp)
          B(L)=B(L)+A(MP,J,K)*zexp(-IM*WAVENO*S(MP,J)*(XVAL(M)-
&      XVAL(MP)))*CAPI(M,L,J)
        enddo
      enddo
      CALL CLINEQ(TS,B,ANS,NRMODE(m),maxmds,0,ERR)
      DO I=1,NRMODE(m)
        A(M,I,K) = ANS(I)*S(M,I)/S(NTR,K)
        A(M,I,K) = ANS(I)
      enddo
      DO N=1,maxmds
        B(N) = (0.,0.)
      enddo
    enddo
  else
    DO K=1,NRMODE(mp)
      DO LL=1,NRMODE(m)
        DO L=1,NRMODE(m)
          TS(LL,L) = TNORM(M,LL,L)
          B(L) = CAPI(M,L,K)
        enddo
      enddo
      CALL CLINEQ(TS,B,ANS,NRMODE(m),maxmds,0,ERR)

```

```

c      DO J=1,NRMODE(m)
        A(M,J,K) = ANS(J)*S(M,J)/S(NTR,K)
        A(M,J,K) = ANS(J)
      enddo
    enddo
  endif
RETURN
END

```

```

SUBROUTINE MDHKNL (Z,H1,H2,H1PRME,H2PRME)
C COMPUTE MODIFIED HANKEL FUNCTIONS OF ORDER ONE THIRD
IMPLICIT REAL *8 (A-H,O-Z)
COMPLEX*16 zsqrt,zexp
REAL*8 zabs
COMPLEX*16 Z,I,H1,H2,H1PRME,H2PRME,ZPOWER,TERM1,TERM2,
$ TERM3,ZTERM,TERM,SUM1,SUM2,SUM3,SUM4,SQRTZB,
$ EXP1,EXP2,EXP3,EXP4,EXP5,GM2F,GPMFP,MPOWER,BETA,RTZ,
$ CONST1,CONST2,CONST3,CONST4
DIMENSION A(23), B(23), C(23), D(23), CAP(14)
DATA A/
$ 9.30436716930000D-01,3.10145572309700D 01,2.06763714873160D 02,
$ 5.74343652425450D 02,8.70217655190080D 02,8.28778719228640D 02,
$ 5.41685437404340D 02,2.57945446383020D 02,9.34584950663100D 01,
$ 2.66263518707400D 01,6.12100043005600D 00,1.15928038448000D 00,
$ 1.84012759441000D-01,2.48330309640000D-02,2.88420801000000D-03,
$ 2.91334142000000D-04,2.58274950000000D-05,2.02568600000000D-06,
$ 1.41557000000000D-07,8.87000000000000D-09,5.01000000000000D-10,
$ 2.60000000000000D-11,1.00000000000000D-12/
DATA B/
$ 6.78298725140000D-01,1.13049787524000D 01,5.38332321543100D 01,
$ 1.19629404787350D 02,1.53371031778650D 02,1.27809193148880D 02,
$ 7.47422182157200D 01,3.23559386215200D 01,1.07853128738400D 01,
$ 2.85325737403000D 00,6.13603736351000D-01,1.09376780098000D-01,
$ 1.64229399550000D-02,2.10550512200000D-03,2.33167788000000D-04,
$ 2.25282890000000D-05,1.91567100000000D-06,1.44470000000000D-07,
$ 9.72900000000000D-09,5.89000000000000D-10,3.20000000000000D-11,
$ 2.00000000000000D-12,0.00000000000000D 00/
DATA C/
$ 4.65218358460000D-01,6.20291144619000D 00,2.58454643591500D 01,
$ 5.22130593114000D 01,6.21584039421500D 01,4.87516893663900D 01,
$ 2.70842718702700D 01,1.12150194079600D 01,3.59455750255000D 00,
$ 9.18150064510000D-01,1.91281263439000D-01,3.31222966990000D-02,
$ 4.84244103800000D-03,6.05683682000000D-04,6.55501820000000D-05,
$ 6.19859900000000D-06,5.16550000000000D-07,3.82200000000000D-08,
$ 2.52800000000000D-09,1.50000000000000D-10,8.00000000000000D-12,
$ 0.00000000000000D 00,0.00000000000000D 00/
DATA D/
$ 6.78298725140000D-01,4.52199150096200D 01,3.76832625080150D 02,
$ 1.19629404787350D 03,1.99382341312250D 03,2.04494709038206D 03,
$ 1.42010214609865D 03,7.11830649673510D 02,2.69632821846030D 02,
$ 7.98912064729000D 01,1.90217158268800D 01,3.71881052333900D 00,
$ 6.07648778323000D-01,8.42202048960000D-02,1.00262148690000D-02,
$ 1.03630127800000D-03,9.38678690000000D-05,7.51243500000000D-06,
$ 5.35074000000000D-07,3.41350000000000D-08,1.96200000000000D-09,
$ 1.02000000000000D-10,5.00000000000000D-12/
DATA CAP/
$ 1.04166666666667D-01,8.35503472222222D-02,1.28226574556327D-01,
$ 2.91849026464140D-01,8.81627267443758D-01,3.32140828186277D 00,
$ 1.49957629868626D 01,7.89230130115870D 01,4.74451538868000D 02,
$ 3.20749009100000D 03,2.40865496000000D 04,1.98923120000000D 05,
$ 1.79190200000000D 06,1.74843770000000D 07/
C
DATA I/(0.D0,1.D0)/
DATA ROOT3/1.73205080756888D 00/
DATA ALPHA/8.53667218838951D-01/
DATA CONST1/( 2.58819045102522D-01,-9.65925826289067D-01)/
DATA CONST2/( 2.58819045102522D-01, 9.65925826289067D-01)/

```

|    |                                                             |     |
|----|-------------------------------------------------------------|-----|
|    | DATA CONST3/(-9.65925826289067D-01, 2.58819045102522D-01)/  | 56  |
|    | DATA CONST4/(-9.65925826289067D-01, -2.58819045102522D-01)/ | 57  |
| C  |                                                             | 58  |
|    | ZPOWER=1.0                                                  | 59  |
|    | SUM3=0.0                                                    | 60  |
|    | SUM4=0.0                                                    | 61  |
|    | ZMAG=zabs(Z)                                                | 62  |
|    | IF(ZMAG .GT. 4.2) GO TO 70                                  | 63  |
|    | IF(ZMAG .GE. 3.2) GO TO 10                                  | 64  |
|    | N=12                                                        | 65  |
|    | GO TO 30                                                    | 66  |
| 10 | IF(ZMAG .GE. 4.1) GO TO 20                                  | 67  |
|    | N=15                                                        | 68  |
|    | GO TO 30                                                    | 69  |
| 20 | N=23                                                        | 70  |
| 30 | SUM1=0.                                                     | 71  |
|    | SUM2=0.                                                     | 72  |
|    | ZTERM=-Z**3/200.0                                           | 73  |
|    | DO 50 M=1,N                                                 | 74  |
|    | SUM1=SUM1+A(M)*ZPOWER                                       | 75  |
|    | SUM2=SUM2+B(M)*ZPOWER                                       | 76  |
|    | SUM3=SUM3+C(M)*ZPOWER                                       | 77  |
|    | SUM4=SUM4+D(M)*ZPOWER                                       | 78  |
|    | ZPOWER=ZPOWER*ZTERM                                         | 79  |
|    | IF(zabs(ZPOWER) .LE. 1.0D-30) GO TO 60                      | 80  |
| 50 | CONTINUE                                                    | 81  |
| 60 | GM2F=I*(Z*SUM2-2.*SUM1)/ROOT3                               | 82  |
