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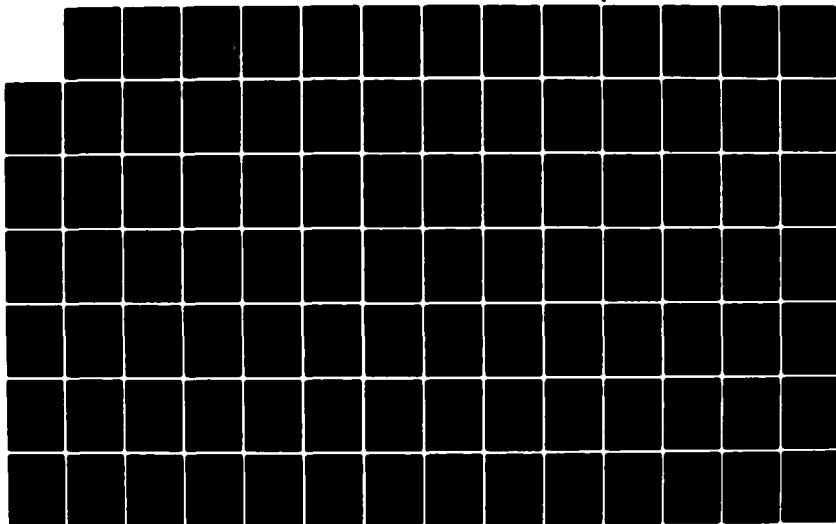
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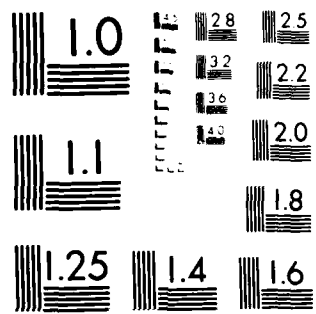
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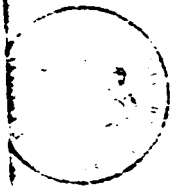


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Scientific Report 475

EFFECT OF HF HEATING ARRAY DIRECTIVITY PATTERN
ON THE FREQUENCY RESPONSE
OF GENERATED ELF/VLF

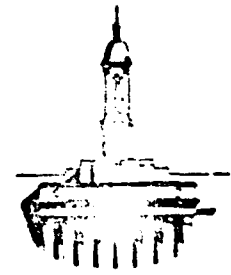
by

Kenneth J. Carroll, A. J. Ferraro
H. S. Lee, Roger Allshouse
Bruce Long, Ray J. Linnen

January 1983

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IONOSPHERE RESEARCH LABORATORY



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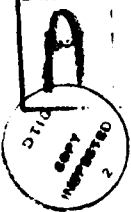
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Office of Naval Research under Contract No. N00014-81-K-0276.

Submitted by:


A. J. Ferraro
Professor of Electrical Engineering

Approved by:


John S. Nisbet
Director, Ionosphere Research Laboratory

Ionosphere Research Laboratory
Department of Electrical Engineering
The Pennsylvania State University
University Park, Pennsylvania 16802

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ABSTRACT

Directivity patterns at 3.17 MHz and 5.1 MHz are calculated for the HF antenna array at the high power HF heating facility at the Arecibo Observatory in Puerto Rico. The pattern was calculated using pattern multiplication and method of moment techniques. The calculated pattern is shown to be a good approximation to an experimentally measured pattern in one plane of the array. A simple model was used to approximate the effect of the pattern on the frequency response of ELF/VLF signals generated by the HF heating. The frequency response was determined at two ELF/VLF receiver sites. Results show that ELF/VLF generated by side lobes of the HF pattern have sufficient strength to create a ELF/VLF interference pattern at receiving locations.

EFFECT OF HF HEATING ARRAY DIRECTIVITY PATTERN ON THE
FREQUENCY RESPONSE OF GENERATED ELF/VLF

INTRODUCTION

ELF/VLF generation experiments were conducted at the Arecibo Observatory (A.O.) in Puerto Rico. The HF heating facility for A.O. is located at $18^{\circ} 29'$ N and $66^{\circ} 40'$ W geographic latitude and longitude respectively. The ELF/VLF receiving site was located 7.7 km from the heating facility and 238° to the east.

The motion of the ionospheric plasma, in the presence of the earth's magnetic field, causes natural ionospheric currents to flow. By changing the conductivity of a small portion of the ionosphere, the natural currents within that portion can be modulated. Modulating the currents in the ELF/VLF range causes a ELF/VLF signal to be radiated by the ionosphere.

The conductivity in the ionosphere is dependent upon the electron collision frequency, which is in turn dependent upon the electron temperature. An HF electromagnetic wave is absorbed by the ionosphere. The EM wave adds kinetic energy to the electrons, which in effect increases the electron temperature. Thus, by modulating the HF transmission at a ELF/VLF rate, the ionospheric conductivities will be modulated at the same rate, and a ELF/VLF signal will be radiated from the ionosphere.

The antenna, radiating the HF signal heating the ionosphere, has a pattern consisting of a main beam, side lobes, and possibly grating lobes. Heating occurs where each of these penetrates the ionosphere. By determining the pattern of the HF antenna, the spatial distribution

of the heating in the ionosphere can be determined. Thus, the location in the ionosphere and the intensity of each of the ELF/VLF radiating sources can be determined. From this the characteristics of the ELF/VLF radiation from the ionosphere can be calculated.

This section will describe the calculation of an approximation to the Arecibo HF heating array directive gain pattern and apply the results to find a zero order approximation to an ELF/VLF radiating array. The technique employed to calculate the HF array pattern is one which uses the combination of pattern multiplication techniques and computer numerical analysis. The numerical program used was the Antenna Modeling Program (AMP)⁽¹⁾. The AMP output was then used with analytical equations in a program written at the Ionosphere Research Laboratory at Penn State University to carry out the pattern multiplication.

PATTERN MULTIPLICATION THEORY

The pattern multiplication technique is based upon the calculation of the total pattern of an array by taking the product of an array factor (AF) with the elemental pattern. The array is made up of identical elements. The elemental pattern is the pattern of an individual element of the array. The AF is obtained by replacing each of the elements of the array with an isotropic radiator and calculating the pattern for the array of isotropic radiators. A detailed discussion of pattern multiplication can be found in reference (2). A description of the theory used in this analysis follows.

For example, assume there are an even number "N" of colinear isotropic radiators separated by a distance "d" as shown in figure (1-1). The far field, at a point "P", due to the n^{th} radiator, is proportional to a complex current amplitude, I_n , a phase factor, $e^{-j\beta R_n}$, and is inversely proportional to the distance from the radiator to "P", equation (1-1).

$$E_n \propto I_n [e^{-j\beta R_n} / (4\pi R_n)] \quad (1-1)$$

The far field approximation states that "P" is far enough away that " R_n " can be assumed to be parallel to "R", and the length of " R_n " is approximately equal to "R". Under these conditions the approximations in equation (1-2) can be made.

$$1/R \approx 1/R_n \quad (1-2a)$$

$$R_n \approx (2 |n| - 1)(d/2) \cos \alpha + R \quad ; n < 0 \quad (1-2b)$$

$$R_n \approx R - (2 |n| - 1)(d/2) \cos \alpha \quad ; n > 0 \quad (1-2c)$$

While the small difference in length of " R_n " can be neglected in the " $1/R_n$ " term, these differences can have a significant effect on the phase term, $e^{-j\beta R_n}$. Incorporating the far field approximation equation (1-2) with equation (1-1), the total field at "P" can be expressed (1-3).

$$E = \sum_{n=(-N/2)}^{-1} E_n + \sum_{n=1}^{N/2} E_n = \left[\sum_{n=(-N/2)}^{-1} I_n e^{-j\beta [(2 |n| - 1)(d/2) \cos \alpha + R]} \right. \\ \left. + \sum_{n=1}^{N/2} I_n e^{-j\beta [R - (2 |n| - 1)(d/2) \cos \alpha]} \right] [1/(4\pi R)] \quad (1-3)$$

Assume that " I_n " is equal to a constant " I_0 " and collect all the like terms. Equation (1-3) reduces to equation (1-4).

$$E = (I_0/4\pi R) e^{-j\beta R} \left[\sum_{n=(-N/2)}^{-1} e^{-j\gamma_n} + \sum_{n=1}^{N/2} e^{j\gamma_n} \right] \quad (1-4)$$

$$\gamma_n = \beta(2|n|-1)(d/2)\cos\alpha$$

The first term is a constant for a fixed value of "R". The second term is dependent on alpha. It defines the antenna pattern and is the AF. The AF is given in equation (1-5).

$$AF = \sum_{n=(-N/2)}^{N-1} e^{-j\gamma_n} + \sum_{n=1}^{N/2} e^{-j\gamma_n} \quad (1-5)$$

Noting that γ_{-n} is equal to γ_n , equation (1-5) can be simplified to equation (1-6).

$$AF = \sum_{n=1}^{N/2} (e^{j\gamma_n} + e^{-j\gamma_n}) = 2 \sum_{n=1}^{N/2} \cos \gamma_n = 2 \sum_{n=1}^{N/2} \cos[\beta(2n-1)(d/2)\cos\alpha] \quad (1-6)$$

Since the 2 in equation (1-6) is a constant, it may be dropped from the array factor. In addition, in equation (1-6) $2n-1$ can be replaced with n , and the result simplified to equation (1-7).

$$AF = \sum_{n=1,3,5,\dots}^{n-1} \cos[n\beta(d/2)\cos\alpha] \quad (1-7)$$

Equation (1-7) is the array factor for a colinear array of an even number of N isotropic radiators with equal current amplitudes. The angle α is measured from the line of the array to the observation point.

ANTENNA MODELING PROGRAM (AMP) THEORY

The Antenna Modeling Program (AMP) was used to analyze the array element. This program was developed by MBA/Information Systems.⁽¹⁾ The computer program applies the method of moments to the thin wire approximation of the integral equation for the electric field due to a volume current distribution, equation (1-8).⁽¹⁾

$$\mathbf{E}(\bar{\mathbf{r}}_0) = \iiint_V i\omega\mu_0 \bar{\mathbf{J}}(\bar{\mathbf{r}}) \cdot \bar{\bar{\mathbf{G}}}(\bar{\mathbf{r}}, \bar{\mathbf{r}}_0) d\bar{\mathbf{v}} \quad (1-8)$$

$$\bar{\bar{\mathbf{G}}}(\bar{\mathbf{r}}, \bar{\mathbf{r}}_0) = -(1/4\pi) [\bar{\mathbf{I}} + (1/k^2)\nabla\nabla]g$$

$$g = (e^{-ik|\bar{\mathbf{r}}-\bar{\mathbf{r}}_0|} / |\bar{\mathbf{r}}-\bar{\mathbf{r}}_0|)$$

$$k = \omega\sqrt{\mu_0\epsilon_0}, \quad \bar{\mathbf{I}} = \text{unit 2nd rank tensor}$$

$|\bar{\mathbf{r}}-\bar{\mathbf{r}}_0|$ = distance measured from wire axis (source point) to observation point on the surface.

The thin wire approximation requires that the diameter of the wire be small compared with the wavelength. Thus azimuthal current flow around the wire can be neglected and the volume integral in equation (1-8) can be changed to a line integral, equation (1-9).⁽¹⁾

$$-\hat{\mathbf{s}}_0 \cdot \bar{\mathbf{E}}^I(\bar{\mathbf{r}}_0) = (-i\omega\mu_0/4\pi) \int_L I(s) [\hat{\mathbf{s}} \cdot \hat{\mathbf{s}}_0 - (1/k^2) (\partial^2/\partial s \partial s_0)] g(\bar{\mathbf{r}}, \bar{\mathbf{r}}_0) ds \quad (1-9)$$

$\hat{\mathbf{s}}$ = unit tangent at source point

$\hat{\mathbf{s}}_0$ = unit tangent at observation point

I = $(\pi a^2 J) 2\pi a$

a = wire radius

Included in equation (1-9) is also the boundary condition for a metal surface, equation (1-10).

$$E_{\text{tan}}^I + E_{\text{tan}}^S = 0 \quad (1-10)$$

E_{tan}^I = Tangential component of incident electric field

E_{tan}^S = Tangential component of scattered electric field

AMP solves equation (1-9) numerically by converting it into matrix form. This is accomplished by expanding the unknown currents, I , in terms of a set of basis functions, I_n , and taking the inner product of both sides of equation (1-9) with a set of weighting functions w_m . A general discussion on this method of solution can be found in reference (3).

Equation (1-11) is obtained by expressing equation (1-9) in operational format, where the operator L_{op} denotes the integral and " $\langle A, B \rangle$ " denotes the inner product of quantities A and B.

$$\sum_n^N A_n \langle w_m, L_{op} I_n \rangle = \langle w_m, E^I \rangle \quad (1-11)$$

where $I = \sum_n^N A_n I_n$

Equation (1-11) must be true for each w_m , and thus may be written in matrix form as expressed in equation (1-12).

$$\begin{bmatrix} \langle w_1, L_{op} I_1 \rangle & \langle w_1, L_{op} I_2 \rangle & \dots & \langle w_1, L_{op} I_n \rangle \\ \langle w_2, L_{op} I_1 \rangle & \langle w_2, L_{op} I_2 \rangle & \dots & \langle w_2, L_{op} I_n \rangle \\ " & " & " & " \\ " & " & " & " \\ " & " & " & " \\ \langle w_N, L_{op} I_1 \rangle & \langle w_N, L_{op} I_2 \rangle & \dots & \langle w_N, L_{op} I_n \rangle \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ " \\ " \\ " \\ A_N \end{bmatrix} = \begin{bmatrix} \langle w_1, E^I \rangle \\ \langle w_2, E^I \rangle \\ " \\ " \\ " \\ \langle w_N, E^I \rangle \end{bmatrix} \quad (1-12)$$

Since E^I , I_n and w_m are known, by matrix inversion the values of A_n can be calculated.

Specifically, AMP uses sine and cosine functions as basis functions and employs a method of collocation, or point matching, by choosing the weighting functions as δ functions.

THEORY APPLIED TO A.O. ARRAY

To apply the techniques of AMP and pattern multiplication to the A.O. heating array, the array's physical characteristics must be known.* The HF antenna consists of a 4x8 array of radiating elements. This array is oriented as shown in figure (1-2). Each of the elements in the array is constructed in the shape of an inverted pyramid with four sides. The faces of the pyramid are at an angle of 45° with the ground and contain two nonplanar log-periodic antennas (NLPA). One NLPA is contained in the north and south faces, and the other is contained in the east and west faces. A sketch of an array element is shown in figure (1-3). Note that the elements in the south and west faces have been rotated 180° about the corresponding face's NLPA elements feed lines. A diagram looking down at the top elements of the pyramid is shown in figure (1-4).

Both NLPAS are designed with a τ of .88. The dimensions of the array elements in the north and south faces are shown in figure (1-5). The dimensions of the east and west faces are scaled to $\tau^{1/4}$ of the north and south faces. This will result in right hand circular polarization radiation when the north and south faces are fed 180° out

*Note: See appendix III for additional information on HF antenna geometry.

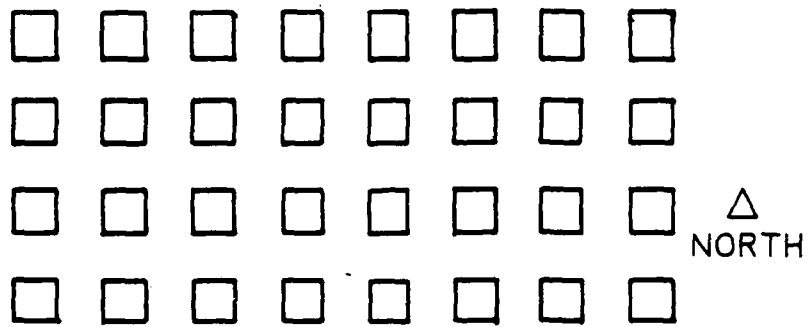


Figure 1-2 HF heating array

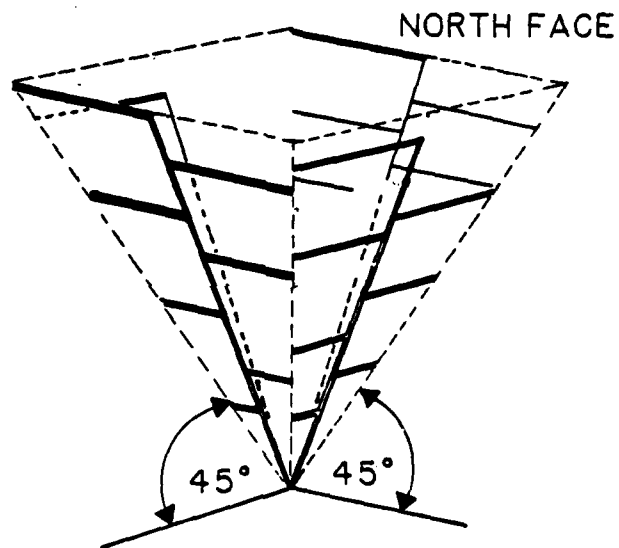


Figure 1-3 HF heating array element

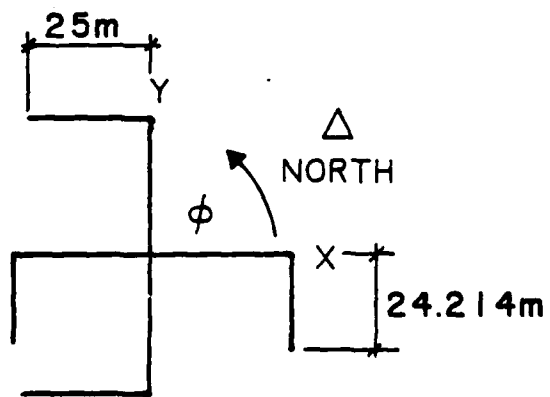


Figure 1-4 View of top elements looking down at pyramid

ALL WIRE RADII=2.0 mm
 ALL DIMENSIONS IN METERS

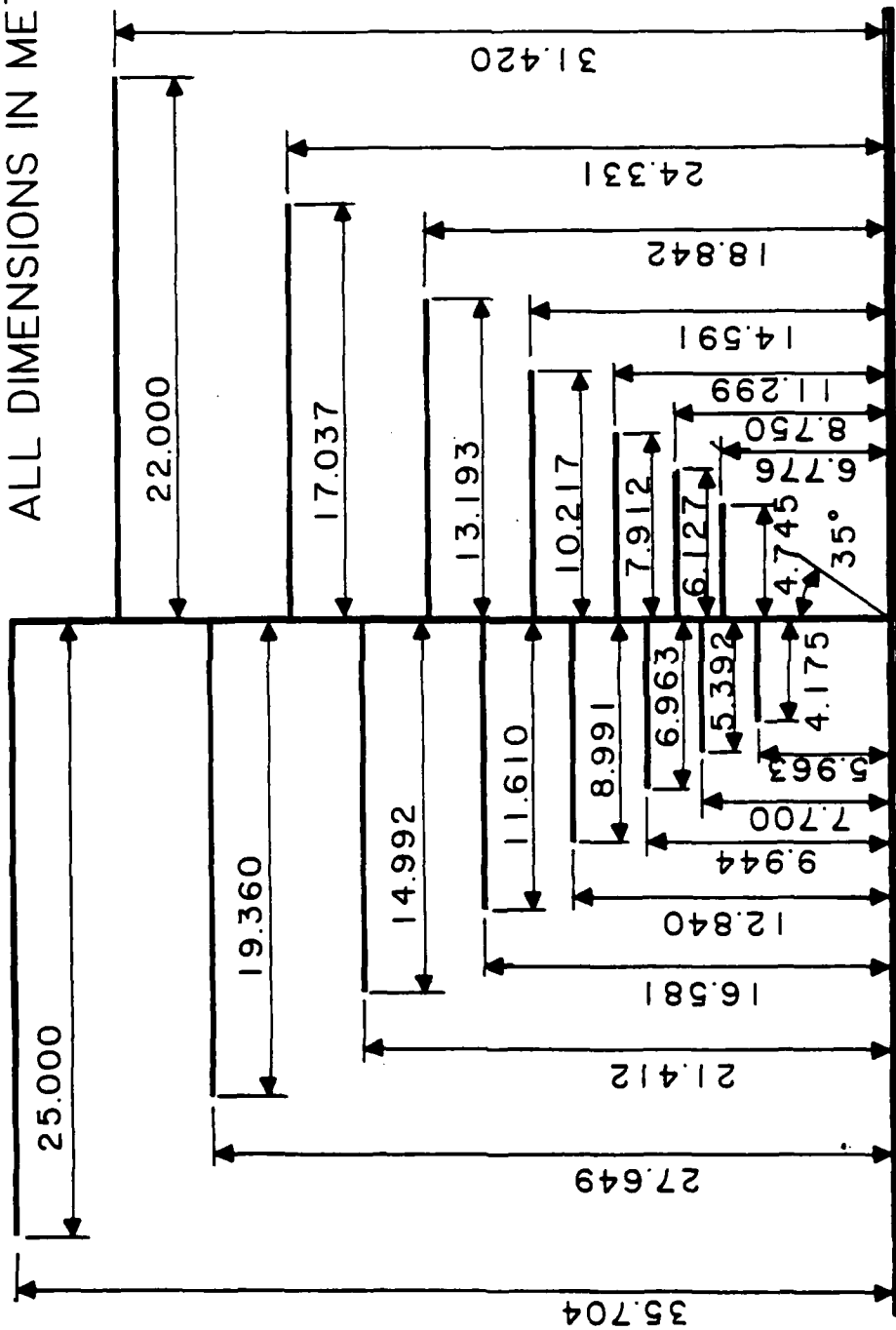


Figure 1-5 Non-planar log-periodic antenna semi-structure dimensions

of phase with the east and west faces. When fed in phase, left hand circular polarization radiation will be transmitted.⁽⁴⁾ The north and south and the east and west faces are fed against ground by separate transmitters. This gives the capability to adjust the phase between different faces and thus change the radiation polarization.

The array element was analyzed using the AMP computer program. Then the pattern multiplication technique was used to calculate the total array pattern.

The array element was analyzed using AMP for frequencies of 3.17 MHz and 5.1 MHz. The data file used is listed in Appendix I program 1. The GW and GM cards generate the antenna structure depicted in figure (1-3) and orient it with respect to the coordinate axis shown in figure (1-4). The GN card specified the conductivity (.03 S/m) and relative permativity (20) of the ground below the HF array. The actual conductivity and permativity for the heater site was not known, but based on the fact that maps indicate the heater array is located on marshy ground, a conductivity and a relative permativity for "good" earth⁽⁵⁾ were used. As shown in the RP card, the power gain was computed for 2.5 degree steps in "theta" and 5 degree steps in "phi."

In order to use the output of AMP in the pattern multiplication, it was necessary to develop an elemental pattern function. Given a "theta" and "phi", the function returns a value of the power gain in that direction. To accomplish this, the power gains from the AMP output for selected constant "phi" surfaces were combined with a linear interpolation scheme. The selected values of "phi" are listed in table I.

Figures (1-6) and (1-7) show the comparison of the interpolated values (shown by X) with the AMP results (shown by ·). The maximum error is approximately one db. Figure (1-6) is a plot of power gain as a function of "phi" for a constant "theta." The power gain decreases as the radius of the polar plot increases. The unsymmetrical nature of the plot is due to the unsymmetrical nature of the array element. Figure (1-7) is a plot of power gain as a function of "theta" for a constant "phi."

3.17 MHz <u>Phi (deg)</u>	5.1 MHz <u>Phi (deg)</u>
0	10
90	60
130	90
180	110
210	150
270	180
320	215
360	270
	320

Table I. Selected Values of Phi for Interpolation Routines

The total array pattern for the A.O. array shown in figure (1-1) was calculated by taking the product of two separate array factors. In essence this is a pattern multiplication. The array pattern of one array becomes the elemental pattern of the other array. One array is the 4-element array on the north and south line. The other array is an 8-element array on an east and west line.

The expansion of equation (1-7) for the 4-element and 8-element arrays can be simplified by using trigonometric identities. These trigonometric identities were obtained from Chebysheff polynomials, as shown in Appendix II. The simplified equation for the antenna factors are given in equations (1-13) and (1-14). The 4-element array factor

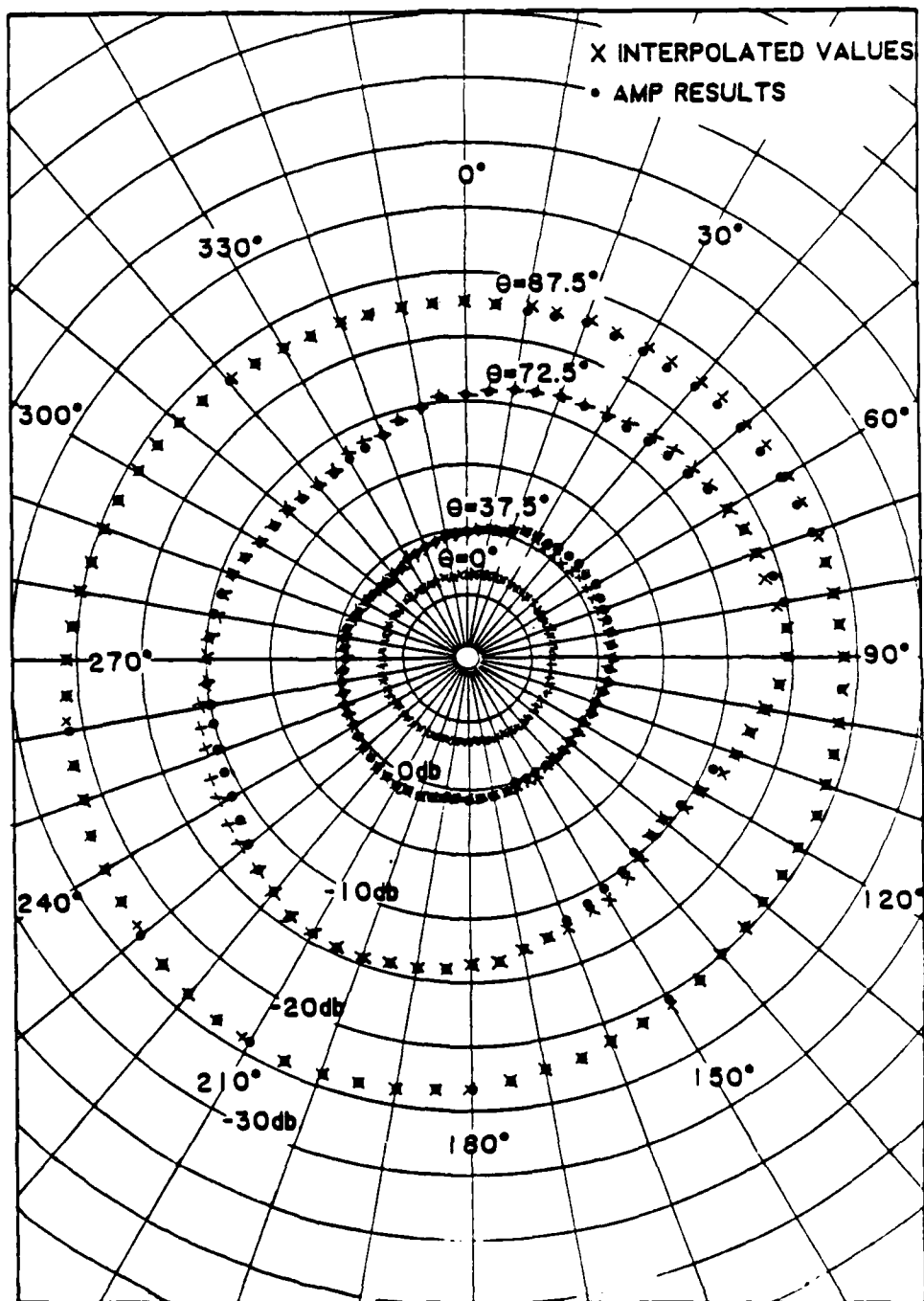


Figure 1-6a Power gain vs. phi for a constant theta, 3.17 MHz

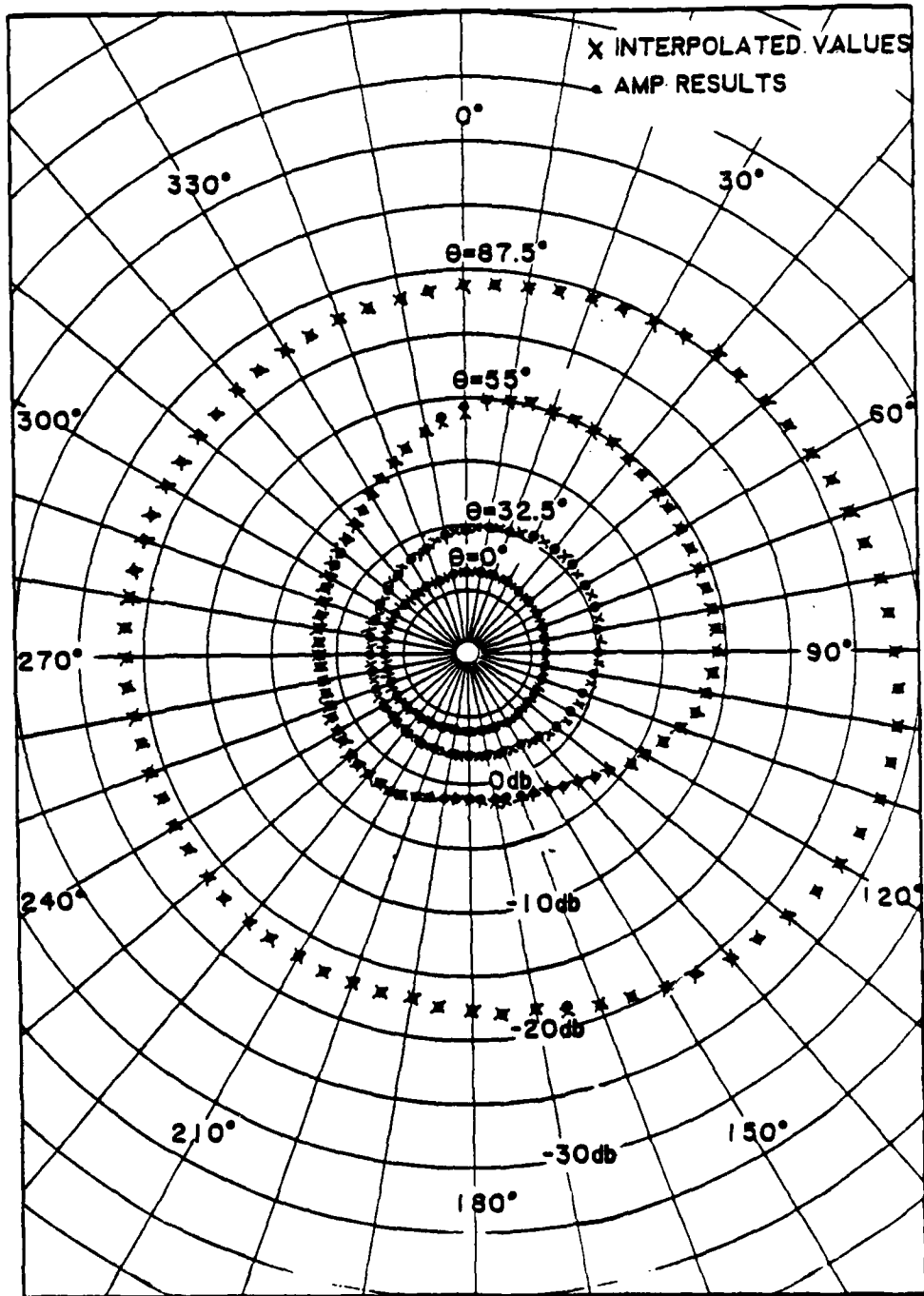


Figure 1-6b Power gain vs. phi for a constant theta, 5.1 MHz

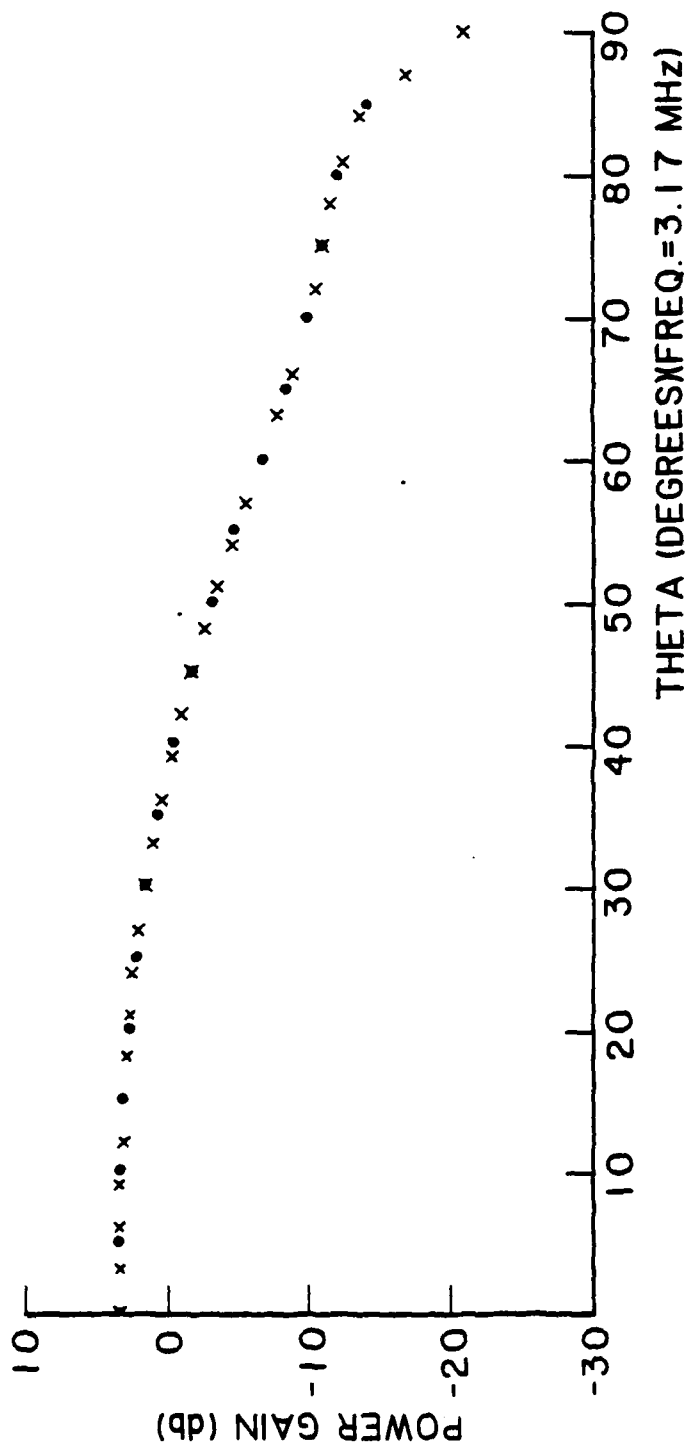


Figure 1-7a.1 Power gain vs. theta for $\phi = 0^\circ$, 3.17 MHz

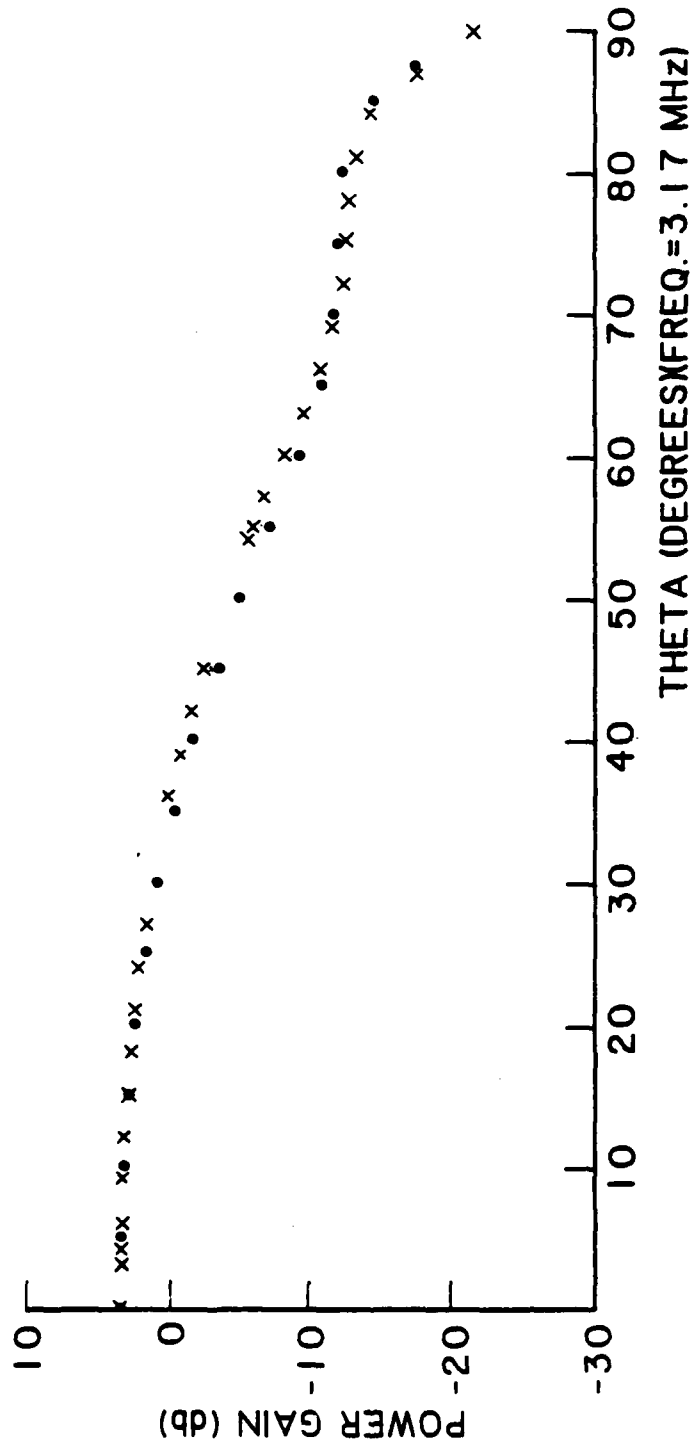


Figure 1-7a.2 Power gain vs. theta for $\phi=40^\circ$, 3.17 MHz

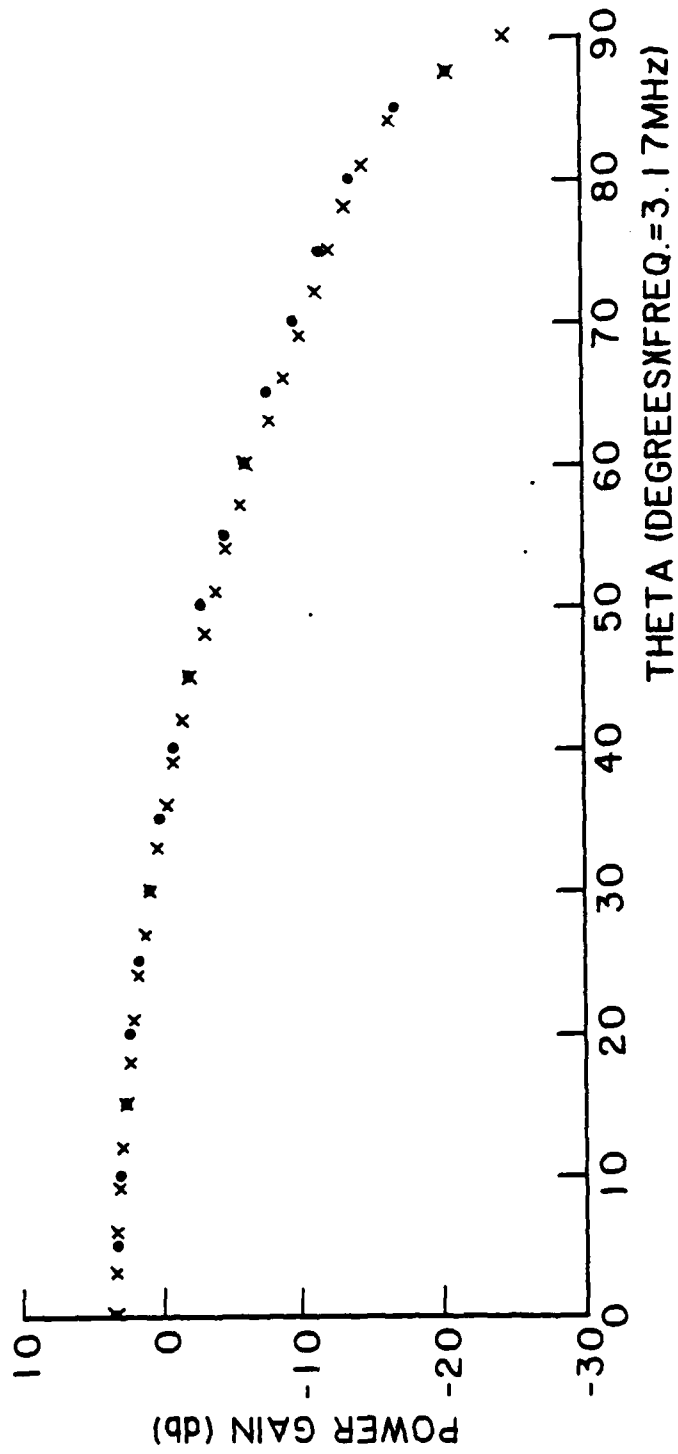


Figure 1-7a.3 Power gain vs. theta for $\phi=150^\circ$, 3.17 MHz

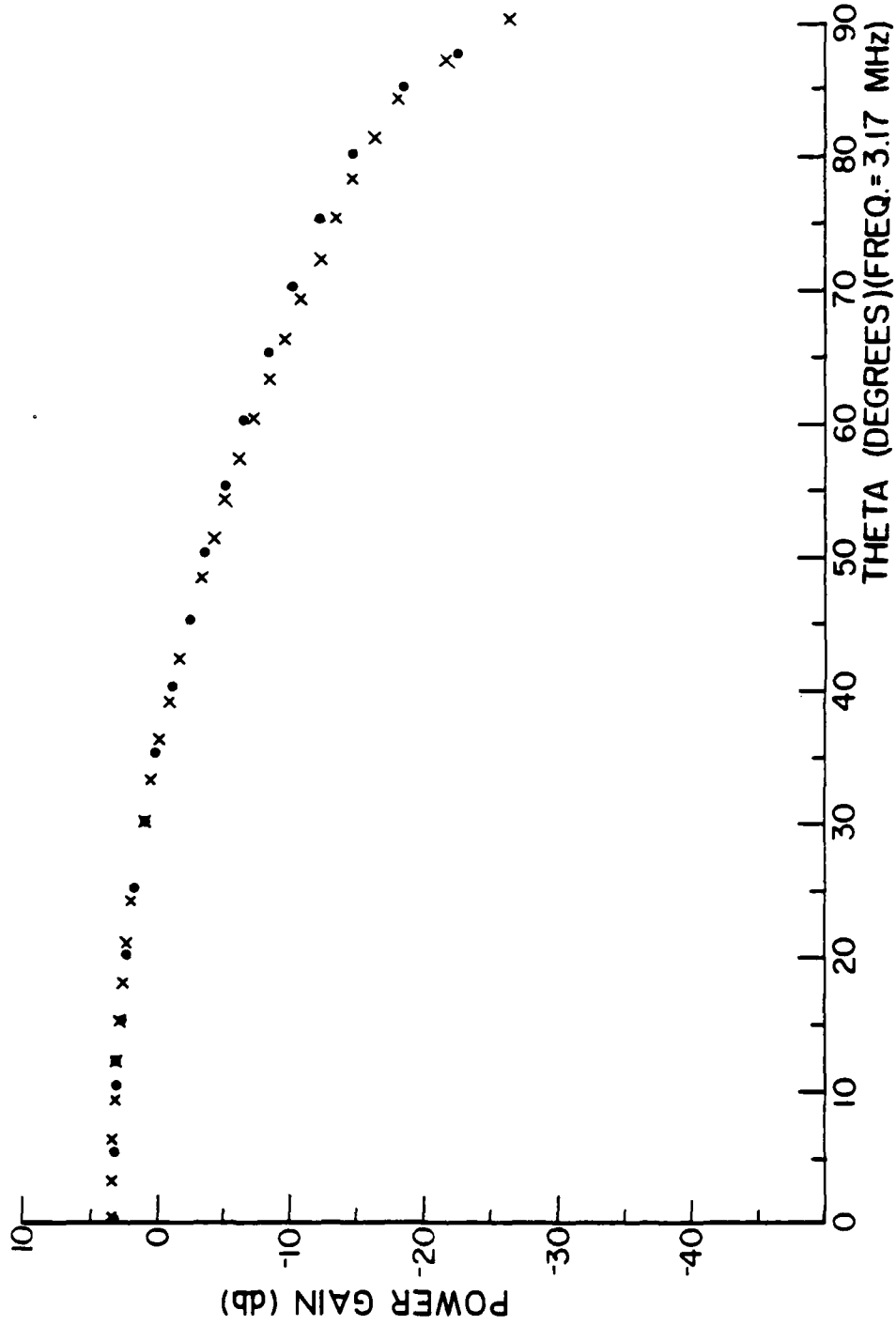


Figure 1-7a.4 Power gain vs. theta for $\phi=240^\circ$, 3.17 MHz

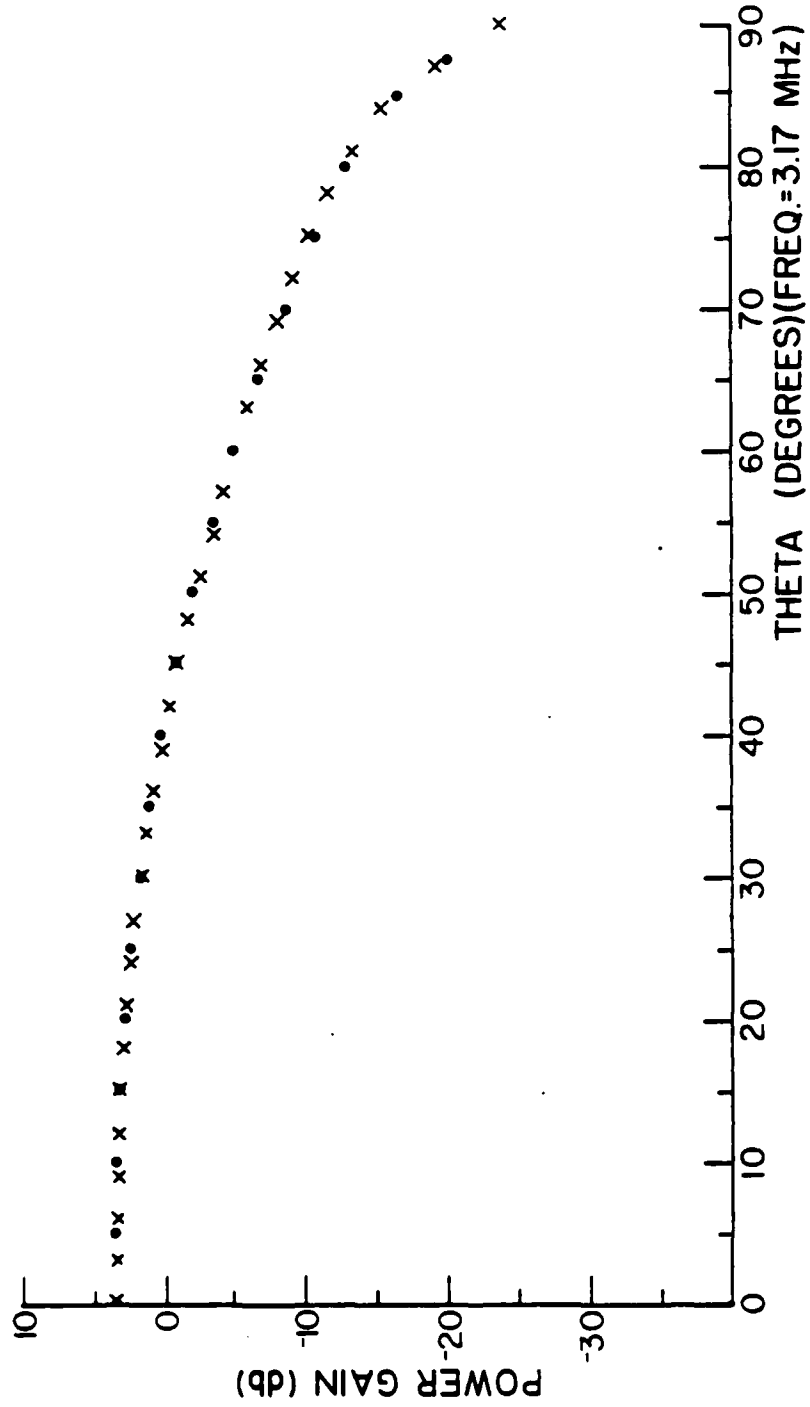


Figure 1-7a.5 Power gain vs. theta for phi=280°, 3.17 MHz

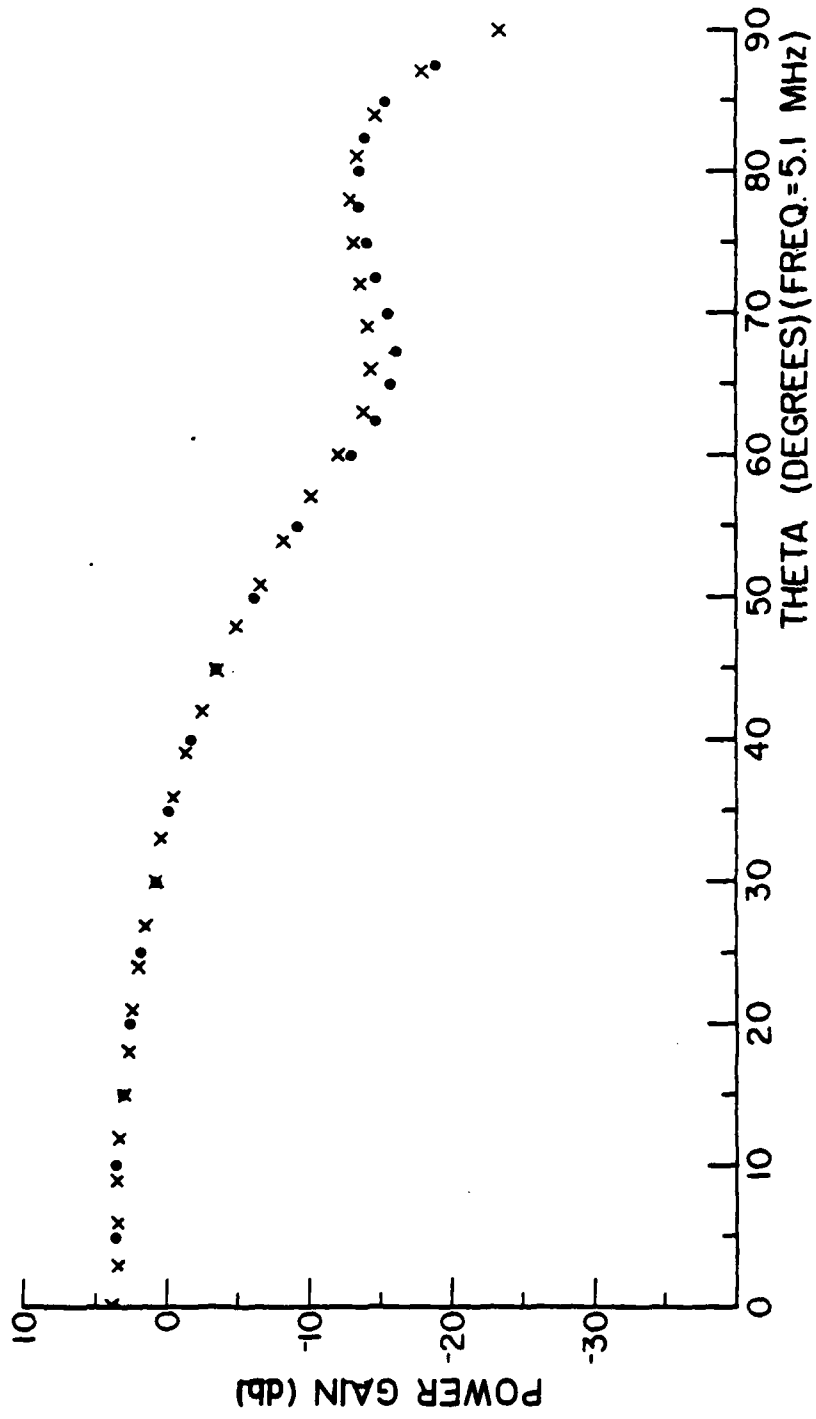


Figure 1-7b.1 Power gain vs. theta for $\phi=0^\circ$, 5.1 MHz

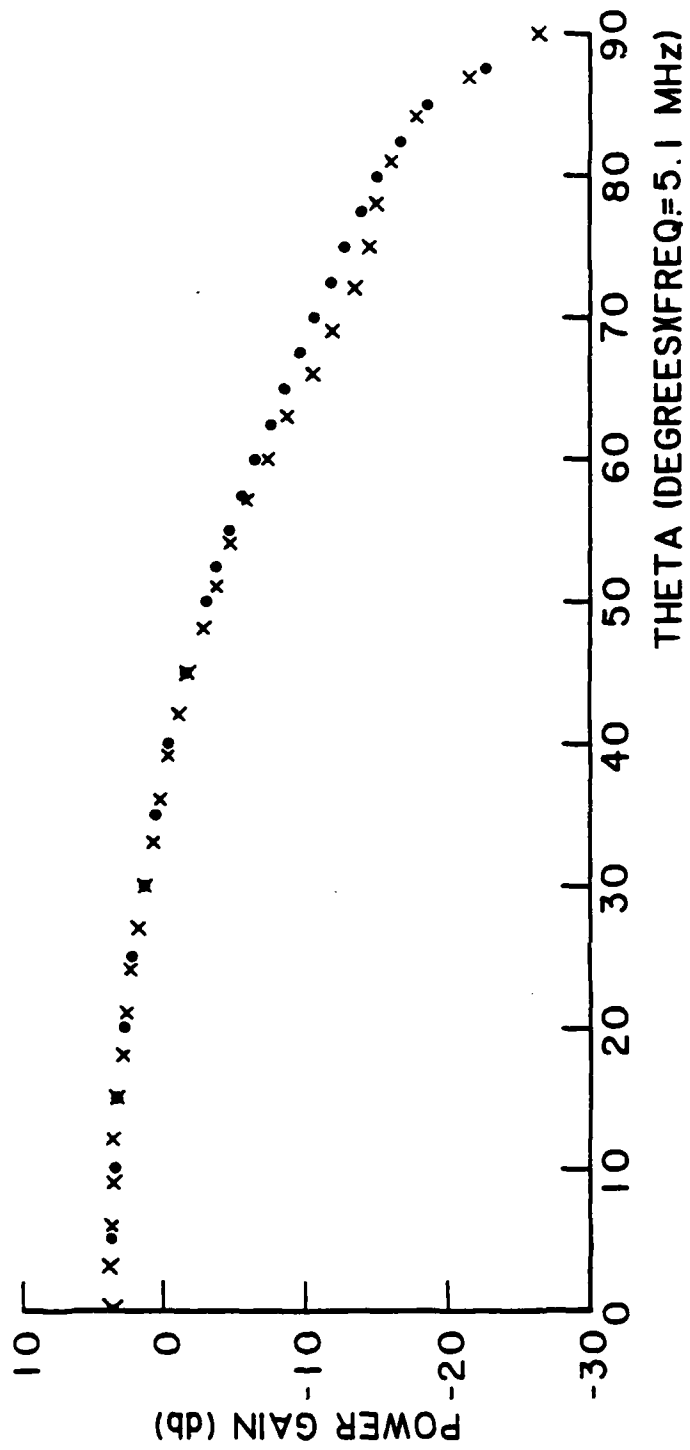


Figure 1-7b.2 Power gain vs. theta for $\phi=130^\circ$, 5.1 Mhz

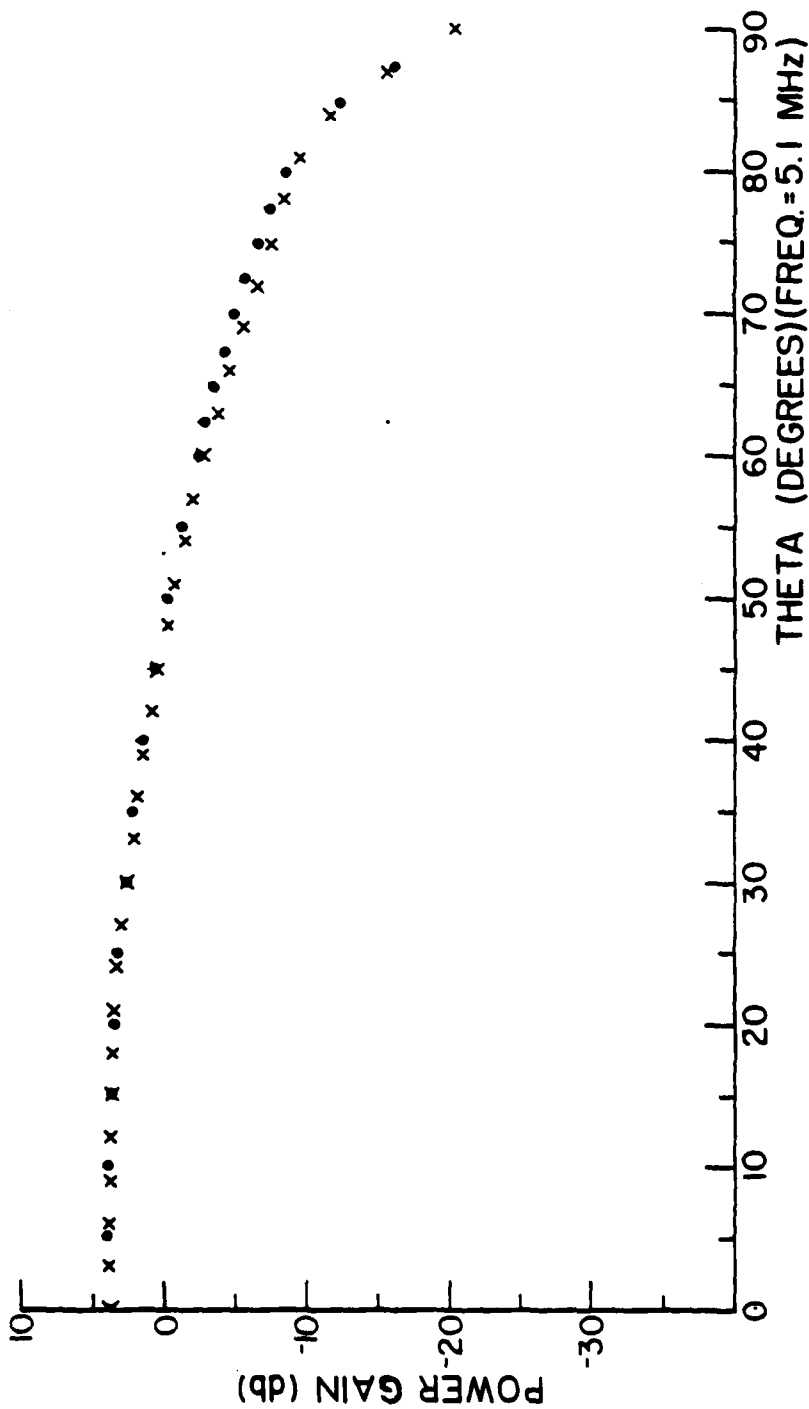


Figure 1-7b.3 Power gain vs. theta for $\phi=250^\circ$, 5.1 MHz

is equation (1-13), and the 8-element array factor is equation (1-14). Figure (1-8) shows the orientation of the 4- and 8-element arrays on an X,Y,Z coordinate system. The Y-axis was taken to be north and the X-axis as east.

$$AF_1 = [\sin(4\beta(d/2) \cos \xi_1)] / \sin(\beta(d/2) \cos \xi_1) \quad (1-13)$$

$$AF_2 = [\sin(8\beta(d/2) \cos \xi_2)] / \sin(\beta(d/2) \cos \xi_2) \quad (1-14)$$

The array pattern of the 8-element array is solid of revolution about the X-axis, and the 4-element array pattern is a solid of revolution about the Y-axis.