|    | GPMFP=I*(SUM4+2.*Z*Z*SUM3)/ROOT3                            | 83  |
|    | H1=Z*SUM2+GM2F                                              | 84  |
|    | H2=H1-2.0*GM2F                                              | 85  |
|    | H1PRME=SUM4+GPMFP                                           | 86  |
|    | H2PRME=H1PRME-2.0*GPMFP                                     | 87  |
|    | RETURN                                                      | 88  |
| C  |                                                             | 89  |
| 70 | SUM1=1.0                                                    | 90  |
|    | SUM2=1.0                                                    | 91  |
|    | RTZ=zsqrz(Z)                                                | 92  |
|    | SQRTZB=RTZ*Z                                                | 93  |
|    | ZTERM=1/SQRTZB                                              | 94  |
|    | MPOWER=1.0                                                  | 95  |
|    | TERM=-1.5/Z                                                 | 96  |
|    | DO 80 M=1,14                                                | 97  |
|    | ZPOWER=ZPOWER*ZTERM                                         | 98  |
|    | MPOWER=MPOWER*(-ZTERM)                                      | 99  |
|    | TERM1=CAP(M)*ZPOWER                                         | 100 |
|    | TERM2=CAP(M)*MPOWER                                         | 101 |
|    | SUM1=SUM1+TERM1                                             | 102 |
|    | SUM2=SUM2+TERM2                                             | 103 |
|    | SUM3=SUM3+M*TERM1                                           | 104 |
|    | SUM4=SUM4+M*TERM2                                           | 105 |
| 80 | CONTINUE                                                    | 106 |
|    | SUM3=SUM3*TERM                                              | 107 |
|    | SUM4=SUM4*TERM                                              | 108 |
|    | EXP1=zexp(2.*I*SQRTZB/3.)                                   | 109 |
|    | EXP2=EXP1*CONST1                                            | 110 |
|    | EXP3=CONST2/EXP1                                            | 111 |
|    | EXP4=CONST3*EXP1                                            | 112 |
|    | EXP5=CONST4/EXP1                                            | 113 |

|                                                                   |     |
|-------------------------------------------------------------------|-----|
| BETA=ALPHA/zsqrt(RTZ)                                             | 114 |
| ZREAL=Z                                                           | 115 |
| ZIMAG=-I*Z                                                        | 116 |
| IF (ZREAL.GE.0.0.OR.ZIMAG.GE.0.0)GO TO 90                         | 117 |
| H1=BETA*(EXP2*SUM2+EXP5*SUM1)                                     | 118 |
| H1PRME=BETA*(EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)+EXP5*(SUM1*(-0.25/Z | 119 |
| \$ -I*RTZ)+SUM3))                                                 | 120 |
| GO TO 110                                                         | 121 |
| 90 H1=BETA*EXP2*SUM2                                              | 122 |
| H1PRME=BETA*EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)                      | 123 |
| 110 IF (ZREAL.GE.0.0.OR.ZIMAG.LT.0.0)GO TO 120                    | 124 |
| H2=BETA*(EXP3*SUM1+EXP4*SUM2)                                     | 125 |
| H2PRME=BETA*(EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)+EXP4*(SUM2*(-0.25/Z | 126 |
| \$ +I*RTZ)+SUM4))                                                 | 127 |
| RETURN                                                            | 128 |
| 120 H2=BETA*EXP3*SUM1                                             | 129 |
| H2PRME=BETA*EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)                      | 130 |
| RETURN                                                            | 131 |
| END                                                               | 132 |

SUBROUTINE MAGANG(ARG,MAG,ANGLE)  
 IMPLICIT REAL \*8(A-H,O-Z)  
 REAL\*8 DSQRT,dacos  
 COMPLEX\*16 ARG,IM  
 REAL\*8 MAG  
 DATA RDTDEG/5.729577951D+01/  
 data IM/(0.D0,1.D0)/

c ENTRY MGNGL(ARG,MAG,ANGLE)  
 ARGAL = ARG  
 ARGMAG = -IM\*ARG  
 MAG = DSQRT(ARGAL\*ARGAL + ARGMAG\*ARGMAG)  
 IF(MAG .EQ. 0.0) GO TO 10  
 COSQ = ARGAL/MAG  
 IF (COSQ .LT. -1.0.AND. COSQ .GT. -1.01) COSQ = -1.0  
 IF(COSQ .GT. 1.0.AND. COSQ .LT. 1.01) COSQ = 1.0  
 5 ANGLE = dacos(COSQ)\*RDTDEG  
 IF(ARGMAG .LT. 0.0) ANGLE = 360.0 - ANGLE  
 RETURN  
 10 COSQ = 0.0  
 GO TO 5  
 END

SUBROUTINE CLIN EQ (A, B, X, N, N DIM, IFLAG, ERR)

C  
 C CLIN EQ USES L-U DECOMPOSITION TO  
 C FIND THE TRIANGULAR MATRICES L, U  
 C SUCH THAT L \* U = A. L AND U ARE  
 C STORED IN A. THIS FORM IS USED WITH  
 C BACK-SUBSTITUTION TO FIND THE SOLN  
 C X OF A \* X = L \* U \* X = B.  
 C N IS THE NUMBER OF EQUATIONS AND  
 C N DIM IS THE DIMENSION OF ALL ARRAYS  
 C IN THE PARAMETER LIST.  
 C  
 C IF IFLAG = 0, L, U, AND X ARE  
 C COMPUTED.  
 C IF IFLAG IS NON-ZERO, IT IS ASSUMED  
 C THAT L AND U HAVE BEEN COMPUTED IN  
 C A PREVIOUS CALL AND ARE STILL STORED

|     |                                   |          |
|-----|-----------------------------------|----------|
| C   | IN A. THUS ONLY X IS COMPUTED.    |          |
| C   | ERR IS THE ESTIMATED RELATIVE     |          |
| C   | ERROR OF THE SOLUTION VECTOR.     |          |
| C   |                                   |          |
|     | COMPLEX*16 A, B, X, T             | 00002300 |
|     | INTEGER*2 IROW                    |          |
|     | DIMENSION A(N DIM, N DIM),        | 00002500 |
|     | \$ B(N DIM), X(N DIM)             | 00002600 |
|     | DIMENSION IROW(50), Q(50)         | 00002700 |
|     | DATA EPS /1.0E-15/                | 00002800 |
| C   |                                   | 00002900 |