Using the transformation in equation (1-15), AF_1 and AF_2 can be transformed to spherical coordinates. The total array factor AF , equation (1-16), is the product of AF_1 and AF_2 .

$$\begin{aligned} \cos \xi_1 &= \sin \theta \sin \phi \\ \cos \xi_2 &= \sin \theta \cos \phi \end{aligned} \quad (1-15)$$

$$AF = AF_1 \times AF_2 = \frac{\sin[4\beta(d/2)\sin\theta\sin\phi]}{\sin[\beta(d/2)\sin\theta\sin\phi]} \frac{\sin[8\beta(d/2)\sin\theta\cos\phi]}{\sin[\beta(d/2)\sin\theta\cos\phi]} \quad (1-16)$$

The total array power pattern can be calculated by taking the square of the total array factor, AF , and multiplying it by the elemental pattern function, which is an interpolation of the AMP results. To achieve the goal of the calculation of a directive gain pattern, a correction factor must be determined. This factor is a result of neglecting the constants in calculating the array factor.

The directive gain "in a given direction is defined as the ratio of the radiation intensity in that direction to the average radiated power."⁵ Since the constants which were neglected in calculating AF are also contained in the calculation of the average radiated power

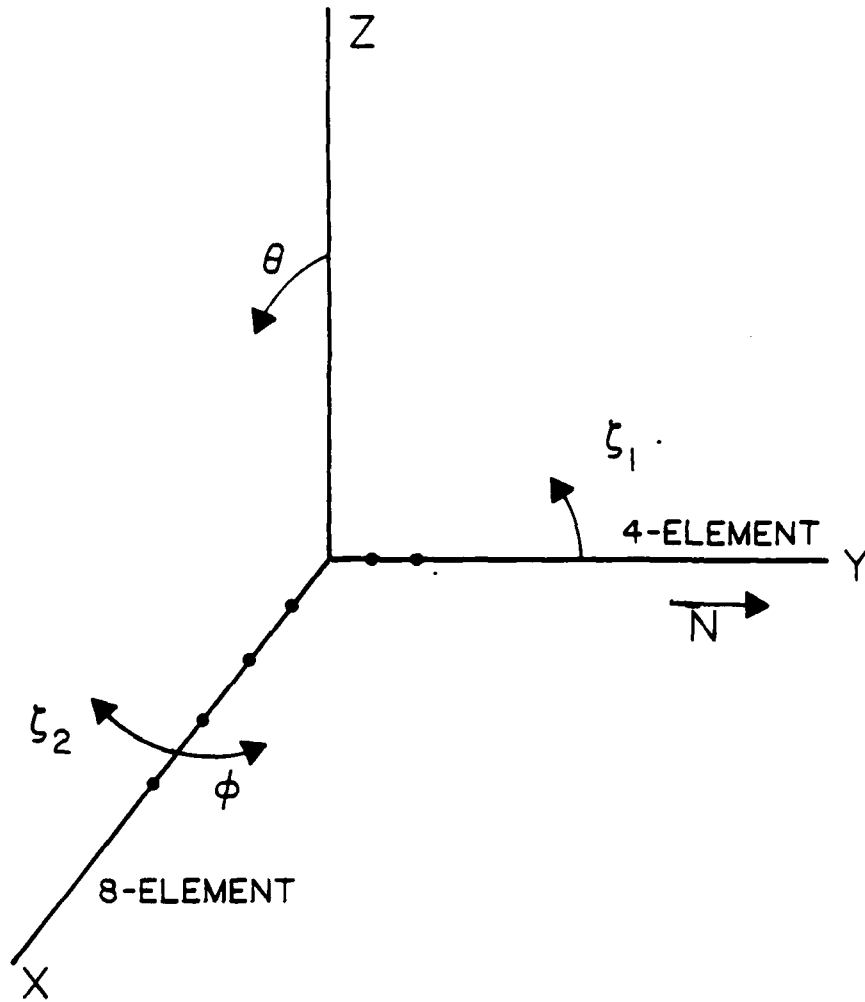


Figure 1-8 Orientation of 4- and 8-element arrays

and the directive gain is a ratio, these same constants must also be neglected in calculation of the average radiated power. Thus the calculation of the average radiated power becomes the correction factor necessary to convert the array power pattern to an array directivity pattern.

Equation (1-17) was used to calculate the average radiated power, W_T .

$$W_T = \int_0^{2\pi} \int_0^{\pi/2} \frac{[AF(\theta, \phi)]^2 \times 10 (ELF(\theta, \phi)/10) \sin \theta d\theta d\phi}{4\pi} \quad (1-17)$$

ELF(θ, ϕ) = Elemental Power gain from interpolated AMP output

AF(θ, ϕ) = Total Array Factor

The integration was performed numerically using Simpson integration, equation⁶ (1-18). The programs are given in Appendix I, programs 2 and 3.

$$\int_a^b f(x)dx = (\Delta x/3) [f(x_0)+4f(x_1)+2f(x_2)+4f(x_3)+2f(x_4)+\dots \quad (1-18)$$

$$+2f(x_{2n-2})+4f(x_{2n-1})+f(x_{2n})]$$

$$\Delta x = (b-a)/(2n)$$

The first quadrant integration was carried out for two cases. One case was with a "phi" step size of 2.5 degrees; the other case was with a "phi" step size of 1 degree. A "theta" step size of 1 degree was used in both cases. No significant difference was found in the result of the integrations. Based on this result, the step sizes chosen for the total integral were 1 degree and 2.5 degrees for "theta" and "phi" respectively. The correction factors determined were 9.82 db and 8.62 db for 5.1 MHz and 3.17 MHz respectively.

Equation (1-19) combines the total array factor AF, the elemental pattern ELF, and the correction factor to calculate the directive gain pattern for the A.O. heating array.

$$D(\theta, \phi) = 20 \log[AF(\theta, \phi)] + ELF(\theta, \phi) - \text{Correction factor} \quad (1-19)$$

Figure (1-9) is a plot of the pattern in the "phi" equal zero plane (north-south plane). The "x's" are experimentally measured values.⁷ The values were measured from a Boeing 707 aircraft at 2900 ft (8.84 km). The plane was flown over the A.O. array on a north-south line, while the heater was operating at 5.1 MHz. The plot shows that the array pattern obtained by the combination of pattern multiplication and numerical techniques is a good approximation of the A.O. array pattern.

Figures (1-10) and (1-11) are plots of the directivity pattern of the A.O. heater array for 3.17 MHz and 5.1 MHz respectively. Each plot is the variation of the directive gain with "theta" in a constant "phi" plane. "Phi" is varied in 5 degree steps from 0 degrees to 180 degrees. Two additional "phi" plane patterns have been plotted in figures (1-12) and (1-13). These two figures are the directivity patterns in the "phi" equal 121.5° and 146° planes respectively. These patterns are in planes corresponding to the direction of Los Canos and the A.O., respectively. The programs used to make the directivity patterns are given in Appendix I, programs 4 and 5 for 3.17 MHz and 5.1 MHz respectively.

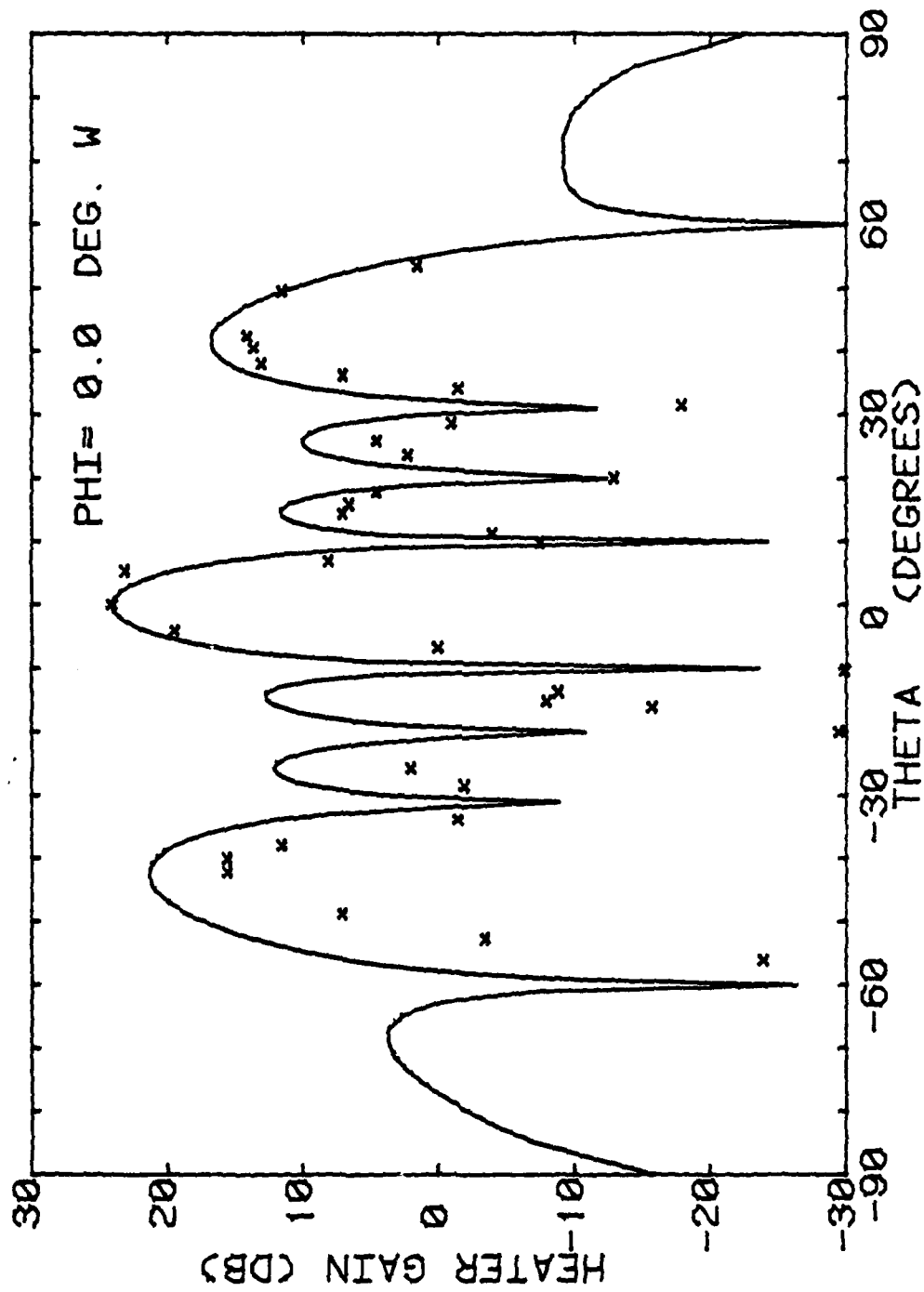
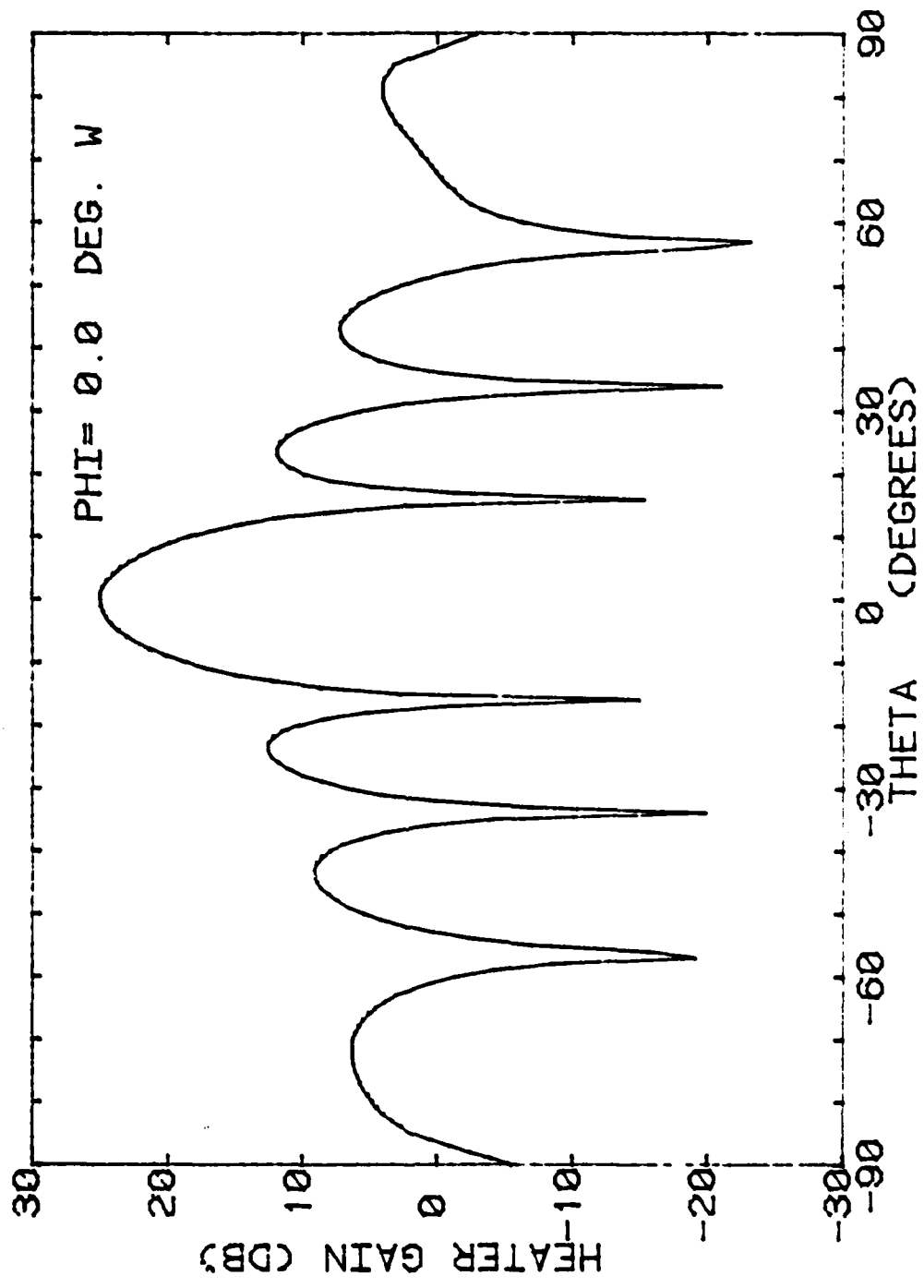
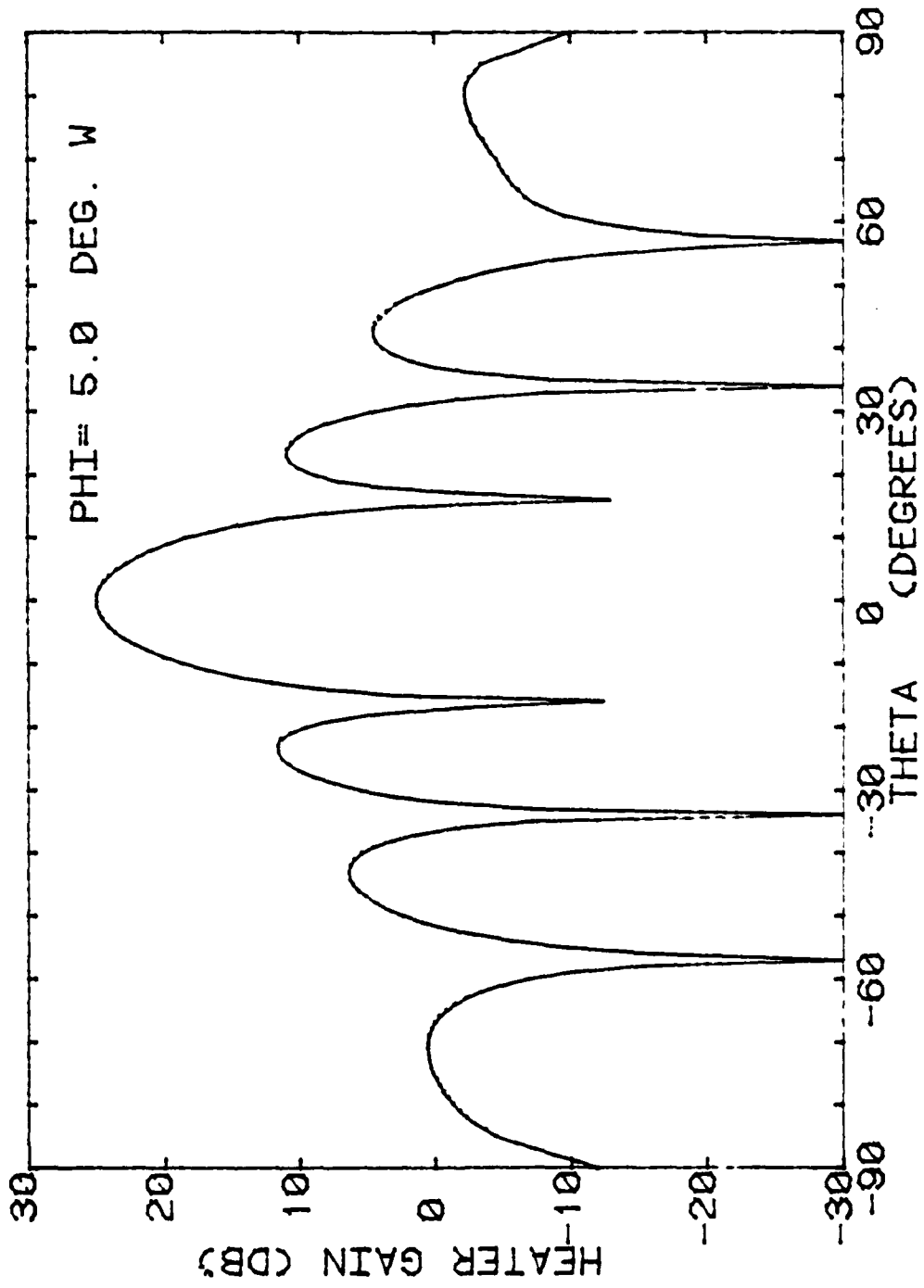
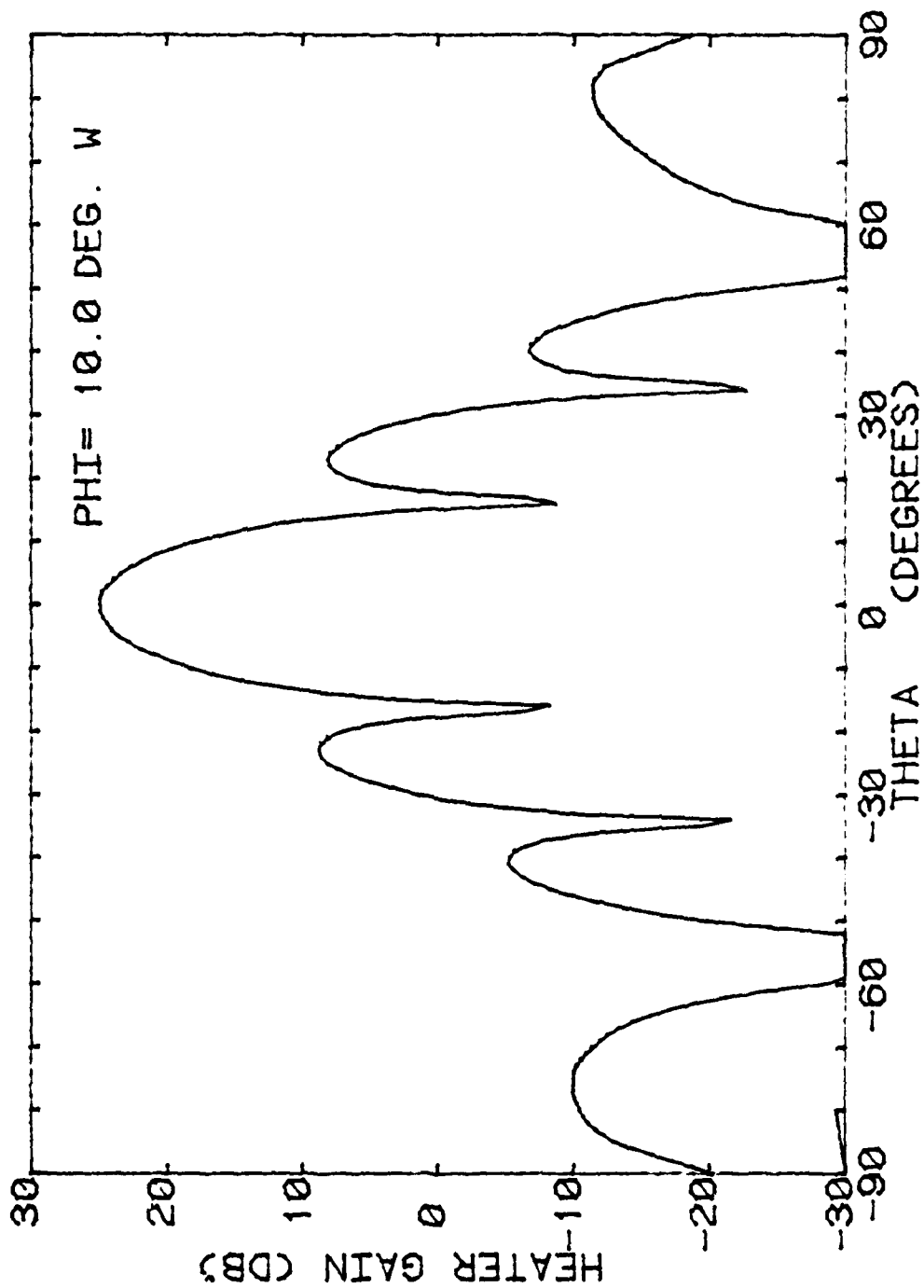


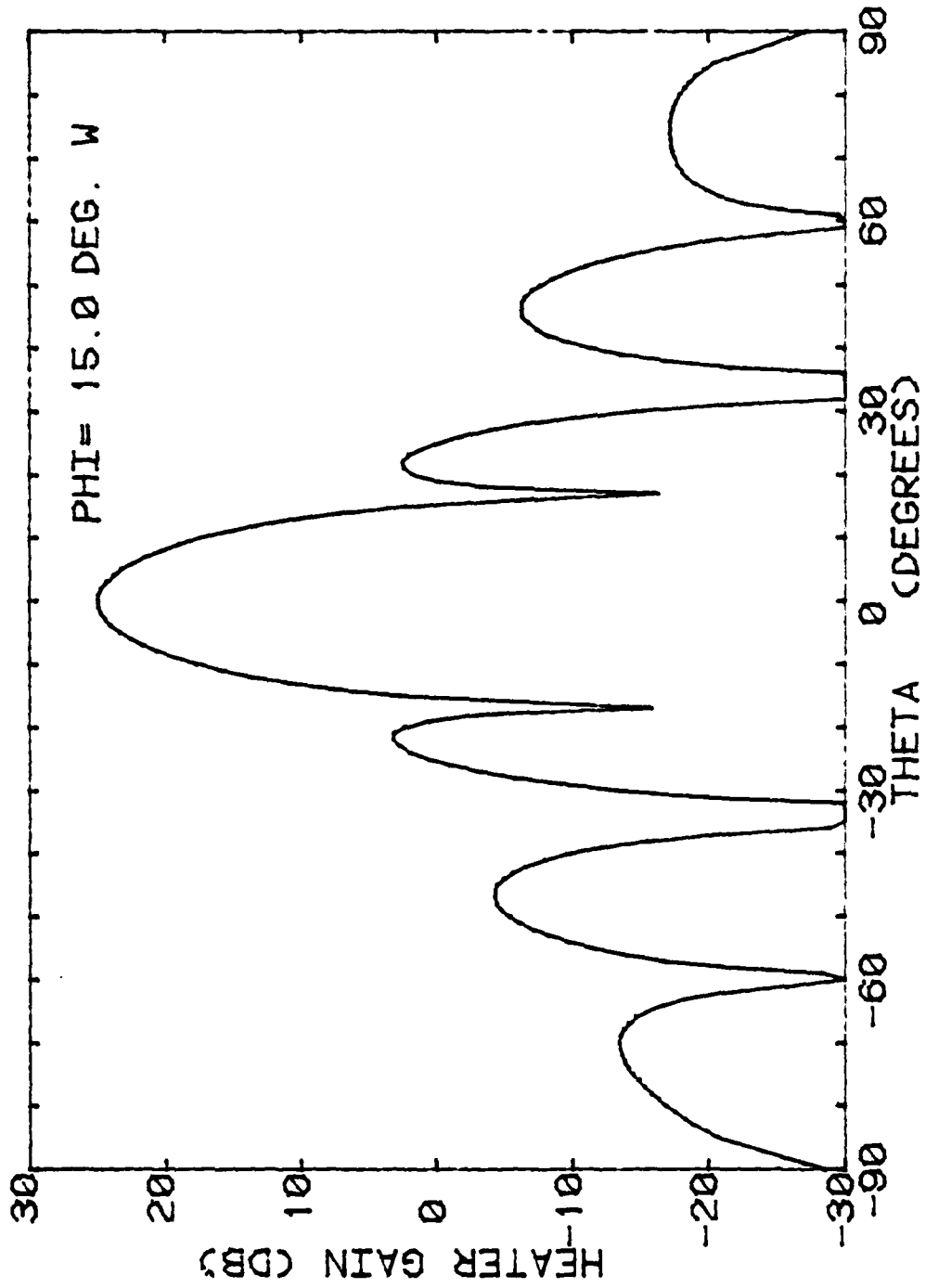
Figure 1-9 Comparison of experimental and theoretical patterns

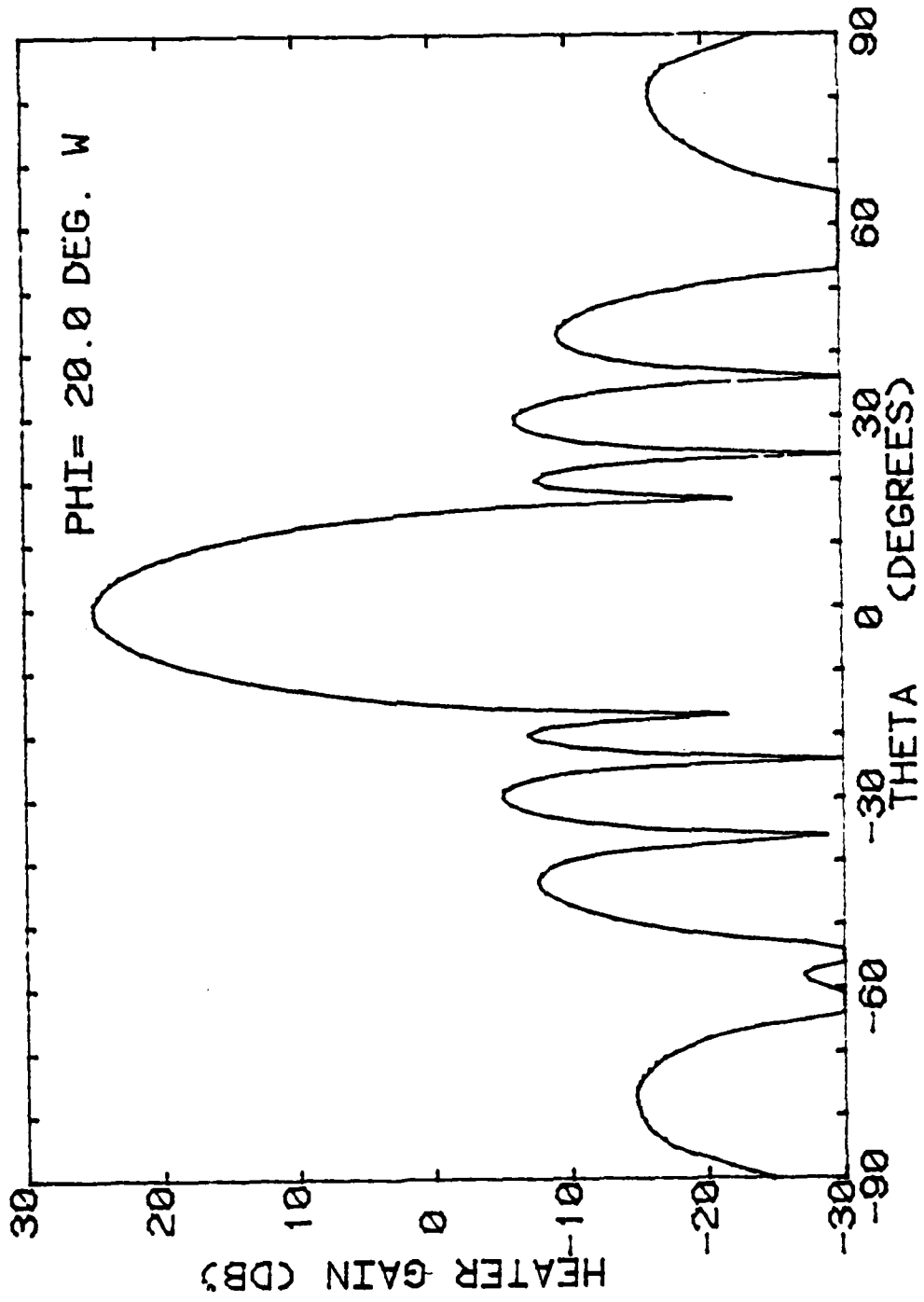
Figure 1-10 Directive gain pattern for Arecibo Observatory
HF heating array. Frequency = 3.17 MHz.

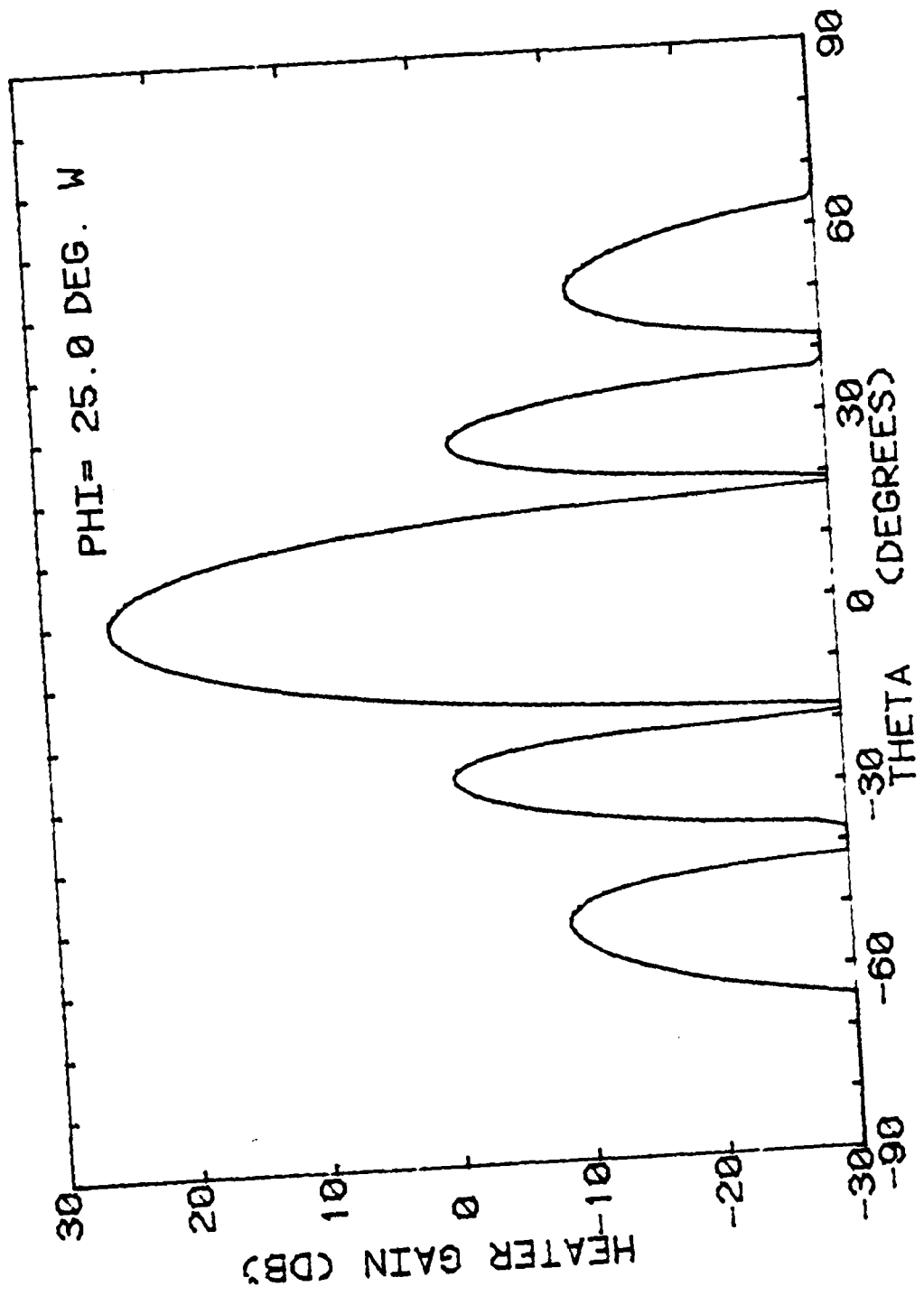


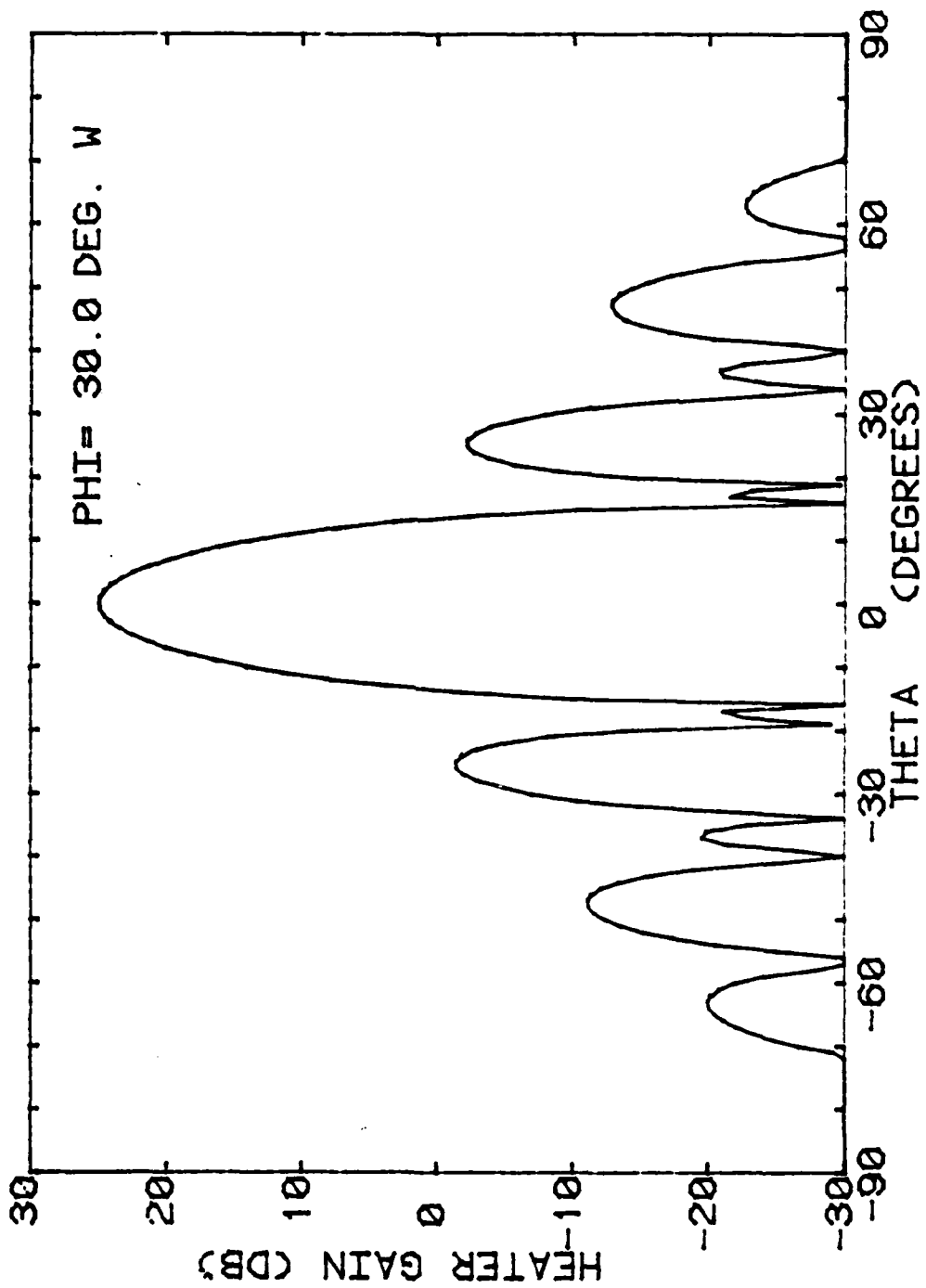


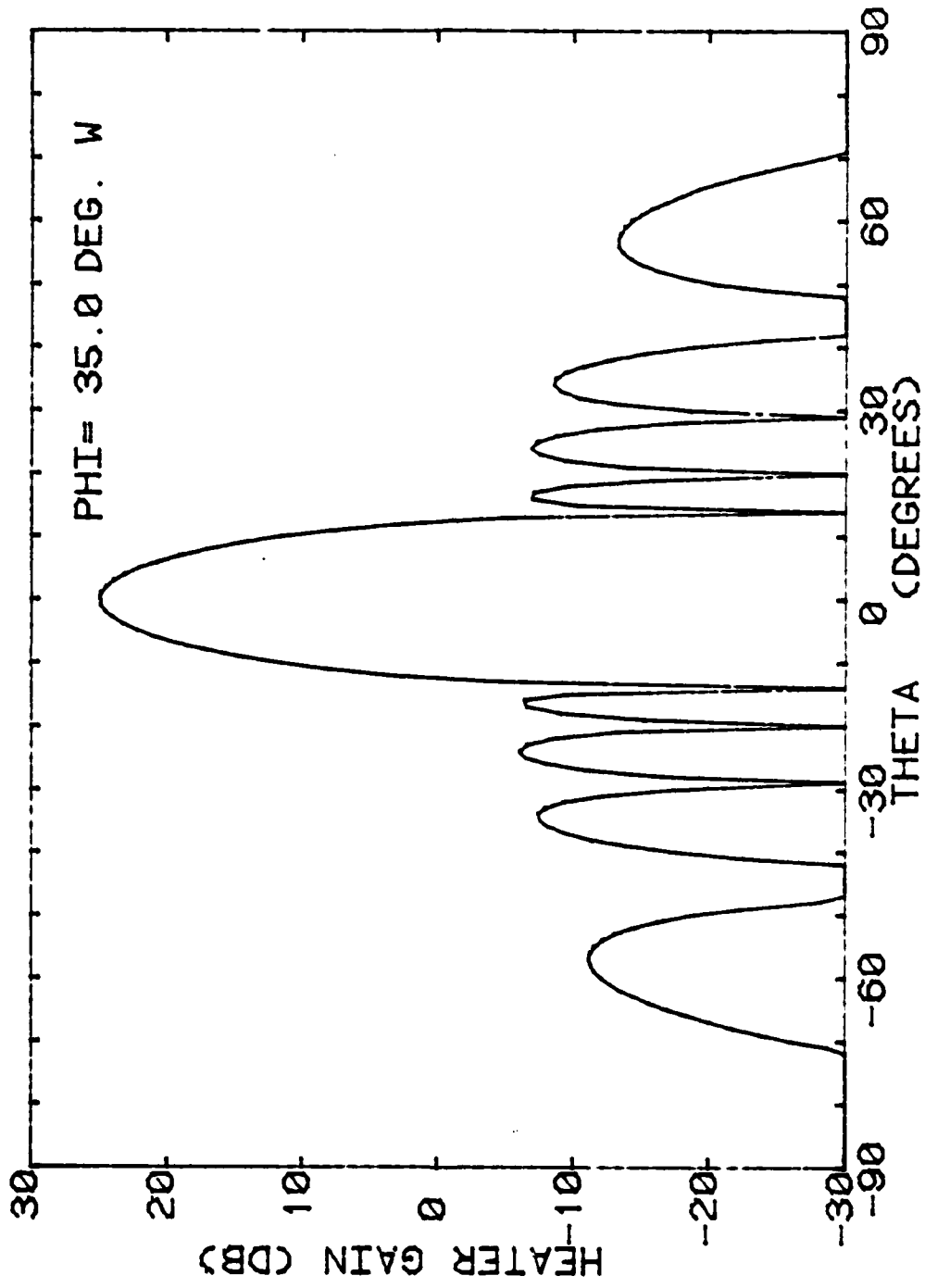


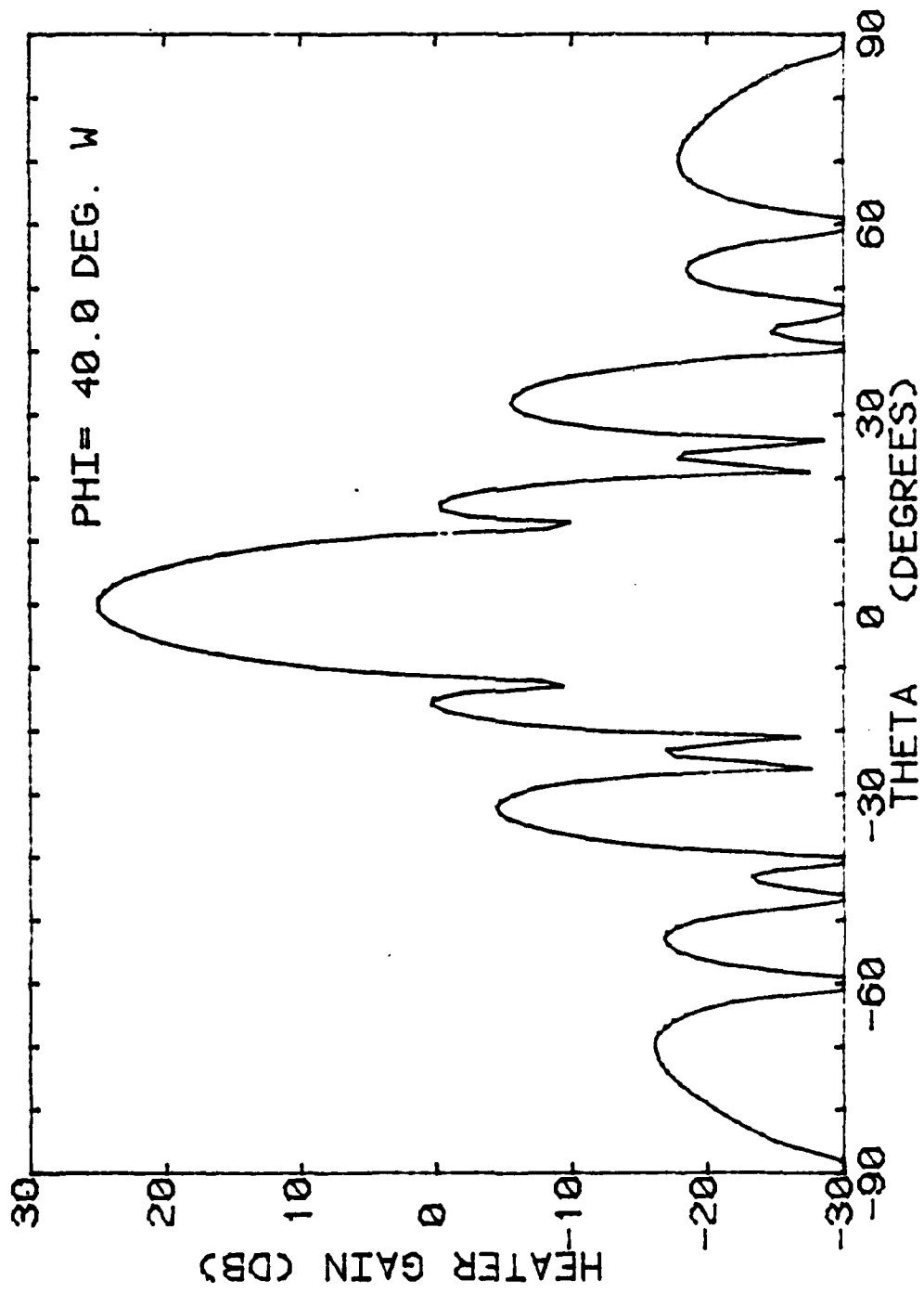


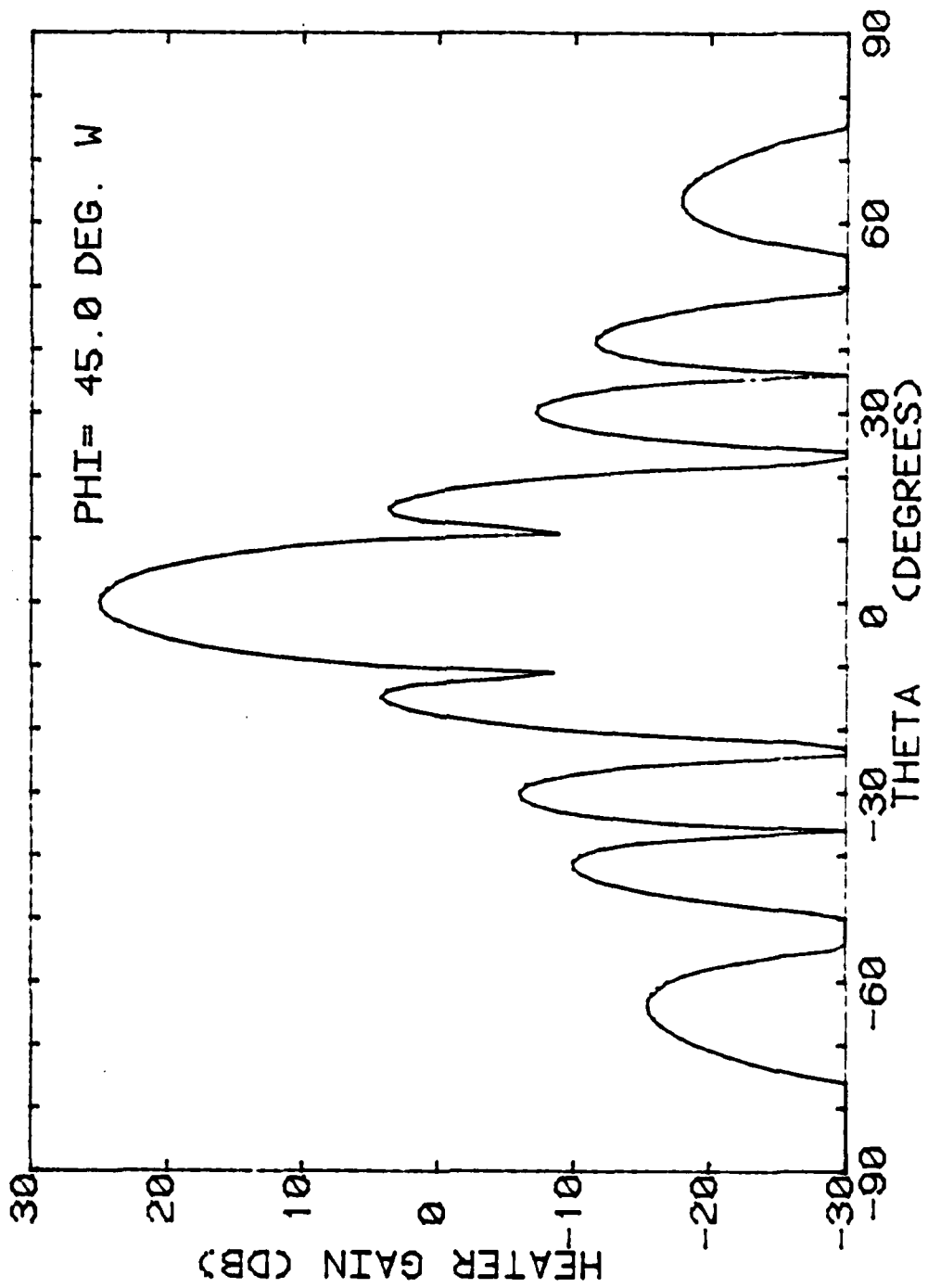


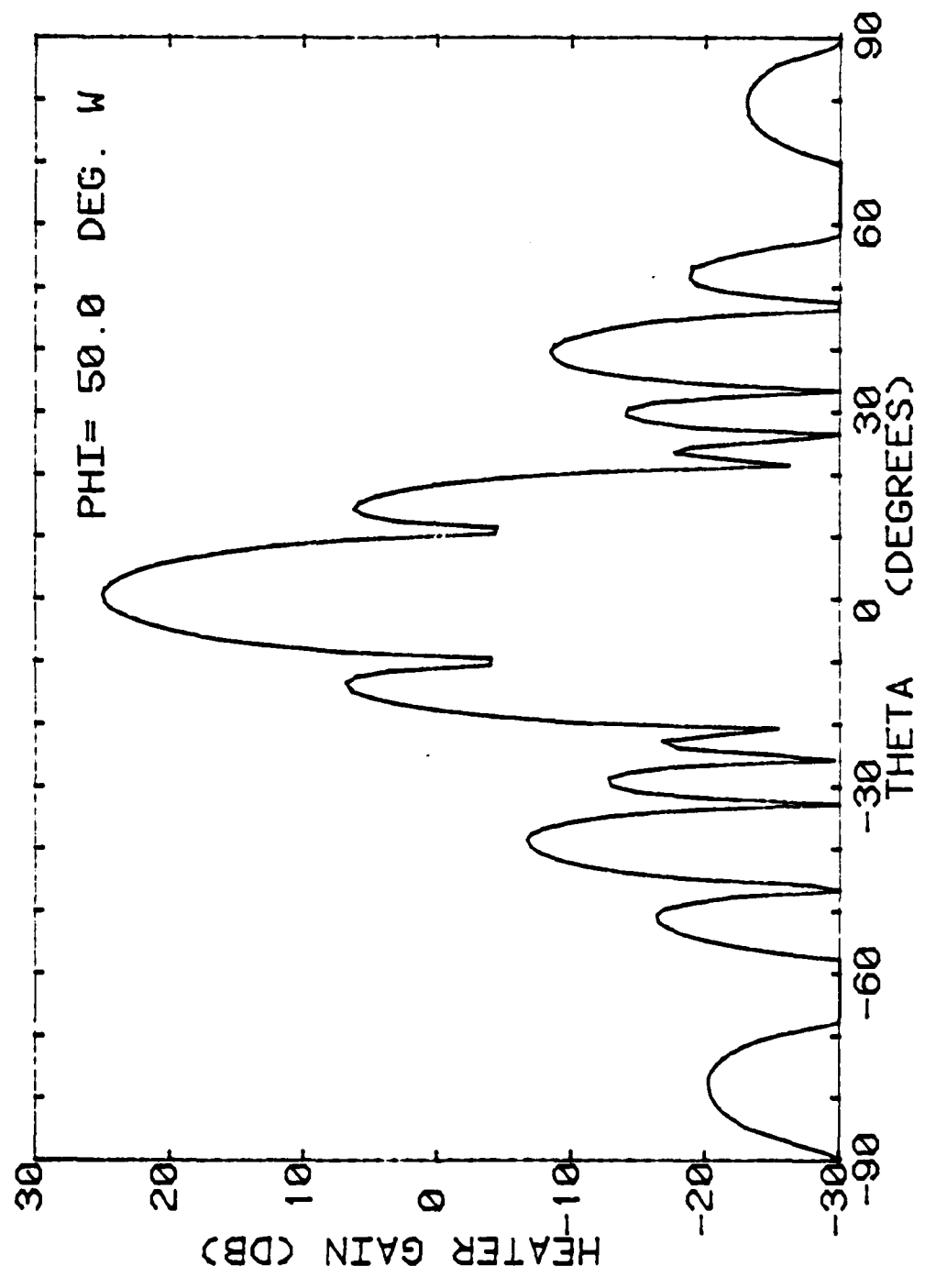


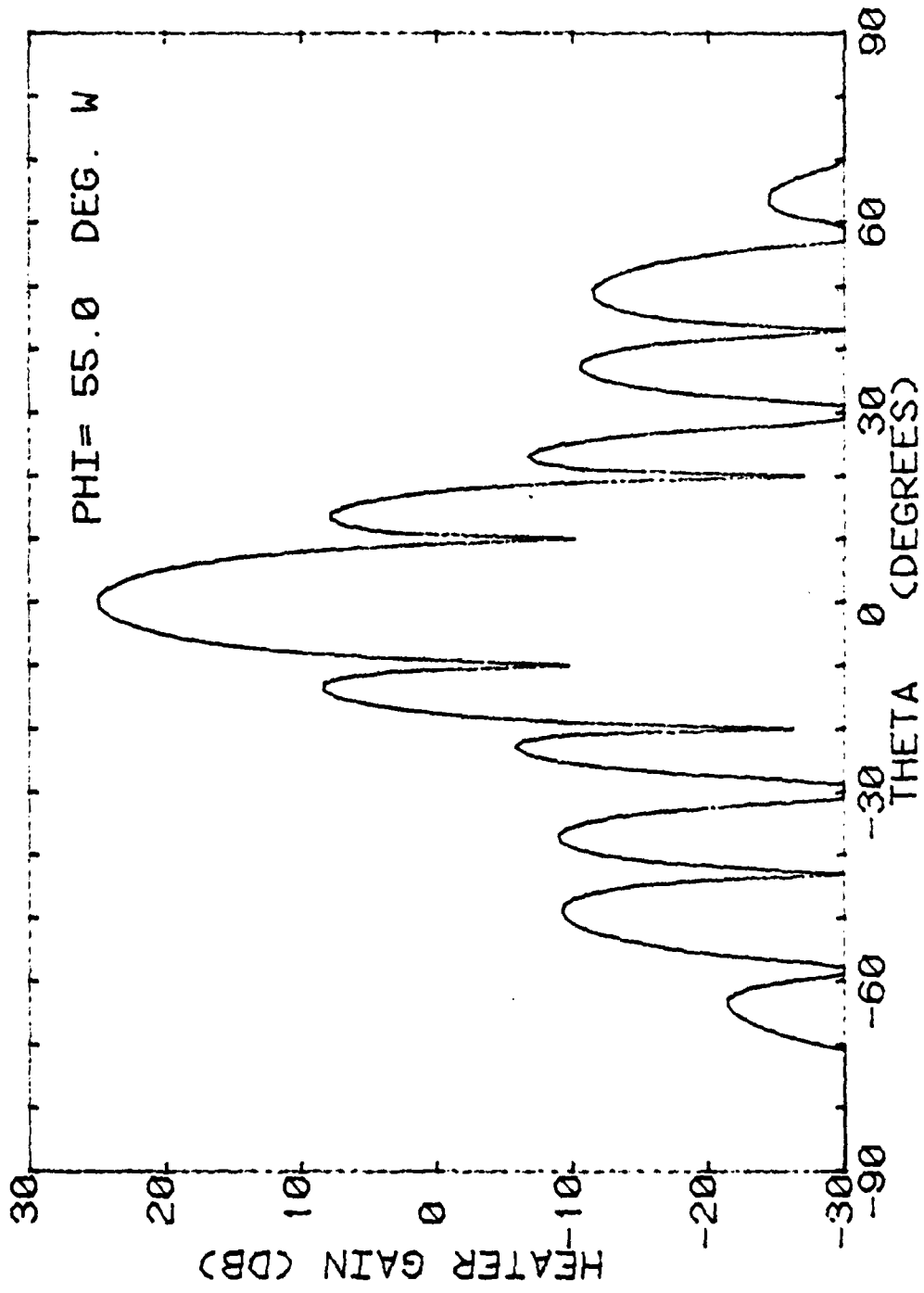


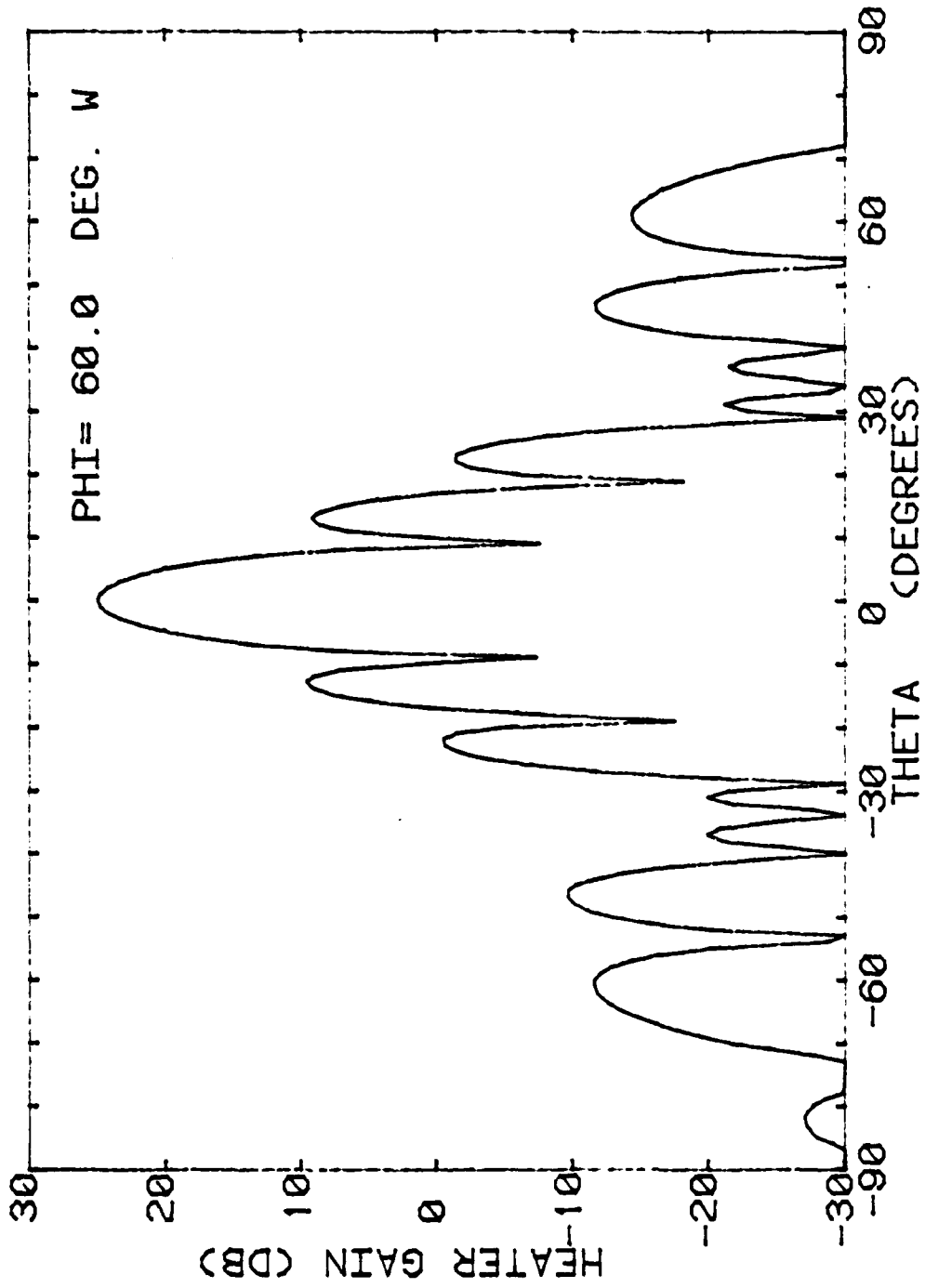