| C   |                                   | 00003000 |
|     | IF (N.GT.50) GO TO 900            | 00003100 |
|     | IF (IFLAG.NE.0) GO TO 600         | 00003200 |
|     | DO 050 I = 1,N                    | 00003300 |
|     | Q(I) = 0.0                        | 00003400 |
|     | DO 040 J = 1,N                    | 00003500 |
|     | QQ = zabs (A(I,J))                |          |
| 040 | IF (Q(I).LT.QQ) Q(I) = QQ         | 00003700 |
|     | IF (Q(I).EQ.0.0) GO TO 901        | 00003800 |
| 050 | CONTINUE                          | 00003900 |
|     | ERR = EPS                         | 00004000 |
|     | PPIV = 0.0                        | 00004100 |
|     | DO 100 I = 1,N                    | 00004200 |
| 100 | IROW(I) = I                       | 00004300 |
| C   |                                   | 00004400 |
|     | DO 500 L = 1,N                    | 00004500 |
|     | PIVOT = 0.0                       | 00004600 |
|     | K = L - 1                         | 00004700 |
|     | DO 240 I = L,N                    | 00004800 |
|     | IF (K.LT.1) GO TO 230             | 00004900 |
|     | DO 220 J = 1,K                    | 00005000 |
| 220 | A(I,L) = A(I,L) - A(J,L) * A(I,J) | 00005100 |
| 230 | F = zabs (A(I,L)) / Q(I)          |          |
|     | IF (PIVOT.GT.F) GO TO 240         | 00005300 |
|     | PIVOT = F                         | 00005400 |
|     | NPIVOT = I                        | 00005500 |
| 240 | CONTINUE                          | 00005600 |
|     | IF (PIVOT.EQ.0.0) GO TO 901       | 00005700 |
|     | IF (PPIV.LE.PIVOT) GO TO 250      | 00005710 |
|     | ERR = ERR * PPIV / PIVOT          | 00005720 |
|     | IF (ERR.GE.1.0) GO TO 901         | 00005730 |
| 250 | PPIV = PIVOT                      | 00005740 |
|     | IF (NPIVOT.EQ.L) GO TO 280        | 00005750 |
|     | Q(NPIVOT) = Q(L)                  | 00005800 |
|     | J = IROW(L)                       | 00005900 |
|     | IROW(L) = IROW(NPIVOT)            | 00006000 |
|     | IROW(NPIVOT) = J                  | 00006100 |
|     | DO 260 I = 1,N                    | 00006700 |
|     | T = A(L,I)                        | 00006800 |
|     | A(L,I) = A(NPIVOT,I)              | 00006900 |
|     | A(NPIVOT,I) = T                   | 00007000 |
| 260 | CONTINUE                          | 00007100 |
| 280 | IF (L.EQ.N) GO TO 500             | 00007110 |
|     | T = (1.0D0,0.0D0) / A(L,L)        | 00007200 |
|     | K = L + 1                         | 00007300 |
|     | M = L - 1                         | 00007400 |
|     | DO 450 I = K,N                    | 00007600 |

|                                                               |          |
|---------------------------------------------------------------|----------|
| IF (M.LT.1) GO TO 400                                         | 00007700 |
| DO 350 J = 1,M                                                | 00007800 |
| 350 A(L,I) = A(L,I) - A(L,J) * A(J,I)                         | 00007900 |
| 400 A(L,I) = T * A(L,I)                                       | 00008000 |
| 450 CONTINUE                                                  | 00008100 |
| 500 CONTINUE                                                  | 00008200 |
| IF (ERR.GT.1.0E-5) PRINT 998, ERR                             | 00008300 |
| C                                                             | 00008400 |
| C                                                             | 00008500 |
| 600 DO 620 I = 2,N                                            | 00008600 |
| 620 X(I) = (0.0D0,0.0D0)                                      | 00008700 |
| J = IROW(1)                                                   | 00008800 |
| X(1) = B(J) / A(1,1)                                          | 00008900 |
| DO 700 I = 2,N                                                | 00009000 |
| J = IROW(I)                                                   | 00009100 |
| K = I - 1                                                     | 00009200 |
| DO 650 L = 1,K                                                | 00009300 |
| 650 X(I) = X(I) + A(I,L) * X(L)                               | 00009400 |
| X(I) = (B(J) - X(I)) / A(I,I)                                 | 00009500 |
| 700 CONTINUE                                                  | 00009600 |
| K = N - 1                                                     | 00009700 |
| DO 800 I = 1,K                                                | 00009800 |
| J = N - I                                                     | 00009900 |
| M = J + 1                                                     | 00010000 |
| DO 800 L = M,N                                                | 00010100 |
| X(J) = X(J) - X(L) * A(J,L)                                   | 00010200 |
| 800 CONTINUE                                                  | 00010400 |
| RETURN                                                        | 00010500 |
| C                                                             | 00010600 |
| 900 PRINT 999                                                 | 00010700 |
| ERR = 1.0                                                     | 00010800 |
| RETURN                                                        | 00010900 |
| 901 PRINT 997                                                 | 00011000 |
| ERR = 1.0                                                     | 00011100 |
| RETURN                                                        | 00011200 |
| 997 FORMAT ('1ERROR IN CLIN EQ, MATRIX IS SINGULAR')          | 00011300 |
| 998 FORMAT (' CAUTION-',                                      | 00011400 |
| \$ ' CLIN EQ HAS DECOMPOSED AN ILL-CONDITIONED MATRIX.',/,    | 00011500 |
| \$ ' RESULTS WILL HAVE RELATIVE ERROR -',E11.2)               | 00011600 |
| 999 FORMAT ('1ERROR IN CLIN EQ, MATRIX SIZE GREATER THAN 50') | 00011700 |
| END                                                           | 00011H?? |

```

SUBROUTINE MCFLD
parameter (maxmds=30)
IMPLICIT REAL *8(A-H,O-Z)
C COMPUTE FIELDS FROM XVAL MIN TO XVAL MAX FOR TWO XMTR-RCVR DISTANCES
C AT DELTAX INTERVALS
C
COMMON/TERM/NT,NTR
COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$      XTRA(3,3,25,maxmds),TOPHT(25),
$      XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$      SIGMA(25),NRSLAB,NRMODE(25),NTMAX
COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
$      NTHSQ(25),KVRAOT,KVRATT,
$      AVRKOT,AVRKT,CONST,OMEGA,WAVENO
character*68 idplot
COMMON/MCPLOT/R(400),DBY(400),DBX(400),ANGCHI(400),
$      IDPLOT,ISUB
COMMON/HTGN/F(4,25,maxmds,2)
COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
common/pltfllg/iplfllg
REAL*4 R,DBY,dbx,angchi
real*8 num
REAL*8 KVRAOT,KVRATT
complex*16 tahy,tahx
COMPLEX*16 SOLNA(maxmds,3),THETA,A,S,C,XTRA,TB,FOFR,F,NTHSQ,IM
DATA ERAD/6.370D3/
data IM/(0.0D0,1.0D0)/

C
C
MP=-10
RHO = RHO MIN
DO 1 LL=2,NRSLAB
IF(XVAL(LL)-RHO .GE. 0.) GO TO 2
1 CONTINUE
M=nrslab
GO TO 3
2 M = LL-1
3 CONTINUE
IF(M .EQ. MP) GO TO 720
DO 710 L=1,3
DO 710 J = 1,NRMODE(m)
SOLN A(J,L) = (0.0,0.0)
DO 710 K = 1,NRMODE(ntr)
IF(M .NE. NTR) GO TO 35
if(l .eq. 1) then
SOLN A(J,L) = SOLN A(J,L)
$      +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)/(-s(ntr,k))
else
SOLN A(J,L) = SOLN A(J,L)
$      +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)
endif
GO TO 710

```

```

35  continue
    if(1 .eq. 1) then
      SOLN A(J,L) = SOLN A(J,L)
      $      +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)
      $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))/(-s(ntr,k))
    else
      SOLN A(J,L) = SOLN A(J,L)
      $      +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)
      $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))
    endif
710 CONTINUE
C
720 CONTINUE
    tahy = (0.0,0.0)
    tahx = (0.0,0.0)
    DO J=1,NRMODE(m)
      IF(M .eq. NTR) then
        TB =zexp(-IM*WAVENO*S(M ,J)*RHO)
      else
        TB =zexp(IM*WAVENO*S(M ,J)*(XVAL(M ) - RHO))
      endif
      tahy=tahy+SOLNA(J,1)*TB*F(1,M,J,2)
      tahx=tahx+SOLNA(J,3)*TB*F(4,M,J,2)
    enddo
    tahy=tahy*CONST/DSQRT(DSIN(RHO/ERAD))
    tahx=tahx*CONST/DSQRT(DSIN(RHO/ERAD))
    tahyr=tahy
    tahyi=-im*tahy
    tahxr=tahx
    tahxi=-im*tahx
    phshy=datan2(tahyi,tahyr)
    phshx=datan2(tahxi,tahxr)
    amphy=dsqrt(tahyr*tahyr+tahyi*tahyi)
    amphx=dsqrt(tahxr*tahxr+tahxi*tahxi)
    beta=datan2(amphy,amphx)
    delta=phshy-phshx
    num=dsin(2.0*beta)*dcos(delta)
    den=dcos(2.0*beta)
    psi=0.5*datan2(num,den)*57.295779
    if(psi .lt. 0.0) psi=psi+180.0
    chi=90.0-psi
    ampy=10.0*dlog10(dmax1(1.0d-30,amphy*amphy)*1.0d12)
    ampx=10.0*dlog10(dmax1(1.0d-30,amphx*amphx)*1.0d12)
    R(NT) = XVAL(2)
    dby(nt) = ampy
    dbx(nt) = ampx
    angchi(nt) = chi
    MP = M
    IF(NT .NE. NTMAX) RETURN
    PGAMMA = GAMMA/1.745329D-2
    PPHI = PHI/1.745329D-2
    PRINT 927,PGAMMA,PPHI,ZT,ZR

```

```

927  FORMAT(//,' GAMMA(DEG)=' ,F6.1,'  PHI(DEG)=' ,F6.1,'  ZT(KM)=' ,F7.2,
$'  ZR(KM)=' ,F7.2)
      print 929
929  FORMAT(/,13X,' RHO-KM' ,3X,' MAG(HY)-DB' ,3X,' MAG(HX)-DB' ,3X,
$      'DOA ERROR-DEG')
      DO JJ=1,NTMAX
          PRINT 908,R(JJ),dby(jj),dbx(jj),angchi(jj)
908  FORMAT(9X,F10.2,2x,F10.5,3x,F10.5,3x,F10.5)
      enddo
      write(*,'( /)')
      IF (iplflg.EQ.0) RETURN
      CALL MCPLTS
      RETURN
      END

```