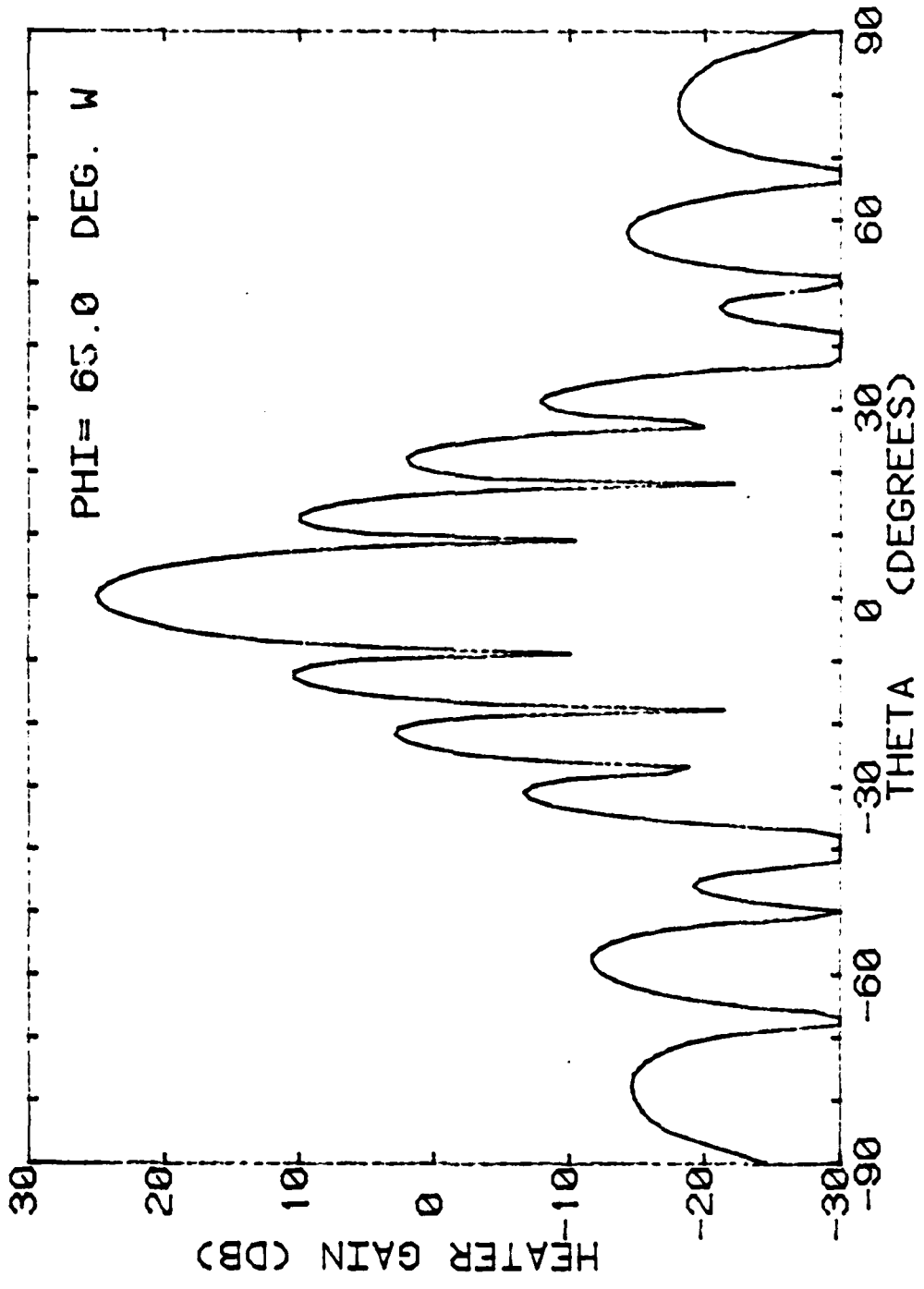


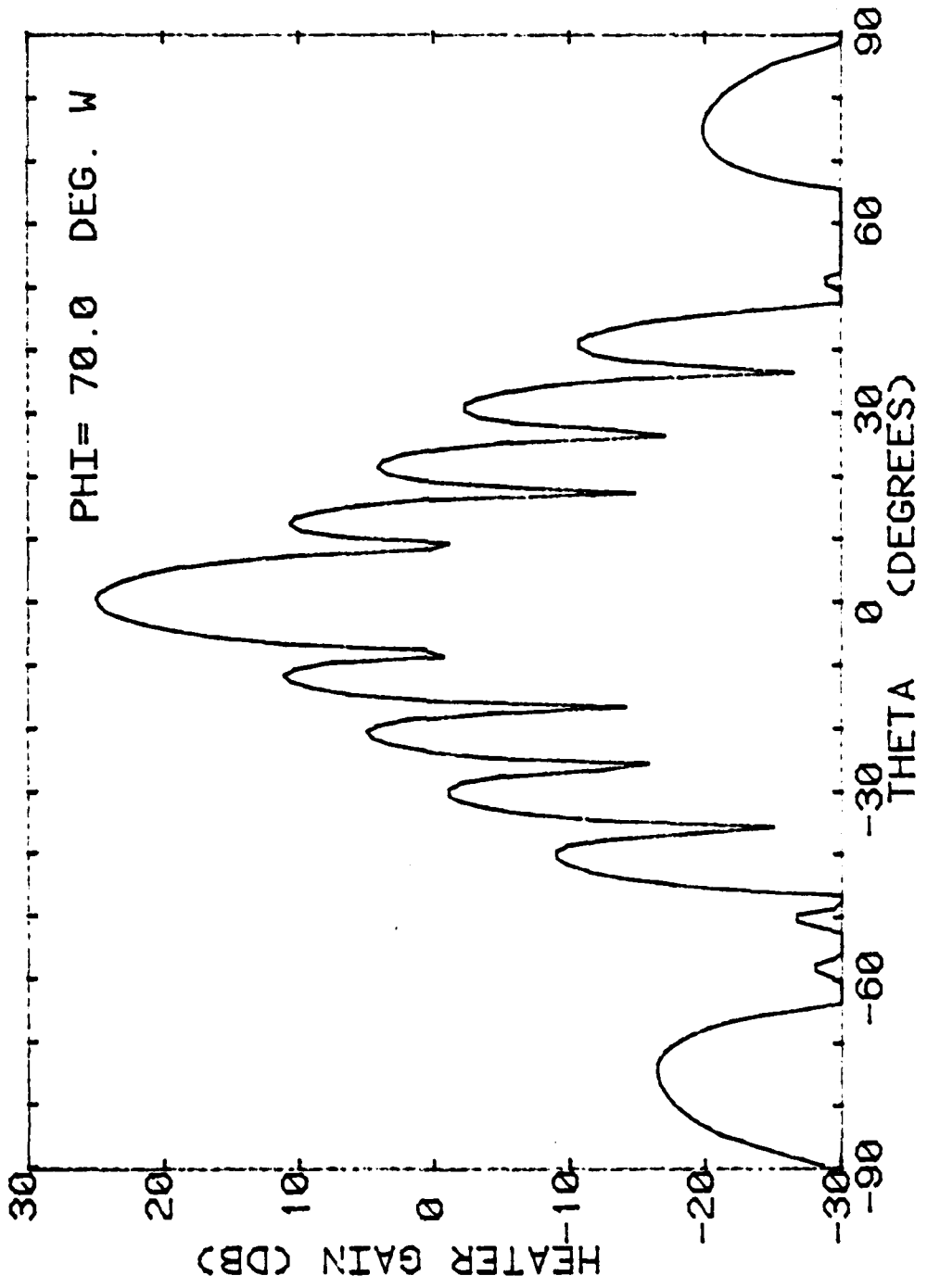


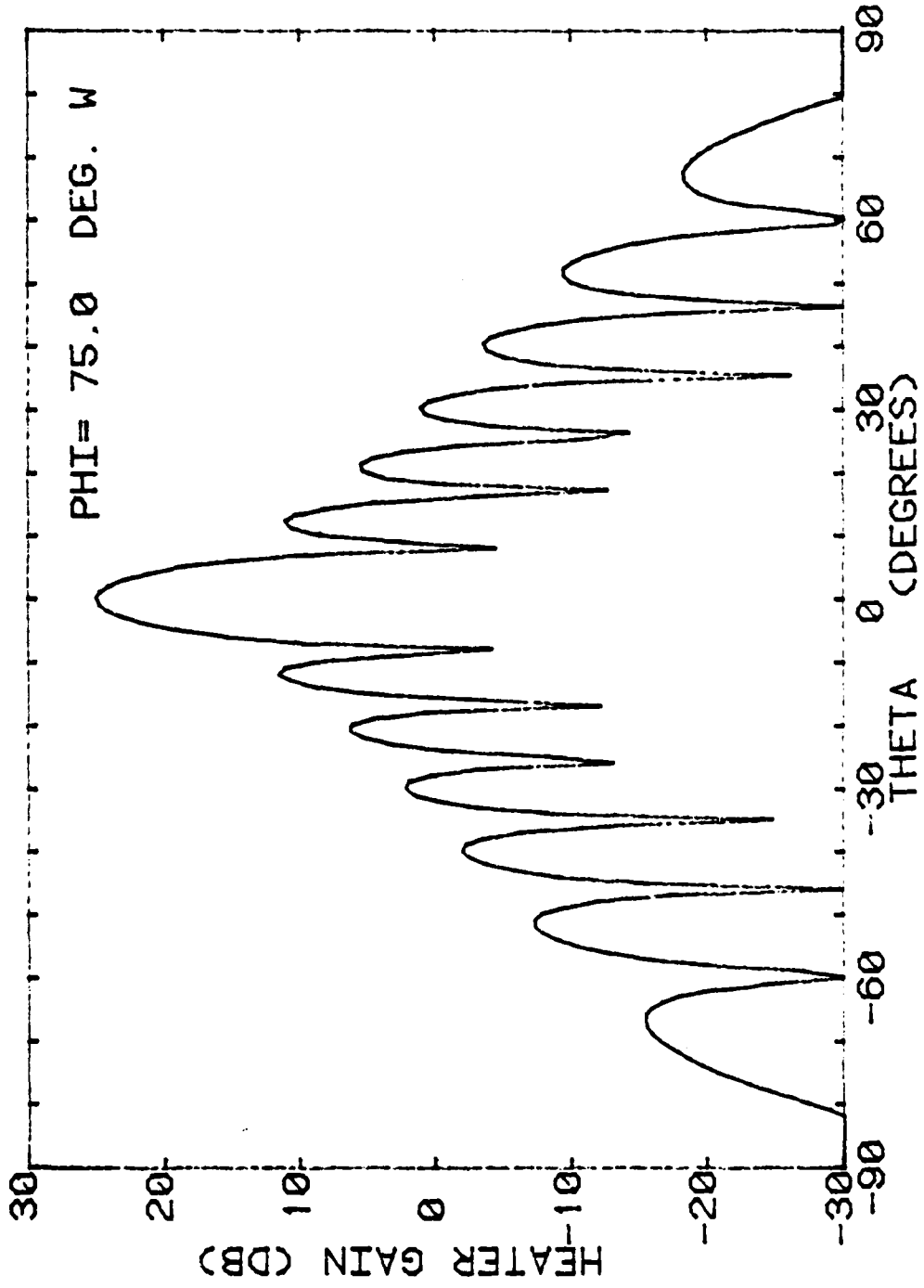


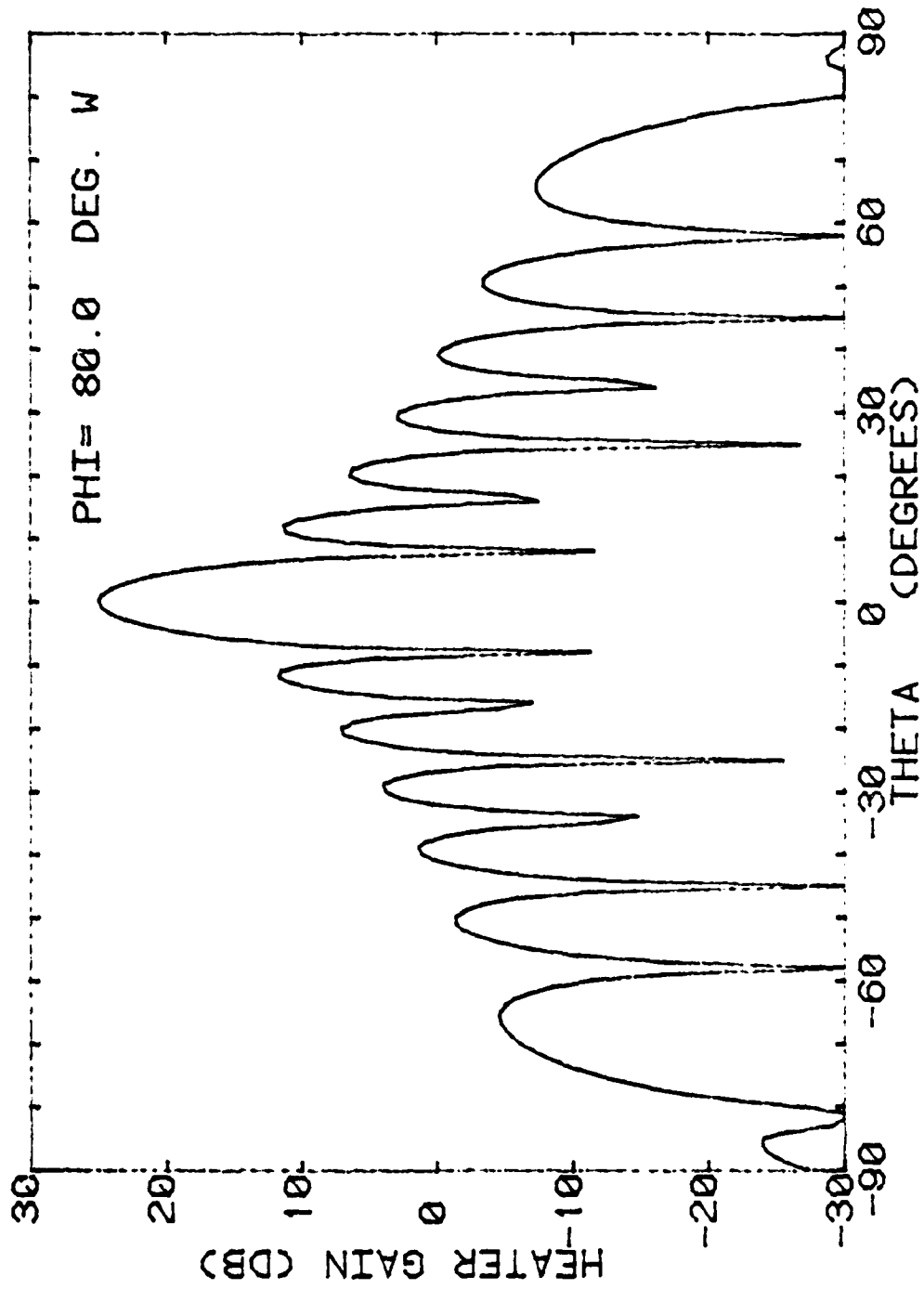


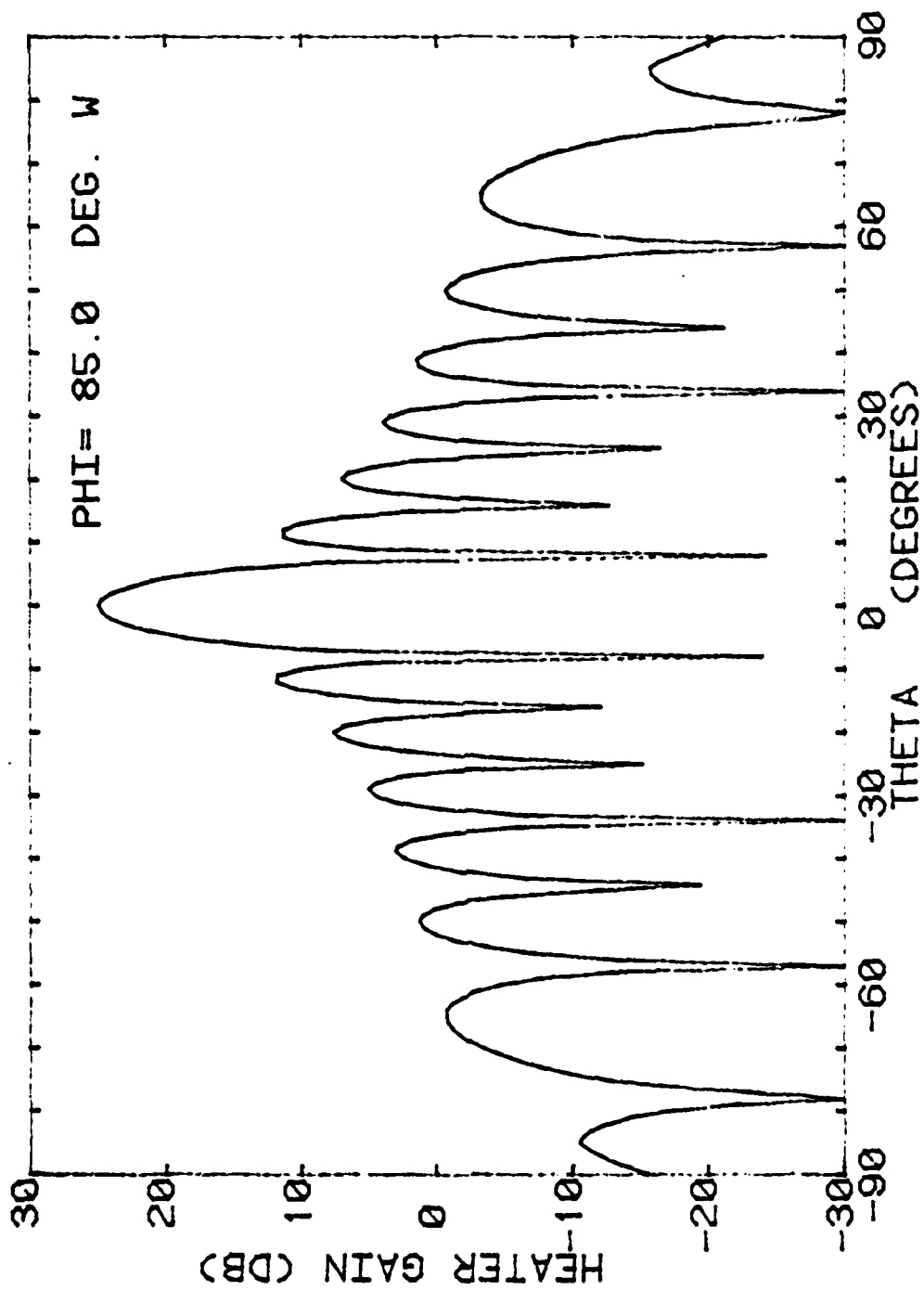


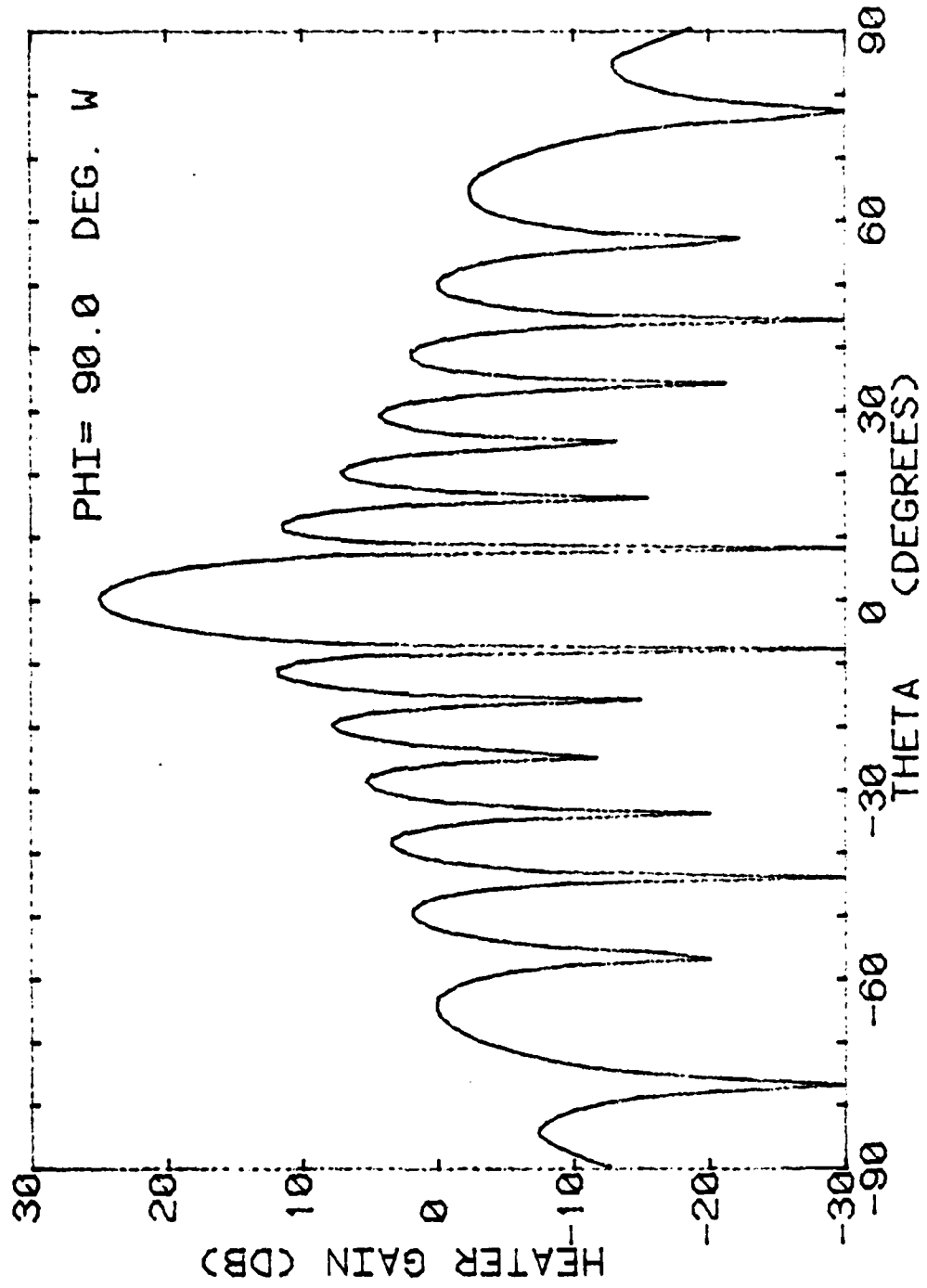


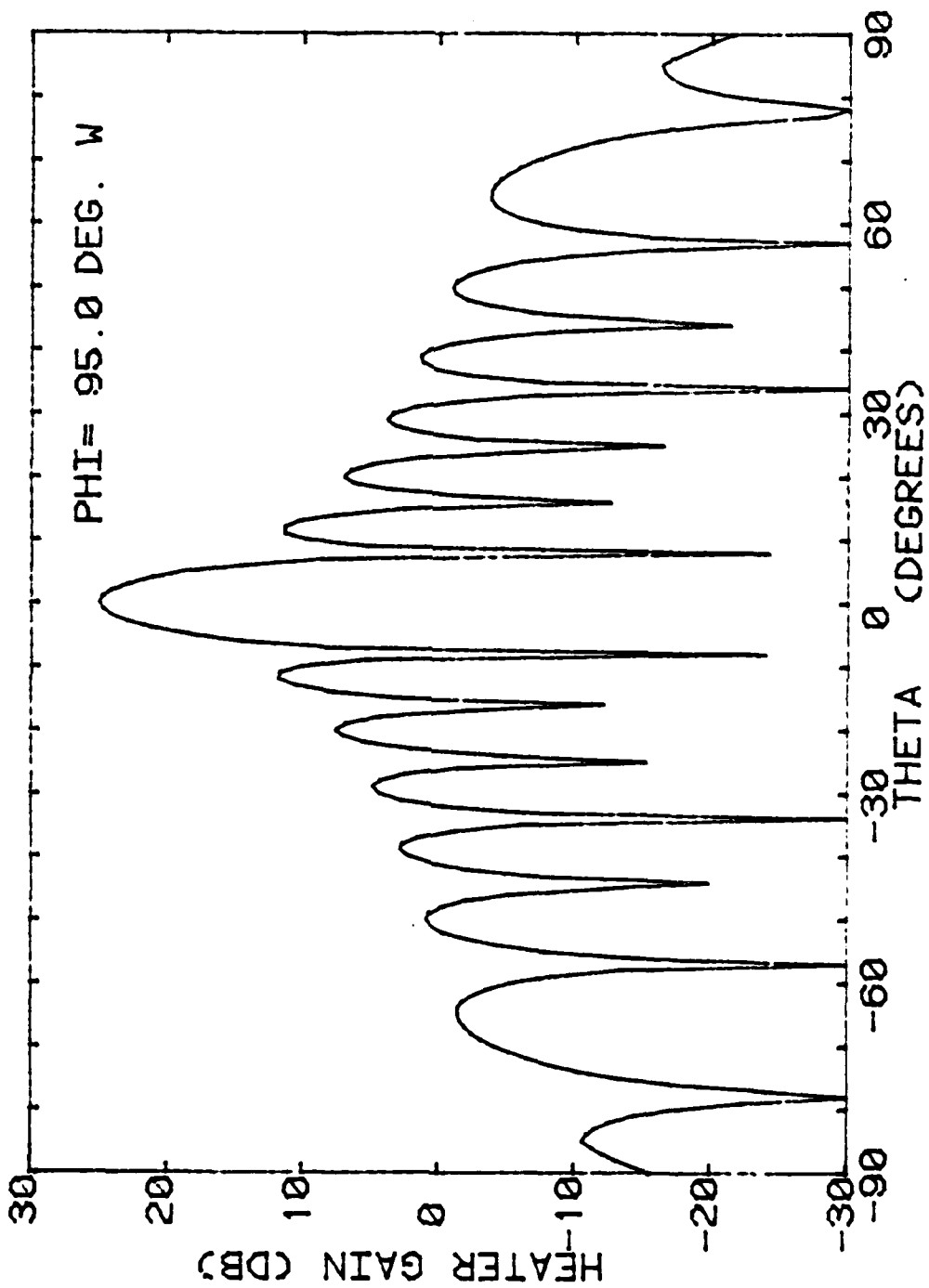


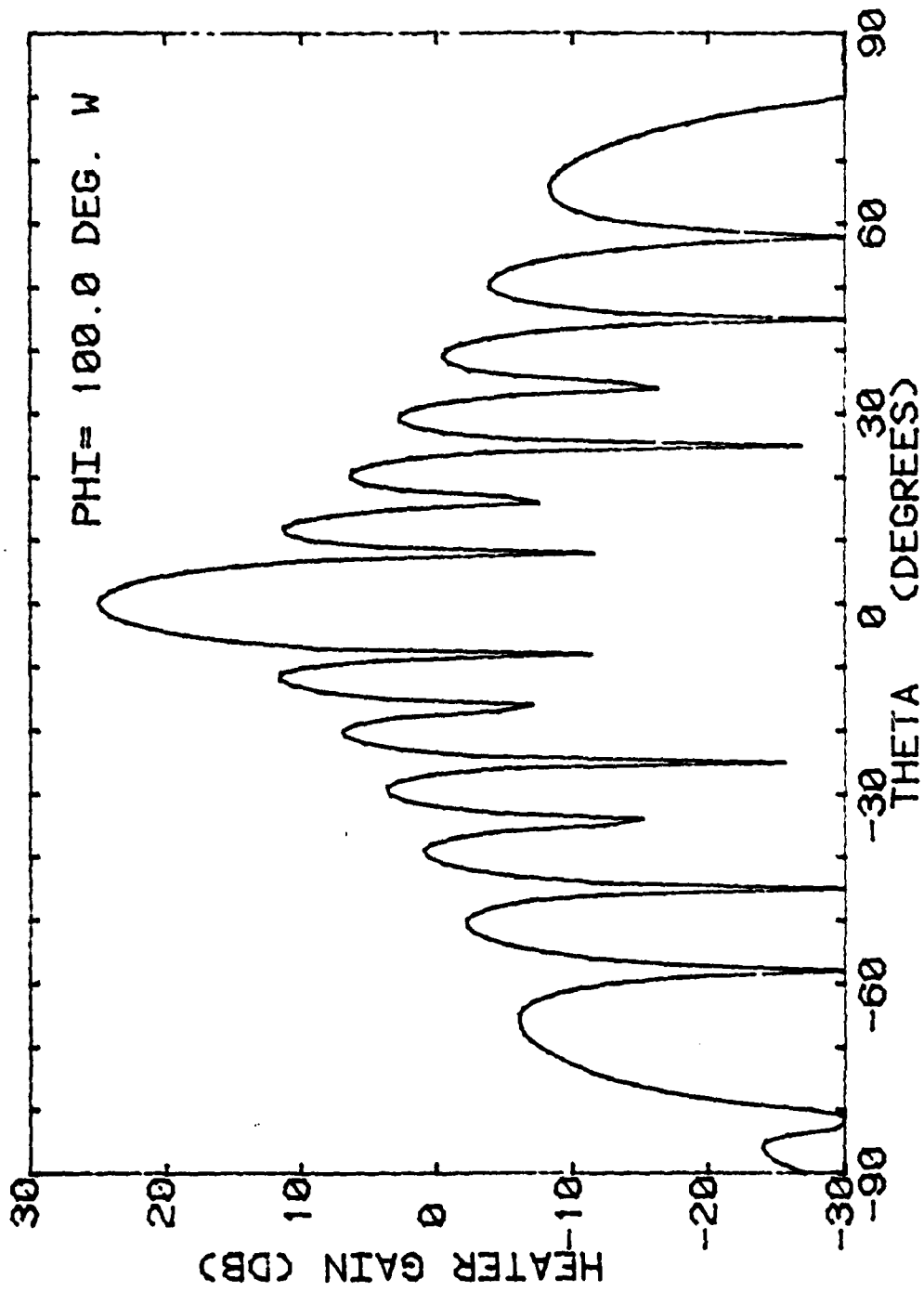


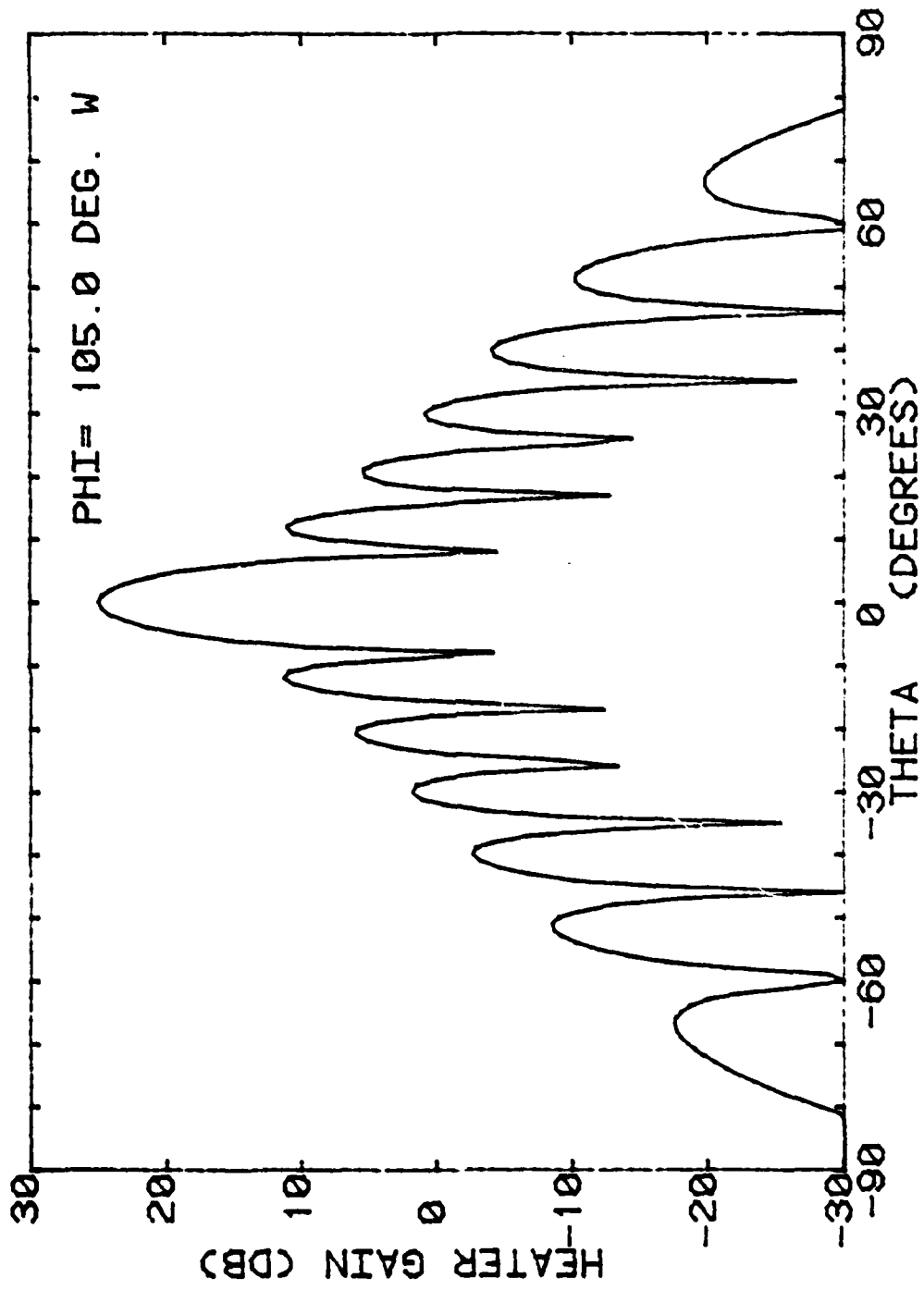