```

SUBROUTINE MCFLD2
  parameter (maxmds=30)
  IMPLICIT REAL *8(A-H,O-Z)
C  COMPUTE FIELDS FROM RHO MIN TO RHO MAX
C  AT DEL RHO INTERVALS.
C
  COMMON/TERM/NT,NTR
  COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$      XTRA(3,3,25,maxmds),TOPHT(25),
$      XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$      SIGMA(25),NRSLAB,NRMODE(25),NTMAX
  COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
$      NTHSQ(25),KVRAOT,KVRATT,
$      AVRKOT,AVRKT,CONST,OMEGA,WAVENO
  character*68 idplot
  COMMON/MCPLT/R(400),DBY(400),DBX(400),ANGCHI(400),
$      IDPLOT,ISUB
  COMMON/HTGN/F(4,25,maxmds,2)
  COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
  common/pltfldg/iplfldg
  REAL*4 R,DBY,DBX,ANGCHI
  COMPLEX*16 SOLNA(maxmds,3)
  COMPLEX*16 THETA,A,S,C,XTRA,TB,IM,FOFR,F,NTHSQ
  complex*16 tahy,tahx
  REAL*8 KVRAOT,KVRATT
  real*8 num
  DATA ERAD/6.370D3/
  data IM/(0.D0,1.D0)/
C
C
  ISUB = 1
  DBMAX = -1000.0
  RHO = RHO MIN
  M = NTR
  X = RHO - 1.0
600  CONTINUE
700  IF (RHO.LE.X) GO TO 720
  DO 710 L=1,3
  DO 710 J = 1,NRMODE(m)
  SOLN A(J,L) = (0.0,0.0)
  DO 710 K = 1,NRMODE(ntr)
  IF(M.NE.NTR) GO TO 35
  if(1.eq.1) then
  SOLN A(J,L) = SOLN A(J,L)
$      +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)/(-s(ntr,k))
  else
  SOLN A(J,L) = SOLN A(J,L)
$      +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)
  endif
  GO TO 710
35  continue
  if(1.eq.1) then

```

```

      SOLN A(J,L) = SOLN A(J,L)
      $          +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)
      $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))/(-s(ntr,k))
      else
      SOLN A(J,L) = SOLN A(J,L)
      $          +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
$COSGAM      +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
$COSPHI      +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
$SINPHI)
      $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))
      endif
710 CONTINUE
      M = M + 1
      X = XVAL(M)
      if(m .gt. nrslab) x=1.0e6
      GO TO 700
C
720 CONTINUE
      tahy = (0.0,0.0)
      tahx = (0.0,0.0)
      DO J=1,NRMODE(m-1)
        IF(M-1 .eq. NTR) then
          TB =zexp(-IM*WAVENO*S(M-1,J)*RHO)
        else
          TB =zexp(IM*WAVENO*S(M-1,J)*(XVAL(M-1) - RHO))
        endif
        tahy = tahy+SOLN A(J,1)*TB*F(1,M-1,J,2)
        tahx = tahx+SOLN A(J,3)*TB*F(4,M-1,J,2)
      enddo
      tahy = tahy*CONST/DSQRT(DSIN(RHO/ERAD))
      tahx = tahx*CONST/DSQRT(DSIN(RHO/ERAD))
      tahyr=tahy
      tahyi=-im*tahy
      tahxr=tahx
      tahxi=-im*tahx
      phshy=datan2(tahyi,tahyr)
      phshx=datan2(tahxi,tahxr)
      amphy=dsqrt(tahyr*tahyr+tahyi*tahyi)
      amphx=dsqrt(tahxr*tahxr+tahxi*tahxi)
      beta=datan2(amphy,amphx)
      delta=phshy-phshx
      num=dsin(2.0*beta)*dcos(delta)
      den=dcos(2.0*beta)
      psi=0.5*datan2(num,den)*57.295779
      if(psi .lt. 0.0) psi=psi+180.0
      chi=90.0-psi
      ampy=10.0*dlog10(dmax1(1.0d-30,amphy*amphy)*1.0d12)
      ampx=10.0*dlog10(dmax1(1.0d-30,amphx*amphx)*1.0d12)
      R(ISUB) = RHO
      DBy(ISUB) = ampy
      DBx(ISUB) = ampx
      angchi(isub)=chi
      RHO = RHO + DEL RHO
      ISUB = ISUB+1
      IF (RHO .LE. RHOMAX) GO TO 600

```

```

ISUB = ISUB-1
PGAMMA = GAMMA/1.745329D-2
PPHI = PHI/1.745329D-2
PRINT 927,PGAMMA,PPHI,ZT,ZR
PRINT 929
927  FORMAT(//,11X,'GAMMA(DEG)=-',F6.1,'  PHI(DEG)=-',F6.1,'  ZT(KM)=-',
$    F7.2,'  ZR(KM)=-',F7.2)
929  FORMAT(/,13X,'RHO-KM',3X,'MAG(HY)-DB',3X,'MAG(HX)-DB',3X,
$    'DOA ERROR-DEG')
DO J=1,ISUB
  PRINT 908,R(J),DBY(J),DBX(J),angchi(J)
908  FORMAT(9X,F10.2,2X,F10.5,3X,F10.5,3X,F10.5)
enddo
write(*,'(//)')
IF (iplflg.EQ.0) RETURN
CALL MCPLT2
RETURN
END

```