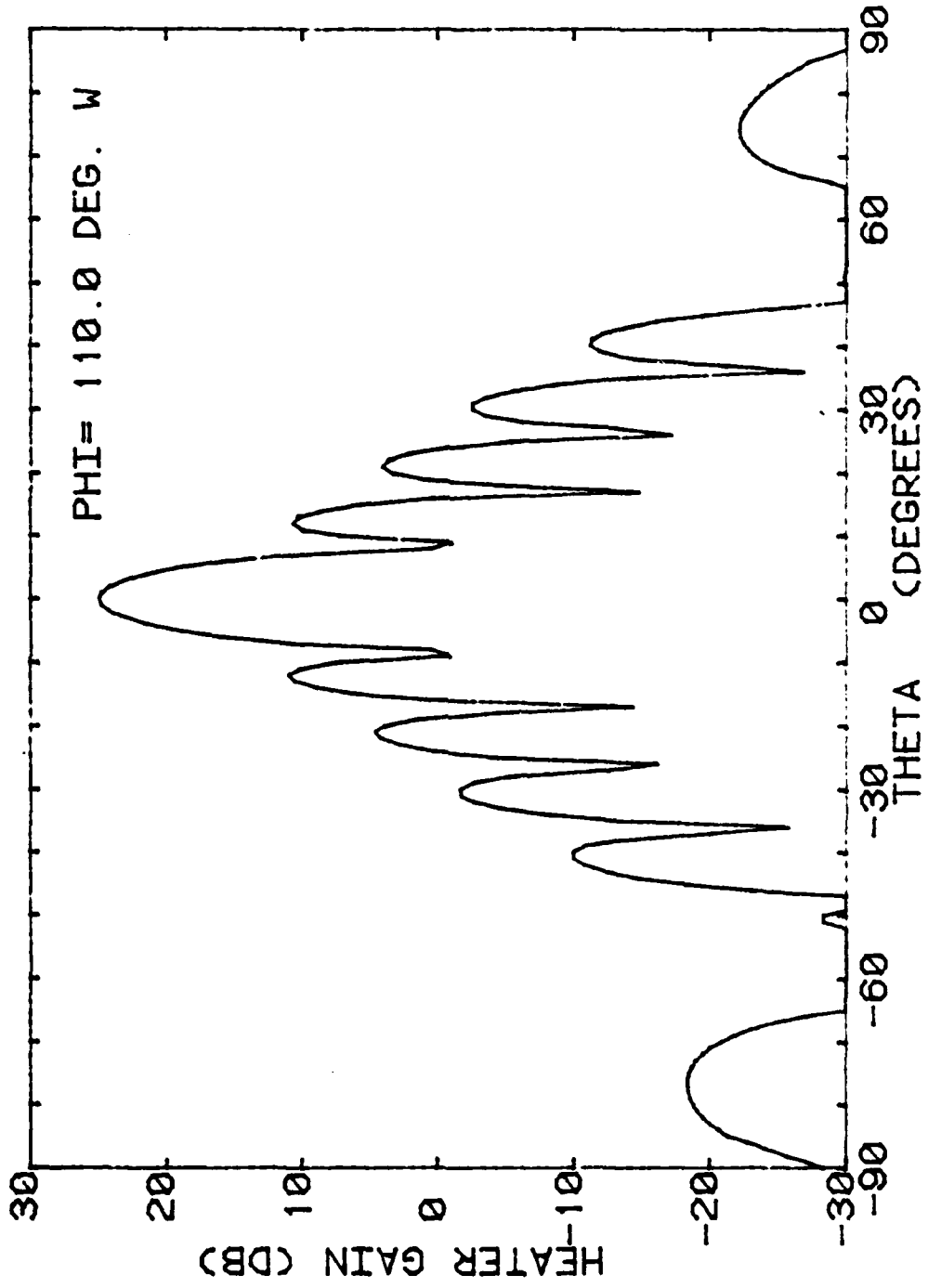


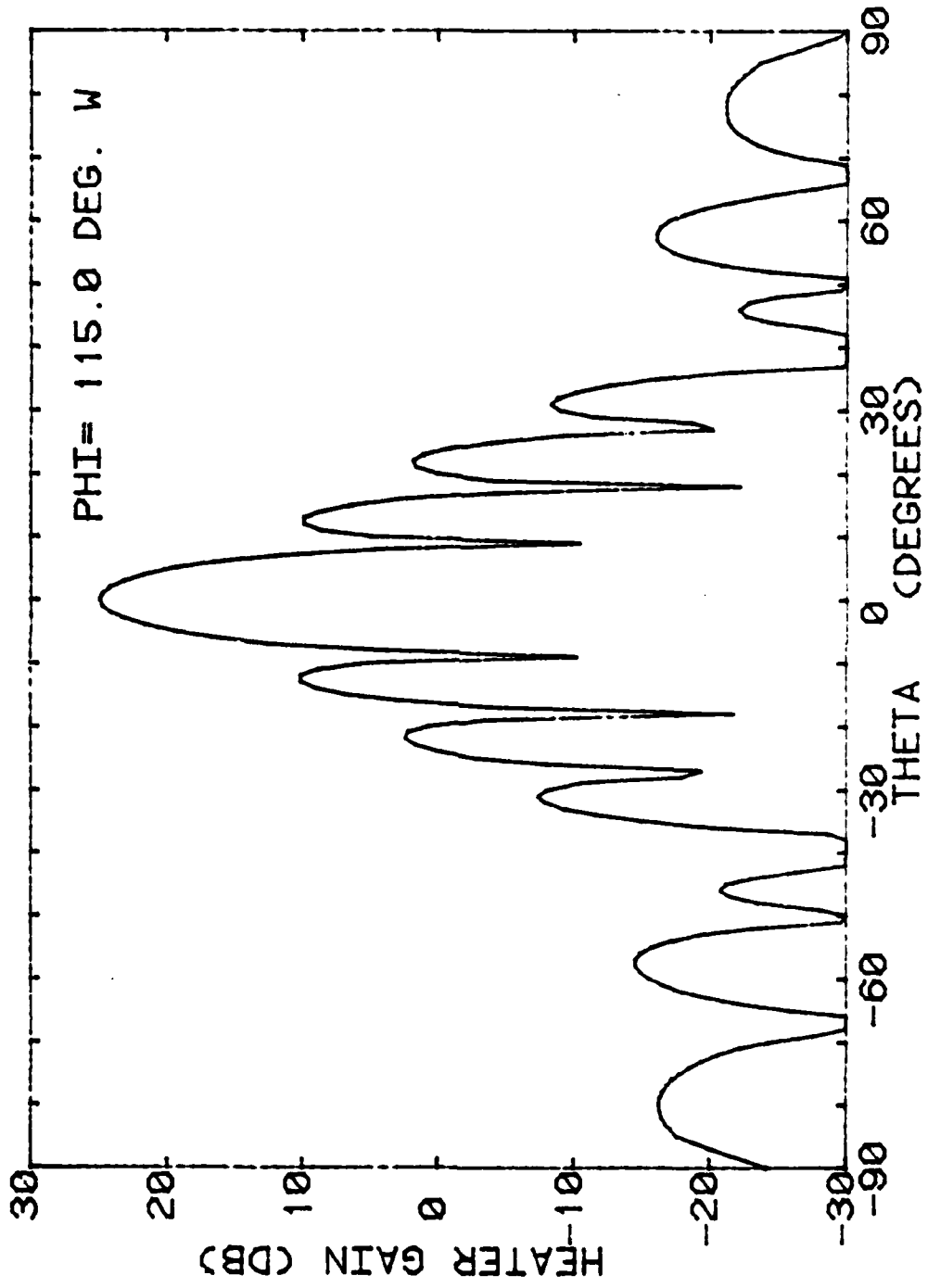


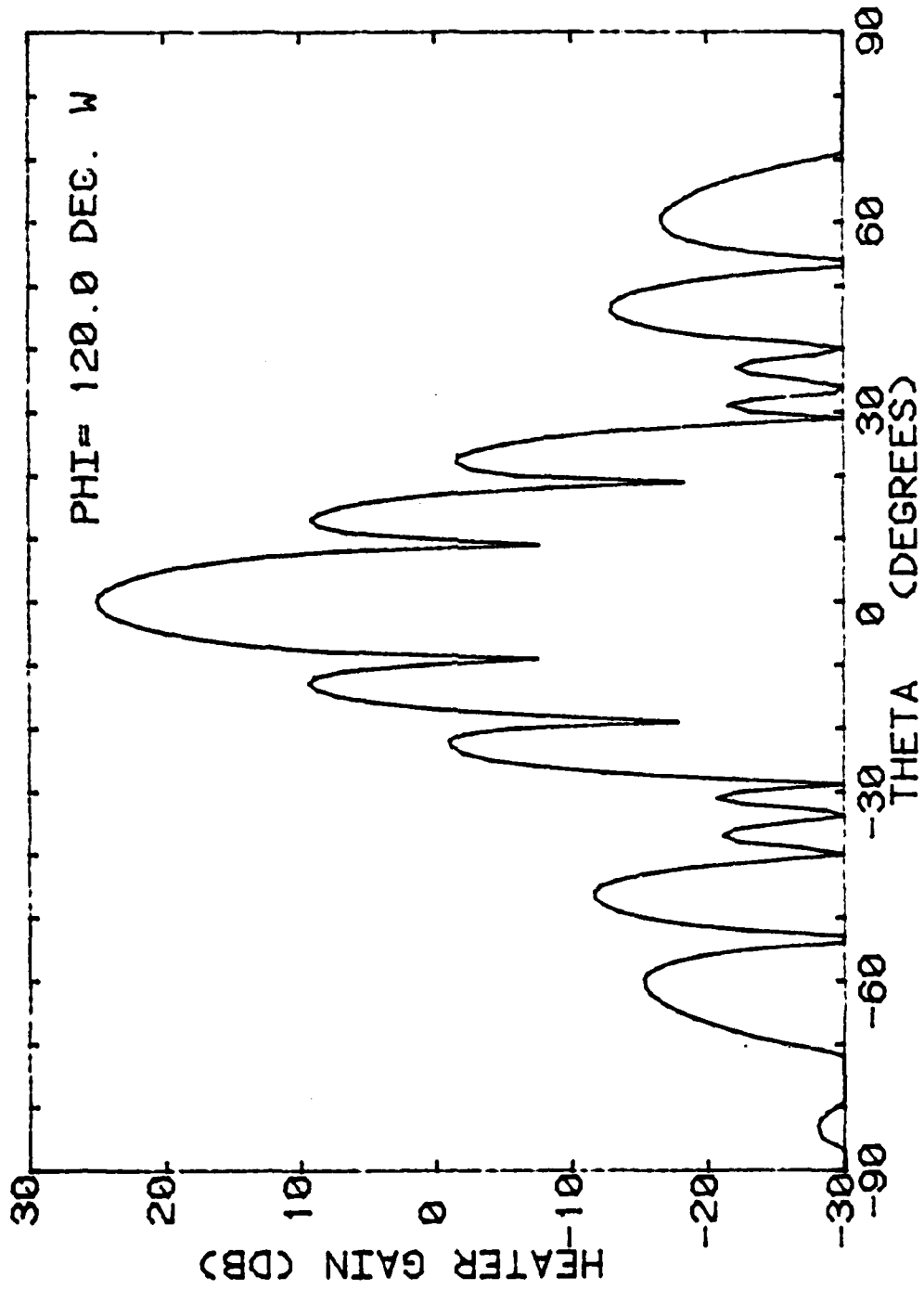


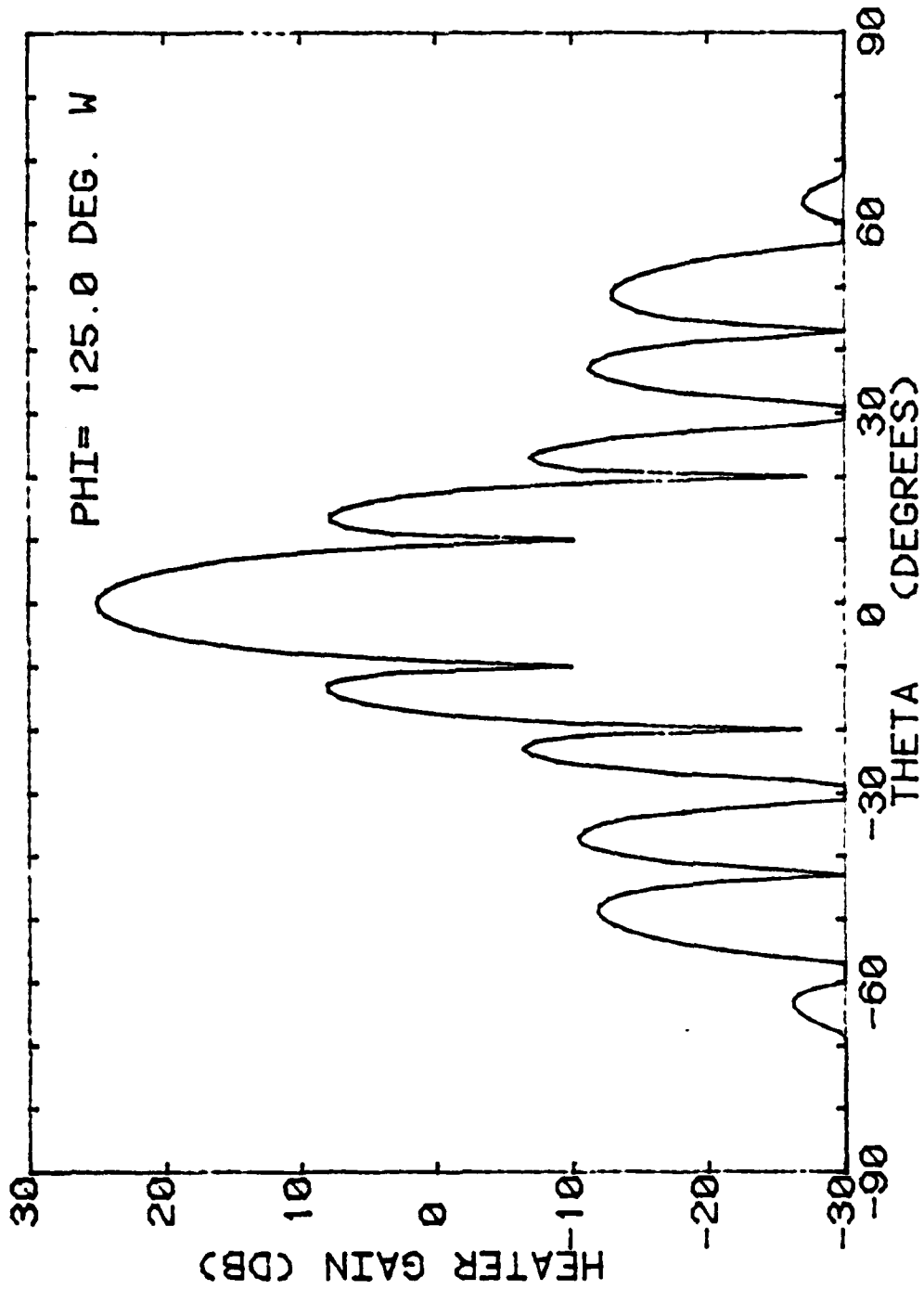


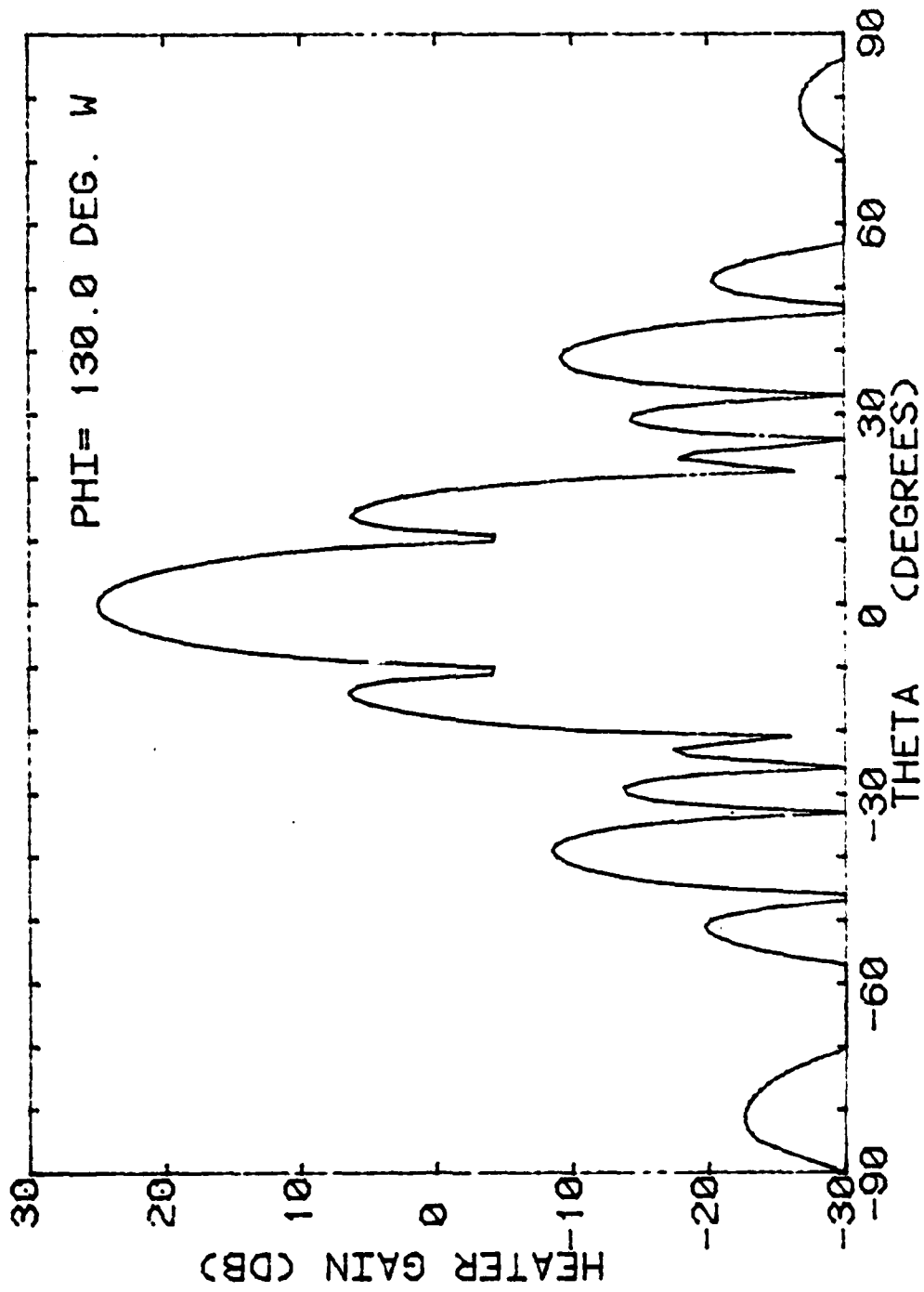


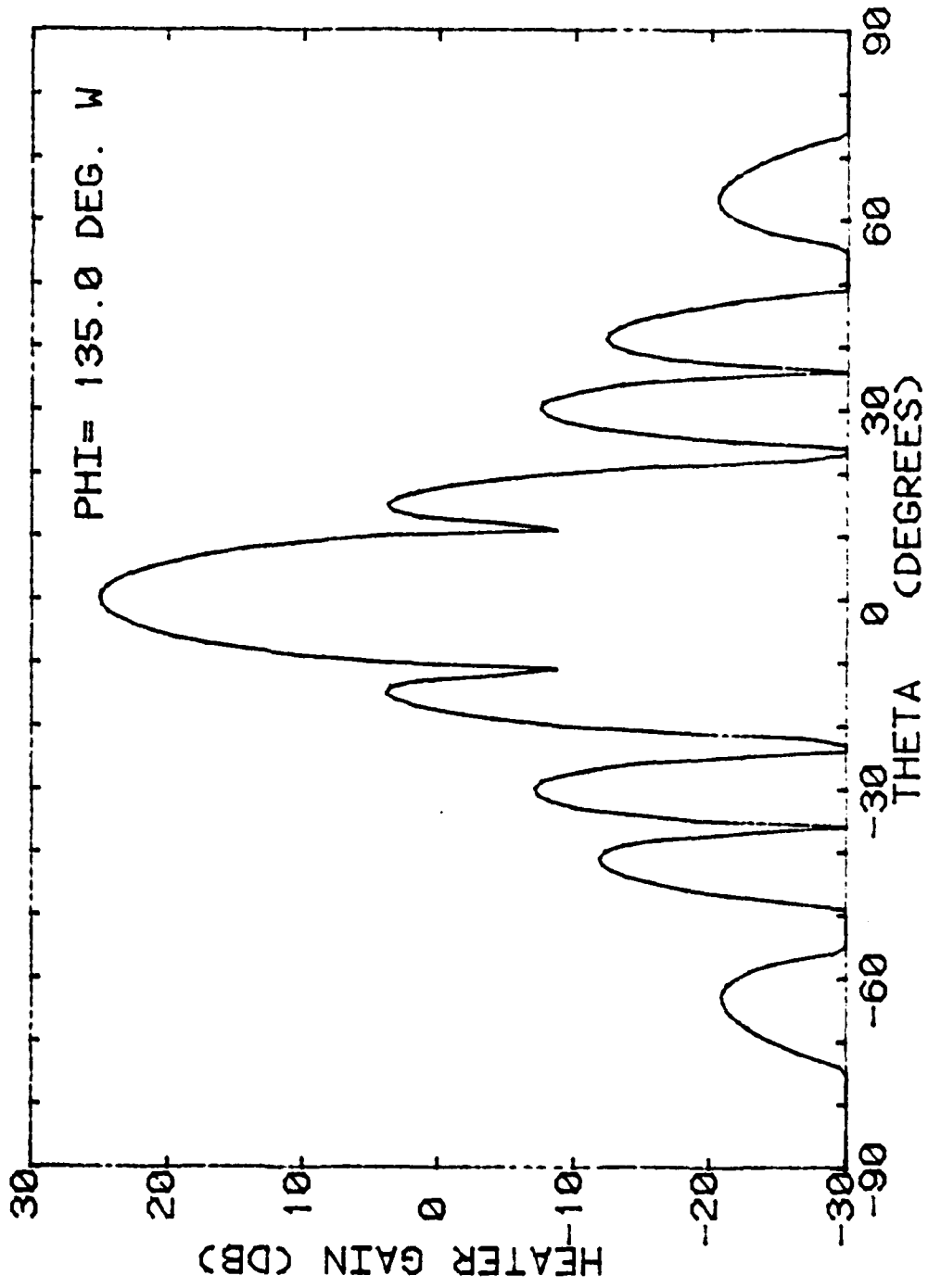


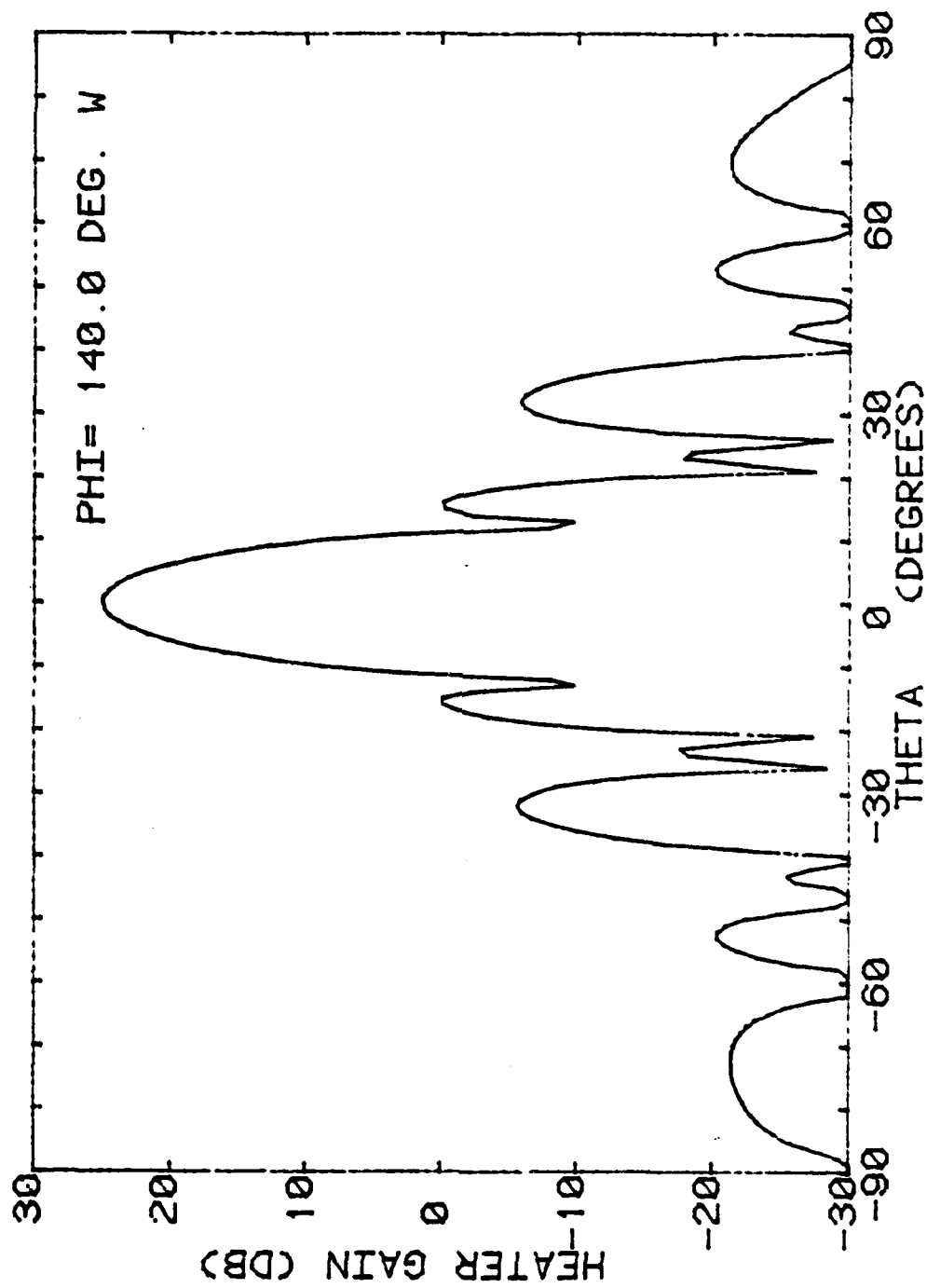


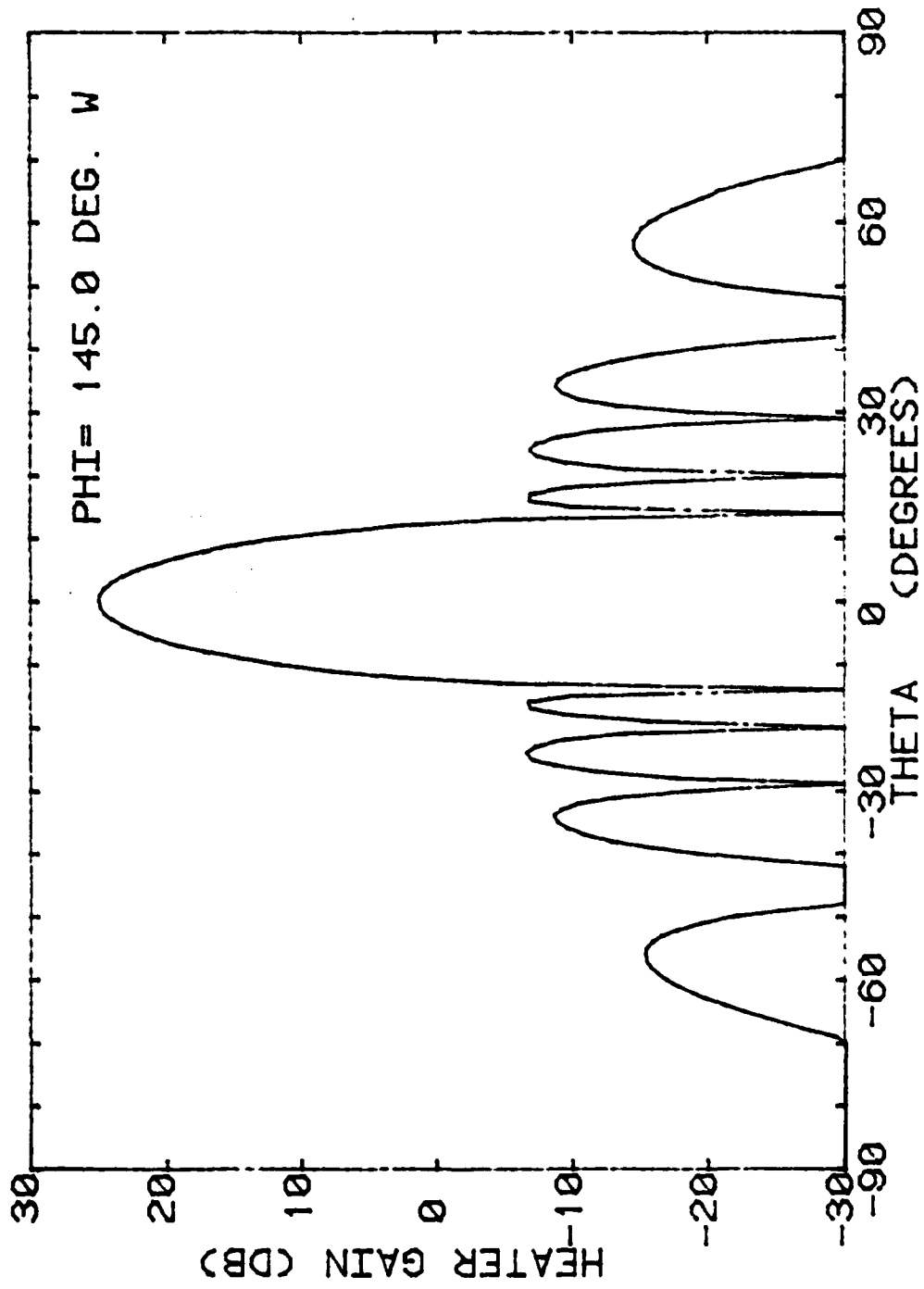


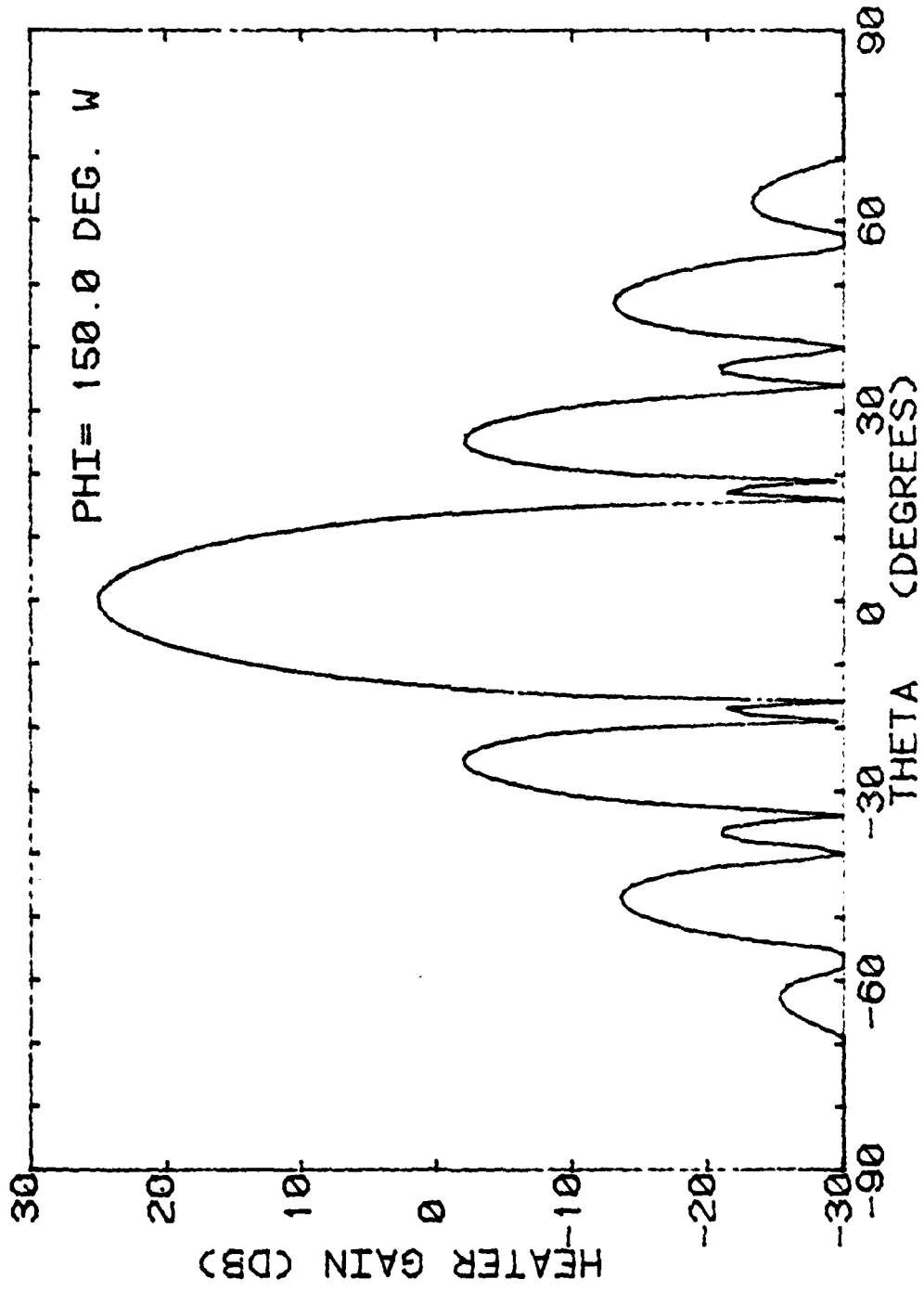


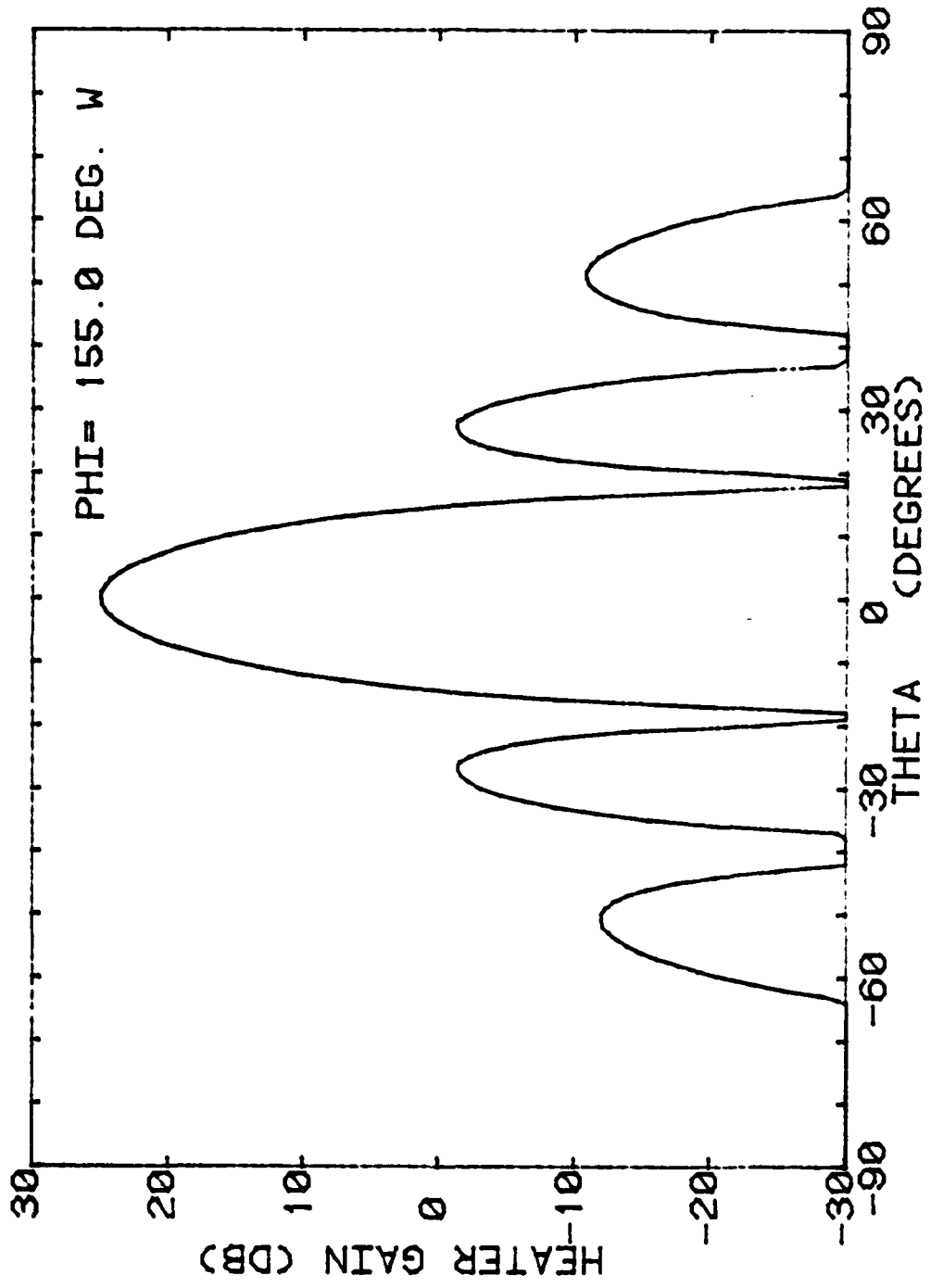


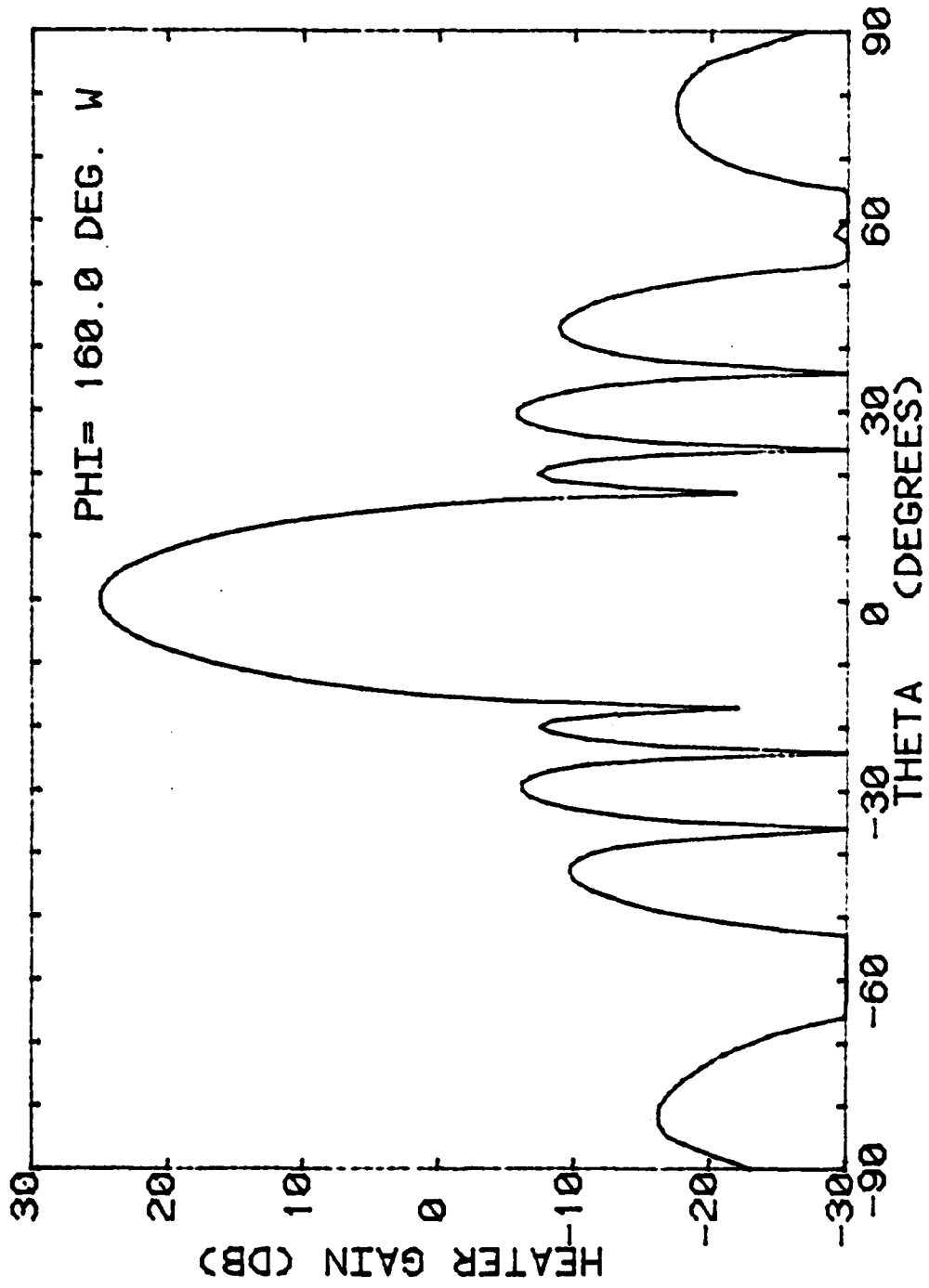


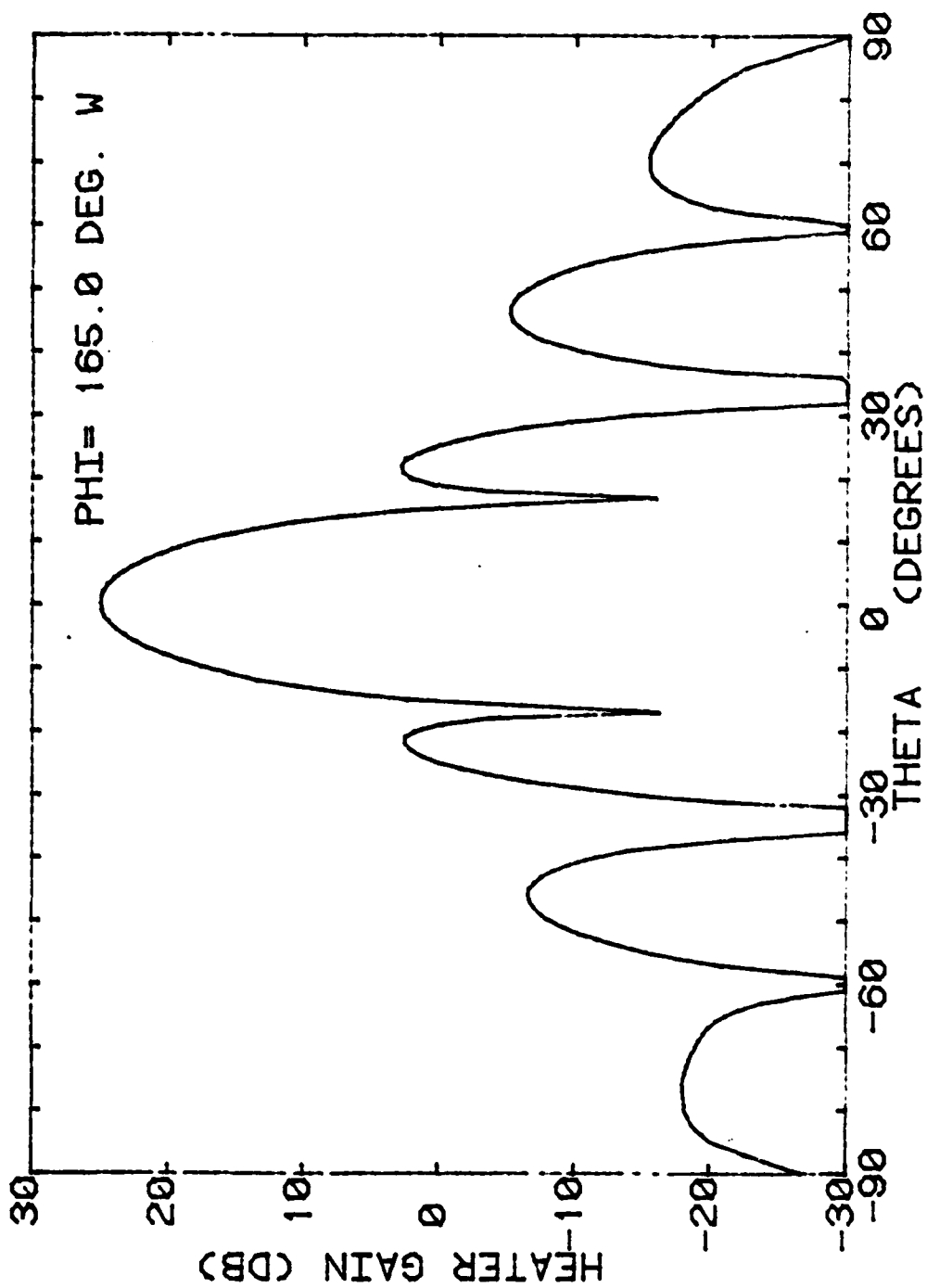


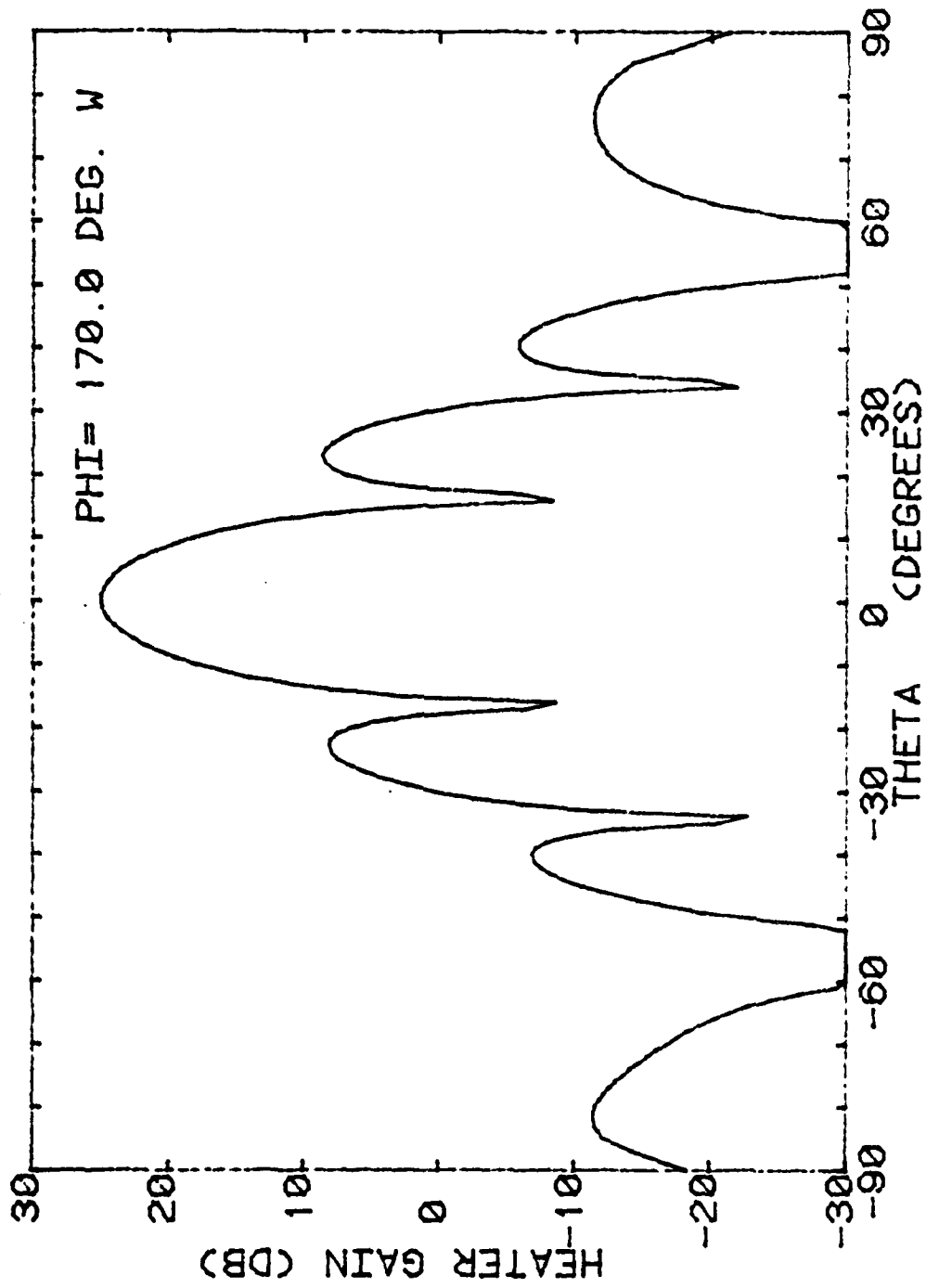


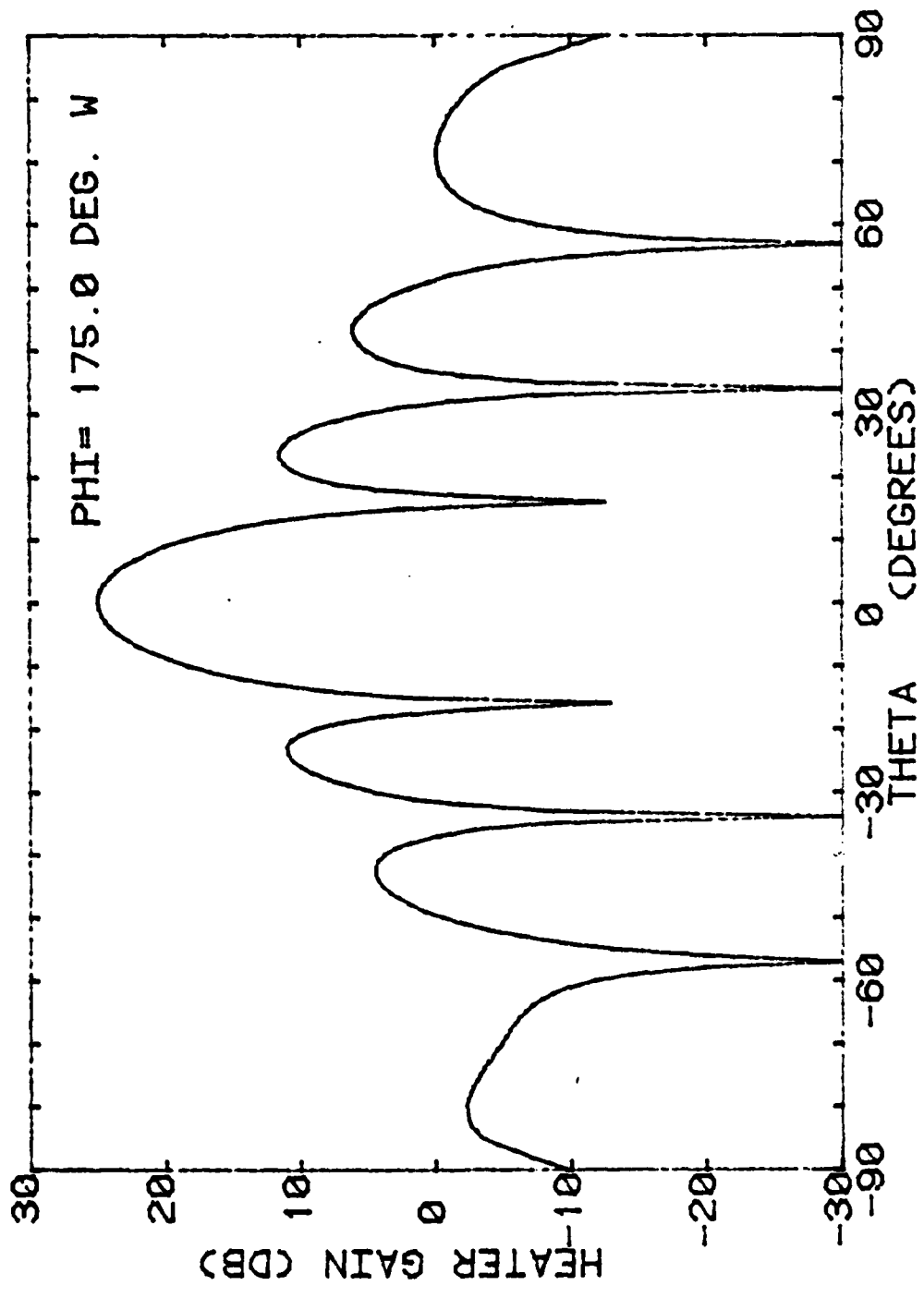












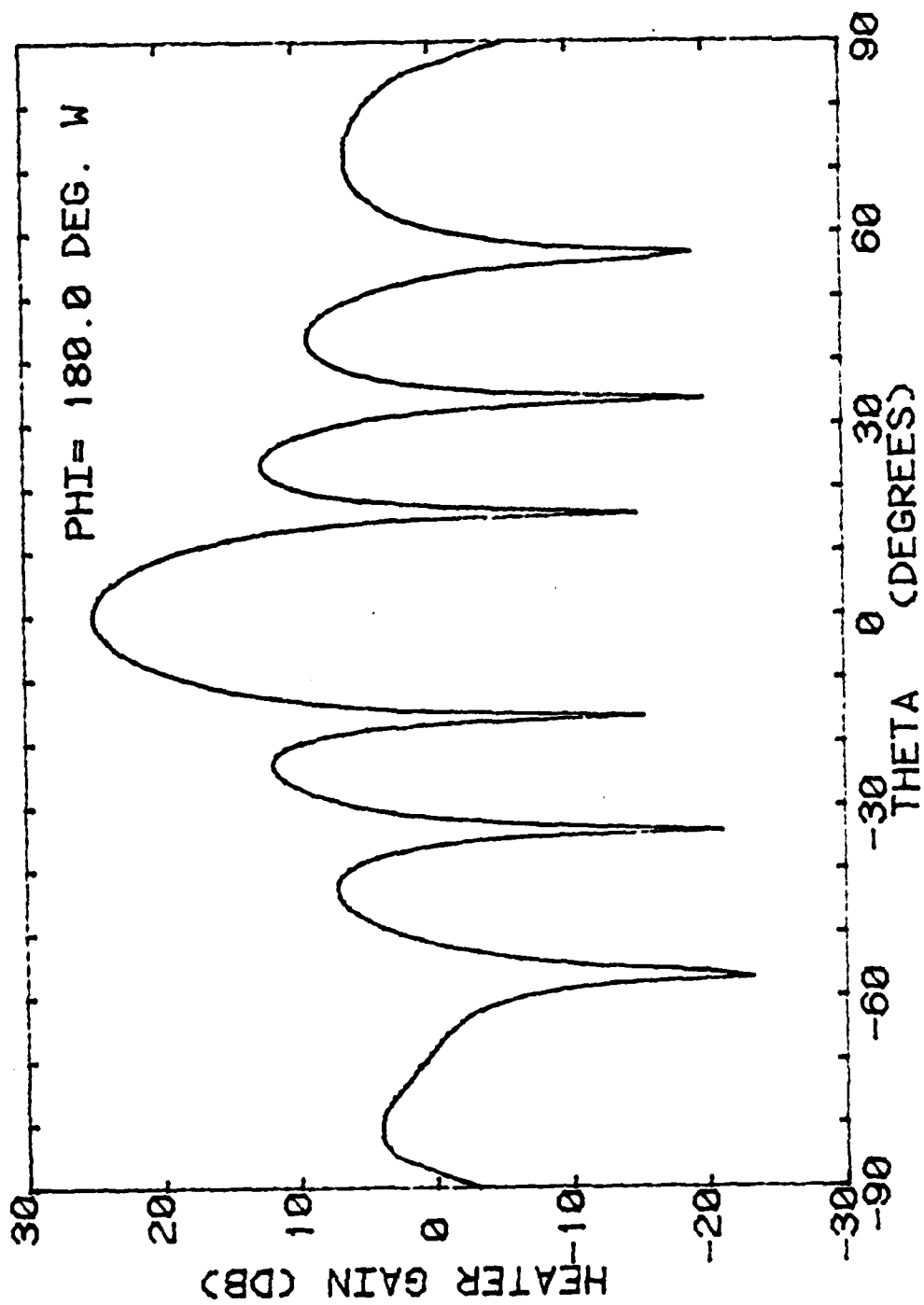
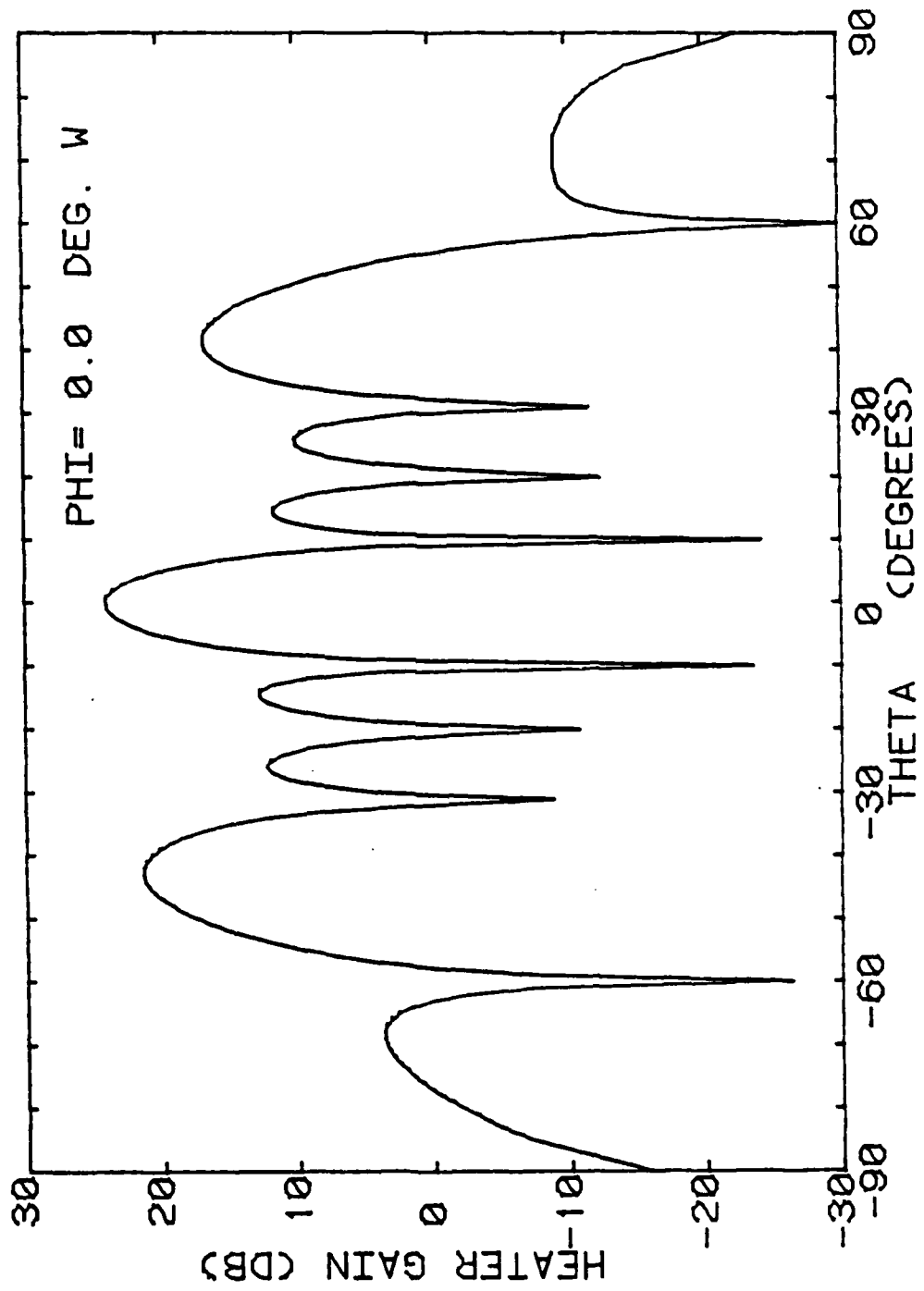