```

SUBROUTINE MCPLTS
  parameter (maxmds=30)
C MCPLTS GENERATES TWO PLOTS (FIELD AMPLITUDE IN DB ABOVE A
C MICRO VOLT PER METER FOR 1 KW RADIATED POWER VERSUS TRANSMITTER-
C TERMINATOR DISTANCE FOR TWO RECEIVER POSITIONS).
  COMMON/MCPLT/R(400),DBY(400),DBX(400),ANGchi(400),
  $ IDPLOT(17),ISUB
  COMMON/XPLOT/XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
  COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
  COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
  $ XTRA(3,3,25,maxmds),TOPHT(25),
  $ XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
  $ SIGMA(25),NRSLAB,NRMODE(25),NTMAX
  dimension xl(2),yl(2)
  COMPLEX*16 THETA,FOFR,XTRA
  REAL*8 XVAL,FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr,SIGMA,TOPHT
  REAL*8 SINGAM,COSGAM,SINPHI,COSPHI,GAMMA,PHI,ZT,ZR
  LOGICAL UP(400),upl(2)

c
  xinc=(xmax-xmin)/sizeX
  yinc=(ymax-ymin)/sizeY
  DO J=1,2
    upl(J)=.FALSE.
  enddo
  DO J=1,400
    UP(J)=.FALSE.
  enddo
  CALL pltbgn
  CALL plot(1.0,1.0,-3)
  call symbol(2.0,-0.5,.10,35HTransmitter-Terminator Distance(Mm),
  $ 0.0,35)
  call symbol(-0.9,0.9,.10,26H Bearing Error (Deg) ,90.0,26)
  call symbol(-0.7,0.9,.10,35HAmplitude (dB above 1uv/m for 1 kW),
  $ 90.0,35)
  CALL border2(sizeX,XMIN/1000,xmax/1000,Xtic/1000,2.*Xtic/1000,1,
  $ sizeY,YMIN,ymax,Ytic,2.*Ytic,-1)
  GAMMAD = GAMMA/1.745329D-2
  PHID = PHI/1.745329D-2
  xpos=0.0
  xstart=xmin

c
c draw legend
  xl(1)=xstart
  xl(2)=xstart+xinc*0.7
  yl(1)=ymax+yinc*0.3
  yl(2)=ymax+yinc*0.3
  call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,2)
  call symbol(xpos+0.7,sizeY+0.25,.1,6H |HY|,0.,6)

c
  xl(1)=xl(1)+1.5*xinc
  xl(2)=xl(2)+1.3*xinc
  call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,4)
  xpos=xpos+1.5
  call symbol(xpos+0.5,sizeY+0.25,.1,6H |HX|,0.,6)

c
  xl(1)=xl(1)+1.5*xinc
  xl(2)=xl(2)+1.5*xinc
  call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,5)

```

```

      xpos=xpos+1 5
      call symbol(xpos+0.5,sizey+0.25,.1,14H Bearing Error,0.,14)
c
c      draw solid line at 0.0
      xl(1)=xmin
      xl(2)=xmax
      yl(1)=0
      yl(2)=0.0
      call curve(xl,yl,upl,2,xmin,ymin,(xmax-xmin)/sizeX,
$          (ymax-ymin)/sizeY,1)
c
      CALL CURVE(R,dbY,up,NTMAX,xmin,ymin,xinc,yinc,2)
      CALL CURVE(R,dbX,up,NTMAX,xmin,ymin,xinc,yinc,4)
      CALL CURVE(R,angchi,up,NTMAX,xmin,ymin,xinc,yinc,5)
      CALL symbol(0.0,sizey+1.3,.10,IDPLOT,0.0,68)
      CALL symbol(0.,sizey+0.9,.10,17HFreq =          kHz,0.0,17)
      CALL number(0.7,sizey+0.9,.10,sngl(FREQ),0.0,3)
      CALL symbol(3.5,sizey+0.9,.10,29HReceiver Distance =          km,
$          0.0,29)
      CALL number(5.5,sizey+0.9,.10,sngl(rhomin),0.0,1)
      CALL symbol(0.,sizey+0.7,.10,29HZt =          km   Zr =          km,
$          0.0,29)
      CALL number(0.50,sizey+0.7,.10,sngl(zt),0.0,2)
      CALL number(2.05,sizey+0.7,.10,sngl(zr),0.0,2)
      CALL symbol(3.5,sizey+.7,.10,
$          35HGamma =          deg   Phi =          deg,0.0,35)
      CALL number(4.30,sizey+0.7,.10,gammad,0.0,1)
      CALL number(6.05,sizey+0.7,.10,phid,0.0,1)
      CALL pltend
      RETURN
      END
      SUBROUTINE MCPLT2
      parameter (maxmds=30)
c  MCPLT2 GENERATES ONE PLOT (FIELD AMPLITUDE IN DB ABOVE A MICRO VOLT
c  PER METER FOR 1 KW RADIATED POWER VERSUS DISTANCE FROM TRANSMITTER).
      COMMON/MCPLT/R(400),DBY(400),DBX(400),ANGchi(400),
$          IDPLOT(17),ISUB
      COMMON/XPLOT/XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
      COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COGAM,SINPHI,COSPHI
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
$          XTRA(3,3,25,maxmds),TOPHT(25),
$          XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
$          SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      dimension xl(2),yl(2)
      COMPLEX*16 THETA,FOFR,XTRA
      REAL*8 XVAL,FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr,SIGMA,TOPHT
      REAL*8 SINGAM,COGAM,SINPHI,COSPHI,GAMMA,PHI,ZT,ZR
      LOGICAL UP(400),upl(2)
c
      xinc=(xmax-xmin)/sizeX
      yinc=(ymax-ymin)/sizeY
      DO J=1,2
          upl(J)=.FALSE.
      enddo
      DO J=1,400
          UP(J)=.FALSE.
      enddo
      CALL pltbgn

```

```

CALL plot(1.0,1.0,-3)
call symbol(1.5,-0.5,.10,21HDistance (Megameters),0.0,21)
call symbol(-0.9,1.5,.10,26H Bearing Error (Deg) ,90.0,26)
call symbol(-0.7,1.5,.10,35HAmplitude (dB above 1uv/m for 1 kW),
$          90.0,35)
CALL bordr2(sizeX,XMIN/1000,xmax/1000,Xtic/1000,2.*Xtic/1000,-1,
$          sizeY,YMIN,ymax,Ytic,2.*Ytic,-1)
GAMMAD = GAMMA/1.745329D-2
PHID = PHI/1.745329D-2
      xpos=0.0
      xstart=xmin
c
c      draw legend
      xl(1)=xstart
      xl(2)=xstart+xinc*0.7
      yl(1)=ymax-yinc*0.3
      yl(2)=ymax+yinc*0.3
      call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,2)
      call symbol(xpos+0.7,sizeY+0.25,.1,6H |HY|,0.,6)
c
      xl(1)=xl(1)+1.5*xinc
      xl(2)=xl(2)+1.3*xinc
      call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,4)
      xpos=xpos+1.5
      call symbol(xpos+0.5,sizeY+0.25,.1,6H |HX|,0.,6)
c
      xl(1)=xl(1)+1.5*xinc
      xl(2)=xl(2)+1.5*xinc
      call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,5)
      xpos=xpos+1.5
      call symbol(xpos+0.5,sizeY+0.25,.1,14H Bearing Error,0.,14)
c
c      draw solid line at 0.0
      xl(1)=xmin
      xl(2)=xmax
      yl(1)=0.0
      yl(2)=0.0
      call curve(xl,yl,upl,2,xmin,ymin,(xmax-xmin)/sizeX,
$          (ymax-ymin)/sizeY,1)
c
CALL CURVE(R,dbY,up,ISUB,xmin,ymin,xinc,yinc,2)
CALL CURVE(R,dbX,up,ISUB,xmin,ymin,xinc,yinc,4)
CALL CURVE(R,angchi,up,ISUB,xmin,ymin,xinc,yinc,5)
CALL symbol(0.0,sizeY+1.5,.10,IDPLOT,0.0,68)
CALL symbol(0.,sizeY+1.1,.10,17HFreq = kHz,0.0,17)
CALL number(0.7,sizeY+1.1,.10,sngl(FREQ),0.0,3)
CALL symbol(0.,sizeY+0.9,.10,29HZt = km Zr = km,
$          0.0,29)
CALL number(0.50,sizeY+0.9,.10,sngl(zt),0.0,2)
CALL number(2.05,sizeY+0.9,.10,sngl(zr),0.0,2)
CALL symbol(0.,sizeY+0.7,.10,33HGamma = deg Phi = deg,
$          0.0,33)
CALL number(0.80,sizeY+0.7,.10,gammad,0.0,1)
CALL number(2.45,sizeY+0.7,.10,phid,0.0,1)
CALL pltend
RETURN
END

```

```

subroutine pltbgn
character*1 answr
logical first,autopl
dimension ia(8),ibuff(2)
data ia/82,79,57,48,73,87,73,80/
c ASCII      R 0 9 0 I W I P
data first/.true./,autopl/.false./
if(first) then
  open(unit=52,file='/dev/plt7550a')
  print *, 'If this is the hp 7550 plotter and you want auto feed,'
  print *, 'then set up the plotter, load a sheet and answer y:'
  print *, 'Do you want auto feed?'
  read 1, answr
1  format(a1)
  if(answr .eq. 'y' .or. answr .eq. 'Y') then
    autopl=.true.
  else
    autopl=.false.
  end if
end if
if(.not.autopl .or. first) then
  print *, 'Set up plotter, enter rotation (y/n) when ready'
  read 1, answr
  first=.false.
end if
call hpinit(2,0,0,0,52)
if(answr .eq. 'y' .or. answr .eq. 'Y')
$ call buff(1,ia,xbuff,8)
call newpen(1)
return
end
subroutine plton
dimension ia(3)
data ia/27,46,89/
c ASCII      esc . Y
call buff(1,ia,xbuff,-3)
call newpen(1)
return
end
subroutine pltend
call newpen(0)
entry pltoff
call plot(0.0,0.0,999)
return
end

```

```

      subroutine bordr2(xlng,xmin,xmax,xtic1,xtic2,ndx,
c      $                  ylng,ymin,ymax,ytic1,ytic2,ndy)
c
      xscale=xlng/(xmax-xmin)
      yscale=ylng/(ymax-ymin)
      if(xtic1*xscale .le. 0. .or. xtic2*xscale .le. 0.) go to 999
      if(ytic1*yscale .le. 0. .or. ytic2*yscale .le. 0.) go to 999
c
      if(iabs(ndx) .gt. 9) then
          sx=.15
          nx=ndx-(ndx/10)*10
      else
          sx=.1
          nx=ndx
      end if
      xo=.5*sx
      if(iabs(ndy) .gt. 9) then
          sy=.15
          ny=ndy-(ndy/10)*10
      else
          sy=.1
          ny=ndy
      end if
      yo=.5*sy
c
      xres=abs(xtic1)/10.
      yres=abs(ytic1)/10.
c
      t1=.05
      t2=.10
      yval=ymin
      ytc2=ymin
      xp=0.
      yp=0.
      go to 115
112  yval=yval+ytic1
      if(abs(yval-ymax) .le. yres) then
          call plot(0.,ylng,2)
          if(abs(yval-ytc2) .le. yres) then
              xln=-sy*(3+ny)
              yln=ylng-yo
              if(abs(yval) .gt. yres .or. abs(yval) .ge. 10.)
c      $          xln=xln-sy*aint(alog10(abs(yval)))
              if(abs(yval) .lt. yres) yval=0.
              if(yval .lt. 0.) xln=xln-sy
              call plot(xln,yln,3)
              call number(xln,yln,sy,yval,0.,ny)
          end if
          call plot(0.,ylng,3)
          go to 120
      end if
      yp=(yval-ymin)*yscale
      call plot(xp,yp,2)
      if(abs(yval-ytc2) .gt. yres) go to 118
          call plot(t2,yp,2)
115  xln=-sy*(3+ny)
      yln=yp-yo
      if(abs(yval) .gt. yres .or. abs(yval) .ge. 10.)

```

```

$      xln=xln-sy*aint(alog10(abs(yval)))
      if(abs(yval) .lt. yres) yval=0.
      if(yval .lt. 0.) xln=xln-sy
      call plot(xln,yln,3)
      call number(xln,yln,sy,yval,0.,ny)
      ytc2=ytic2+ytic2
      go to 119
118  call plot(t1,yp,2)
119  call plot(xp,yp,3)
      if(abs(yval-ymax) .gt. yres) go to 112
c
120  yp=yln
      t1=yln-.05
      t2=yln-.10
      xval=xmin
      xtc2=xmin+xtic2
122  xval=xval+xtic1
      if(abs(xval-xmax) .gt. xres) go to 123
      call plot(xln,yln,2)
      if(abs(xval-xtc2) .le. xres) xtc2=xtc2+xtic2
      go to 130
123  xp=(xval-xmin)*xscale
      call plot(xp,yp,2)
      if(abs(xval-xtc2) .gt. xres) go to 128
      call plot(xp,t2,2)
      xtc2=xtc2+xtic2
      go to 129
128  call plot(xp,t1,2)
129  call plot(xp,yp,2)
      if(abs(xval-xmax) .gt. xres) go to 122
c
130  xp=xln
      t1=xln-.05
      t2=xln-.10
      ytc2=ytic2+ytic2
      if(abs(ytc2-ymax) .le. yres) go to 135
132  yval=yval-ytic1
      if(abs(yval-ymin) .gt. yres) go to 133
      call plot(xln,0.,2)
      go to 140
133  yp=(yval-ymin)*yscale
      call plot(xp,yp,2)
      if(abs(yval-ytc2) .gt. yres) go to 138
      call plot(t2,yp,2)
135  ytc2=ytic2+ytic2
      go to 139
138  call plot(t1,yp,2)
139  call plot(xp,yp,2)
      if(abs(yval-ymin) .gt. yres) go to 132
c
140  yp=0.
      t1=.05
      t2=.10
      yln=-2.*sx
      xtc2=xtc2-xtic2
      if(abs(xtc2-xmax) .le. xres) go to 145
142  xval=xval-xtic1
      if(abs(xval-xmin) .le. xres) then

```

```

    call plot(0.,0.,2)
    if(abs(xval-xtc2) .le. xres) then
        xln=-xo*(2+nx)
        if(abs(xval) .gt. xres .or. abs(xval) .ge. 10.)
$       xln=xln-xo*aint(alog10(abs(xval)))
        if(abs(xval) .lt. xres) xval=0.
        if(xval .lt. 0.) xln=xln-xo
        call plot(xln,yln,3)
        call number(xln,yln,sx,xval,0.,nx)
    end if
    call plot(0.,0.,3)
    return
end if
xp=(xval-xmin)*xscale
call plot(xp,yp,2)
if(abs(xval-xtc2) .gt. xres) go to 148
call plot(xp,t2,2)
145   xln=xp-xo*(2+nx)
        if(abs(xval) .gt. xres .or. abs(xval) .ge. 10.)
$       xln=xln-xo*aint(alog10(abs(xval)))
        if(abs(xval) .lt. xres) xval=0.
        if(xval .lt. 0.) xln=xln-xo
        call plot(xln,yln,3)
        call number(xln,yln,sx,xval,0.,nx)
        xtc2=xtc2-xtic2
        go to 149
148   call plot(xp,t1,2)
149   call plot(xp,yp,3)
        if(abs(xval-xmin) .gt. xres) go to 142
c
999   print 100,xlng,xmin,xmax,xtic1,xtic2,ndx,
$       ylng,ymin,ymax,ytic1,ytic2,ndy
100   format('0Error in BORDR2: '/
$       '0xlng, xmin, xmax, xtic1, xtic2, ndx = ',lp5ell1.3,i5/
$       '0ylng, ymin, ymax, ytic1, ytic2, ndy = ',lp5ell1.3,i5)
        call pltend
        stop
end

```

```

      subroutine curve(x,y,up,nrpts,xmin,ymin,xinc,yinc,line)
c
c x,y,up must be dimensioned at least nrpts
c xmin,ymin are x,y origin in user units
c xinc,yinc are x,y scales in user units per inch
c
c line=1: solid
c       2: long dash
c       3: medium dash
c       4: short dash
c       5: dotted
c       6: short + long dash
c       7: short + short + long dash
c
      logical up,up1,up2
      dimension ipen(8),joc(7),x(nrpts),y(nrpts),up(nrpts)
      data ipen/2,2,2,3,2,3,2,3/,joc/18, 11, 14, 23, 32, 41, 16/
      data delr/.1/
c
      if(nrpts .le. 1) go to 99
c
      if(line) 1,2,3
1      kk=mod(line,7)+7
      go to 4
2      kk=0
      go to 4
3      kk=mod(line,7)
4      kk=kk+1
      jo=joc(kk)/10
      jc=joc(kk)-10*jo
      ip=ipen(jo)
c
      j=0
      dr=0.
      rho1=0.
      rho2=delr
      px1=(x(1)-xmin)/xinc
      py1=(y(1)-ymin)/yinc
      up1=up(1)
      if(.not. up1) then
c
c go to first position with pen up
      call plot(px1,py1,3)
      if(kk .eq. 6) then
        px2=(x(2)-xmin)/xinc
        py2=(y(2)-ymin)/yinc
        delx=px2-px1
        dely=py2-py1
        rho=sqrt(delx**2+dely**2)
        if(rho .eq. 0.) then
          dx 6=delx*.1
          dy 6=dely*.1
        else
          dx 6=delx*delr/rho*.1
          dy 6=dely*delr/rho*.1
        end if
        call plot(px1+dx6,py1+dy6,2)
      end if

```

```

      end if
c
      do 40 i=2,nrpts
      px2=(x(i)-xmin)/xinc
      py2=(y(i)-ymin)/yinc
      up2=up(i)
      if(up2) then
        dr=0.
        rho1=0.
        rho2=delr
        go to 39
      end if
      if(up1) then
c pen has been up, prepare to lower pen
        call plot(px2,py2,3)
        go to 39
      end if
      if(kk .eq. 2) go to 38
      delx=px2-px1
      dely=py2-pyl
      rho=sqrt(delx**2+dely**2)
      rho1=rho1+rho
      if(rho2 .gt. rho1) go to 38
      delx=delx*delr/rho
      dely=dely*delr/rho
      dx 6=delx*.1
      dy 6=dely*.1
      if(dr .eq. 0.) go to 20
      dx=delx*dr/delr
      dy=dely*dr/delr
      px1=px1+dx
      pyl=pyl+dy
      go to 21
20  if(rho2 .gt. rho1) go to 38
      px1=px1+delx
      pyl=pyl+dely
21  call plot(px1,pyl,ip)
      if(kk .eq. 6) call plot(px1+dx6,pyl+dy6,2)
      j=j+1
      ip=ipen(jo+mod(j,jc))
      rho2=rho2+delr
      go to 20
38  call plot(px2,py2,ip)
      dr=rho2-rho1
39  px1=px2
      pyl=py2
      up1=up2
40  continue
99  return
      end

```