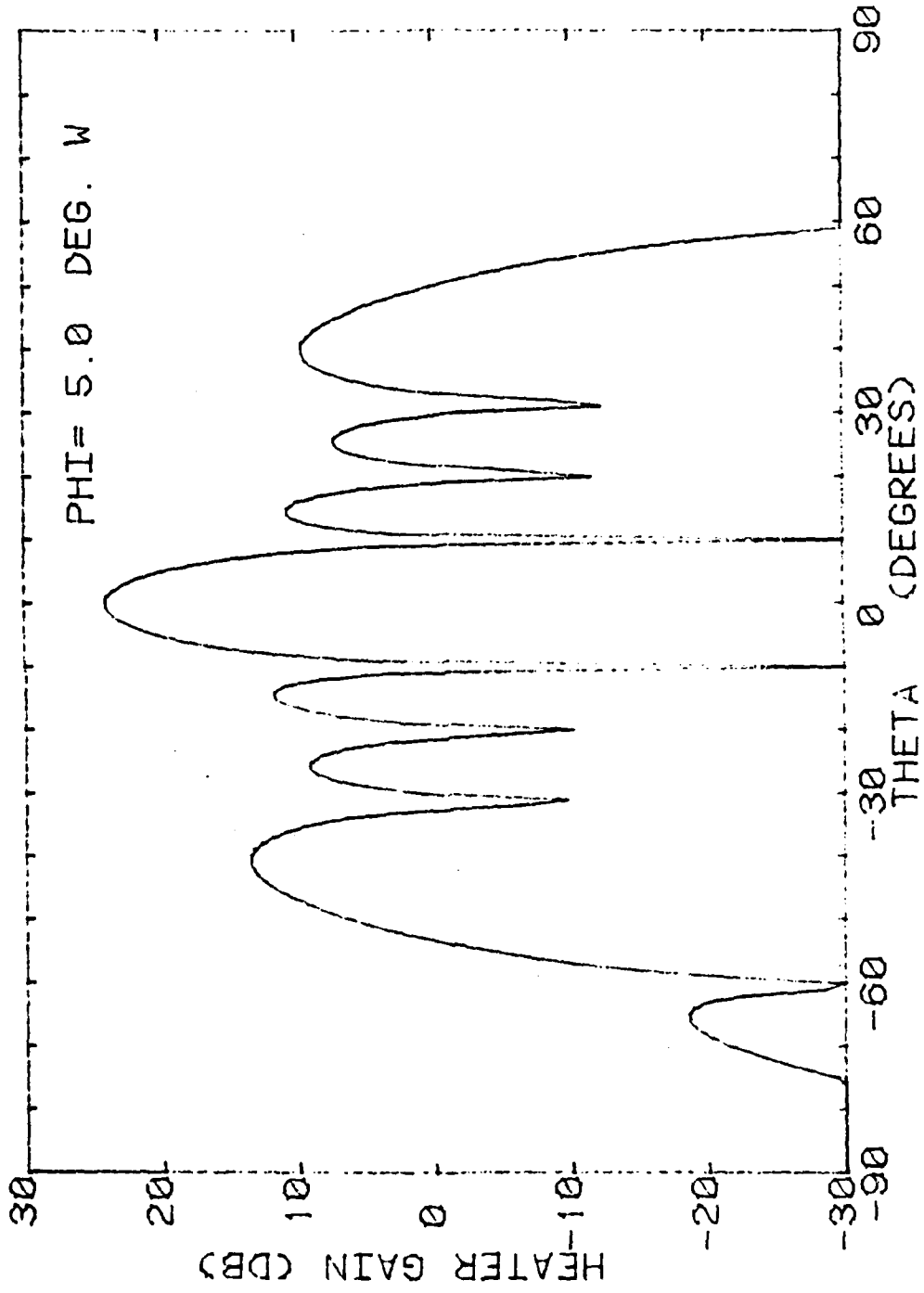
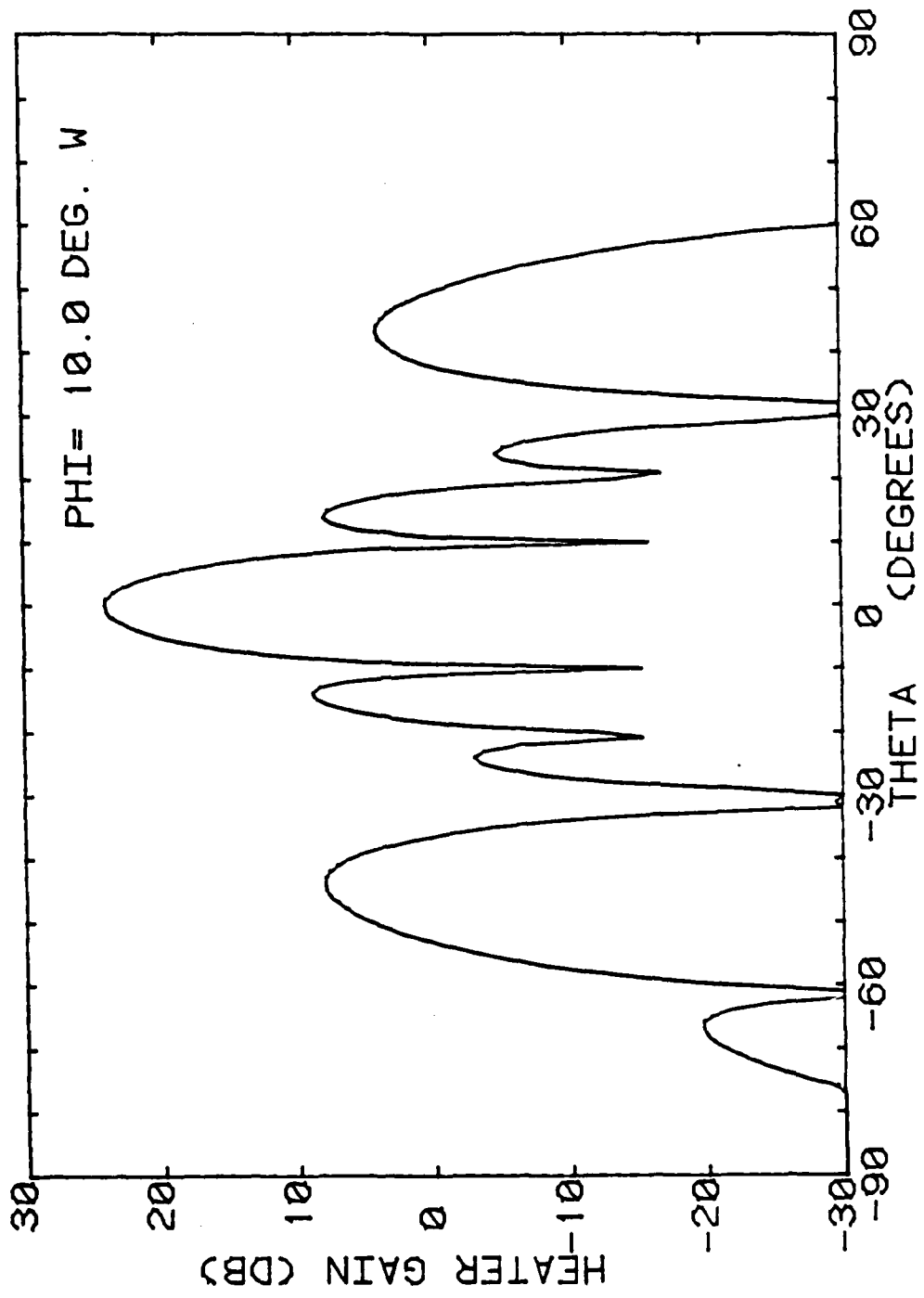
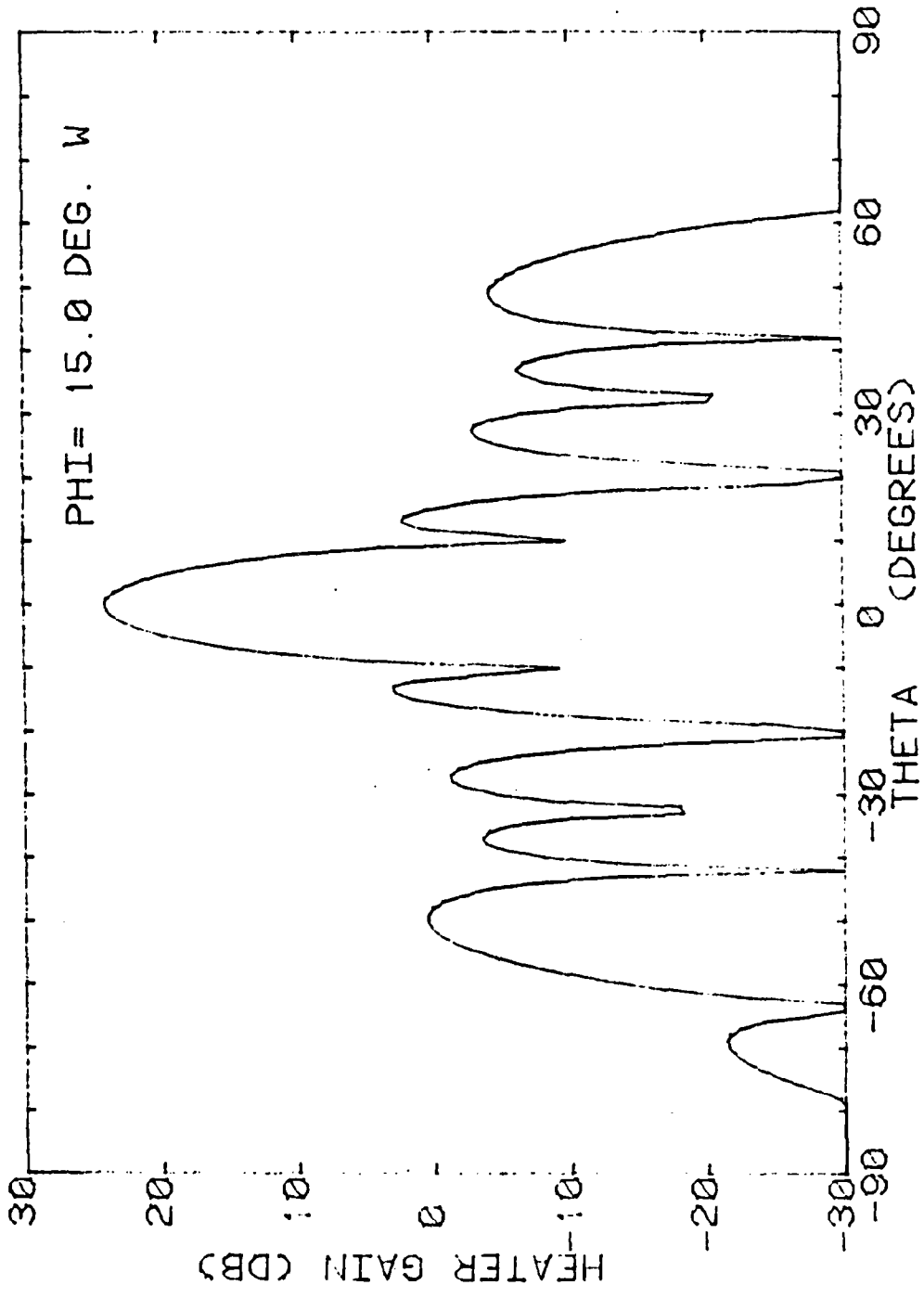


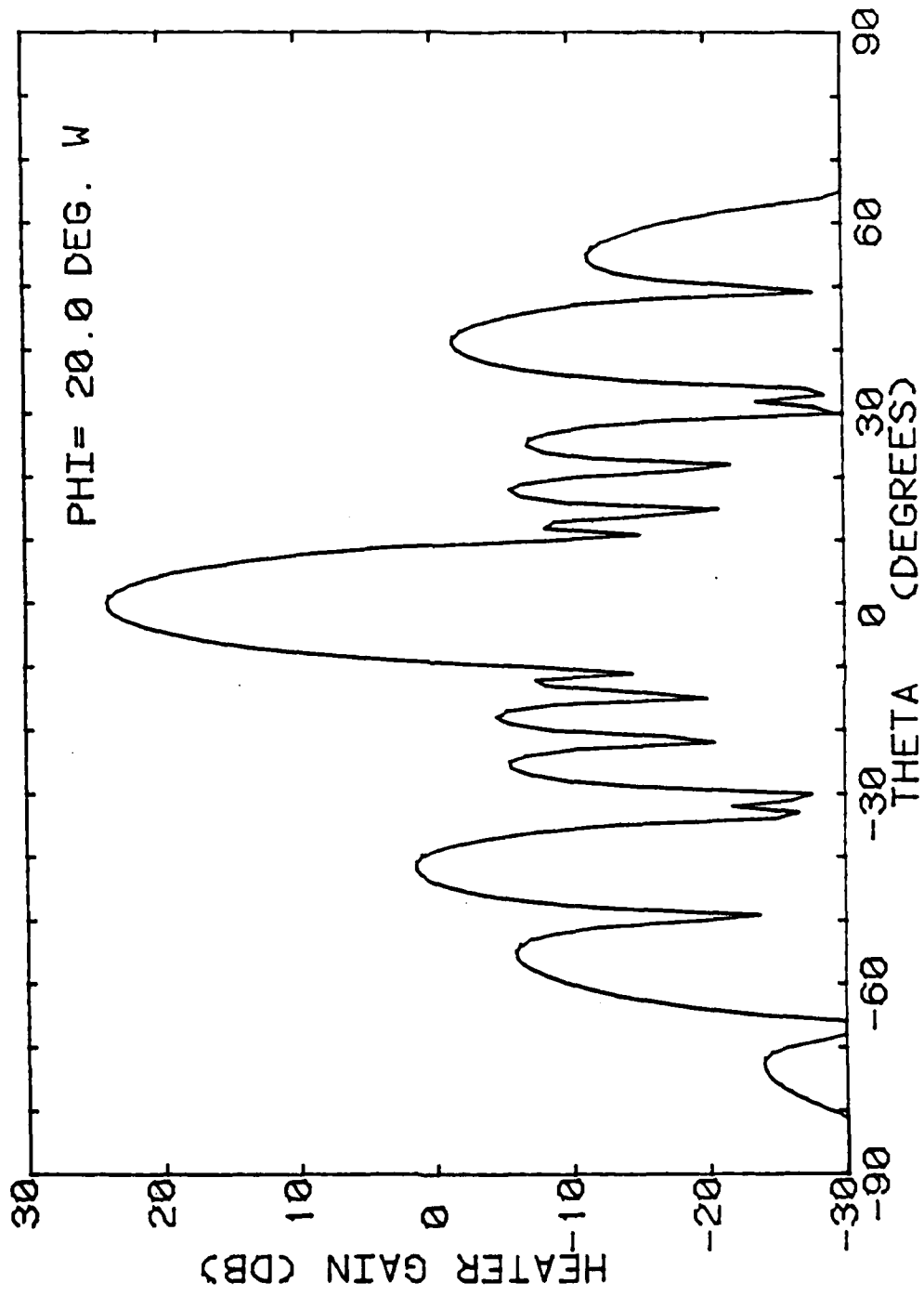
Figure 1-11 Directive gain pattern for Arecibo Observatory
HF heating array. Frequency = 5.1 MHz.

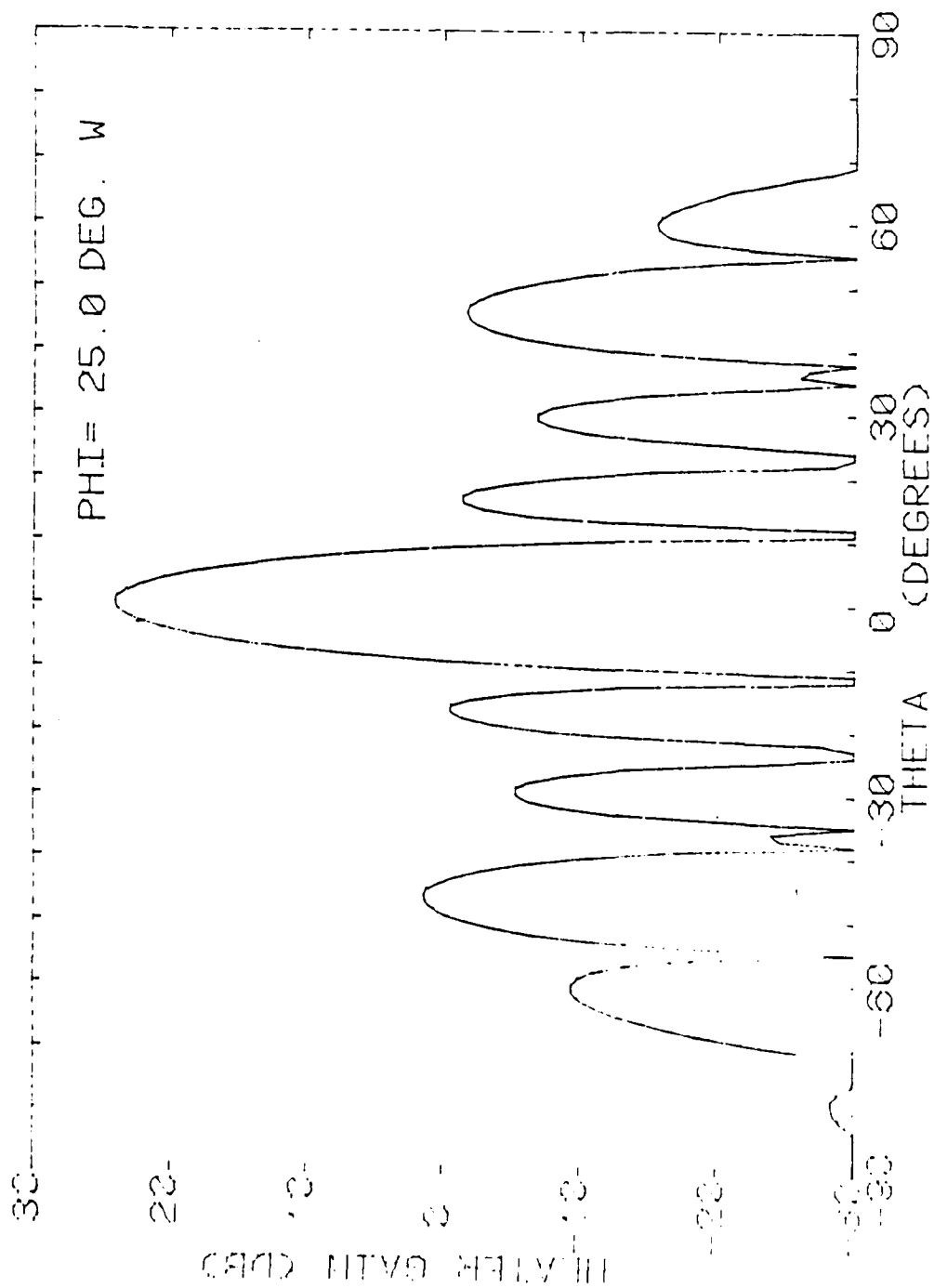


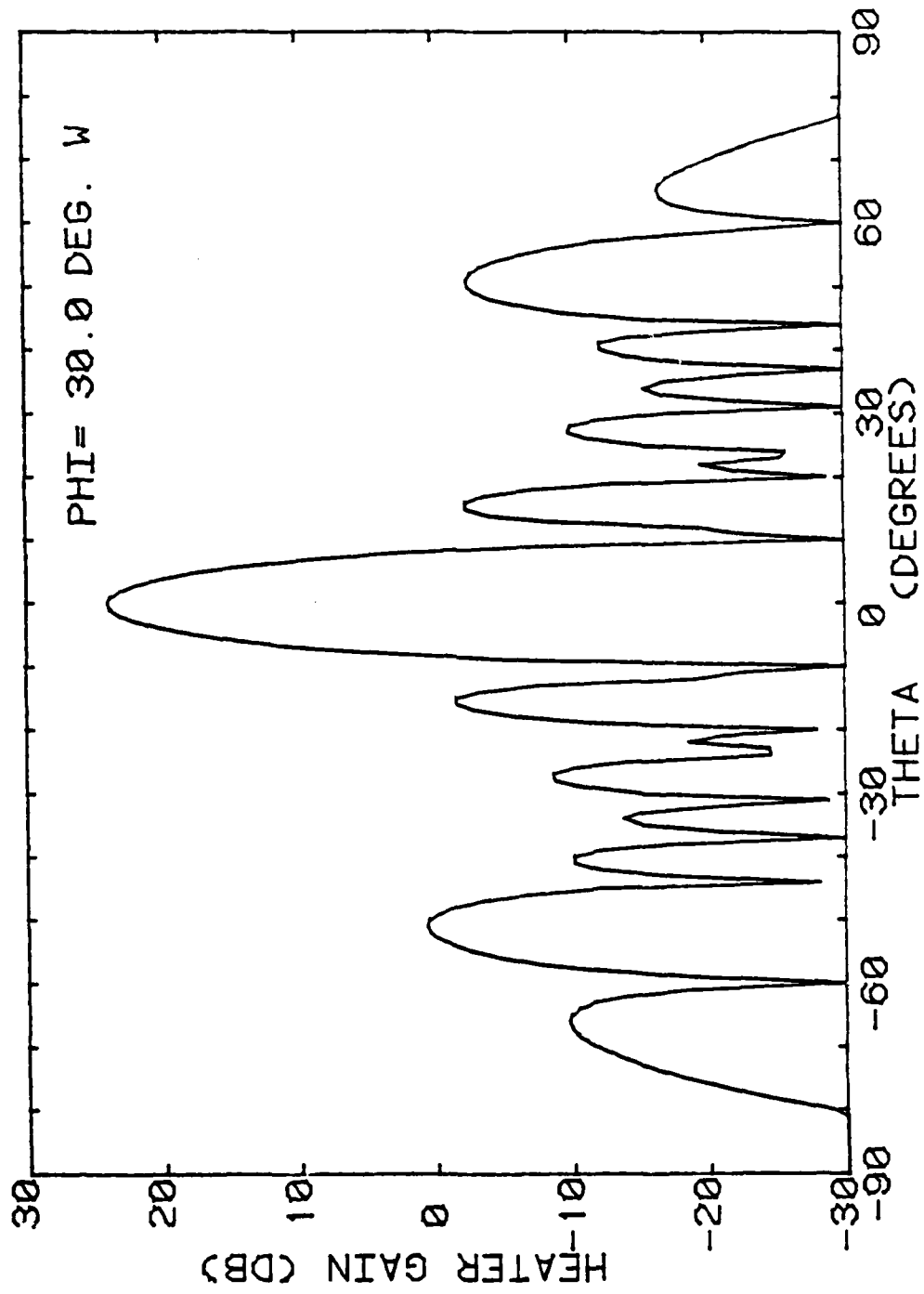


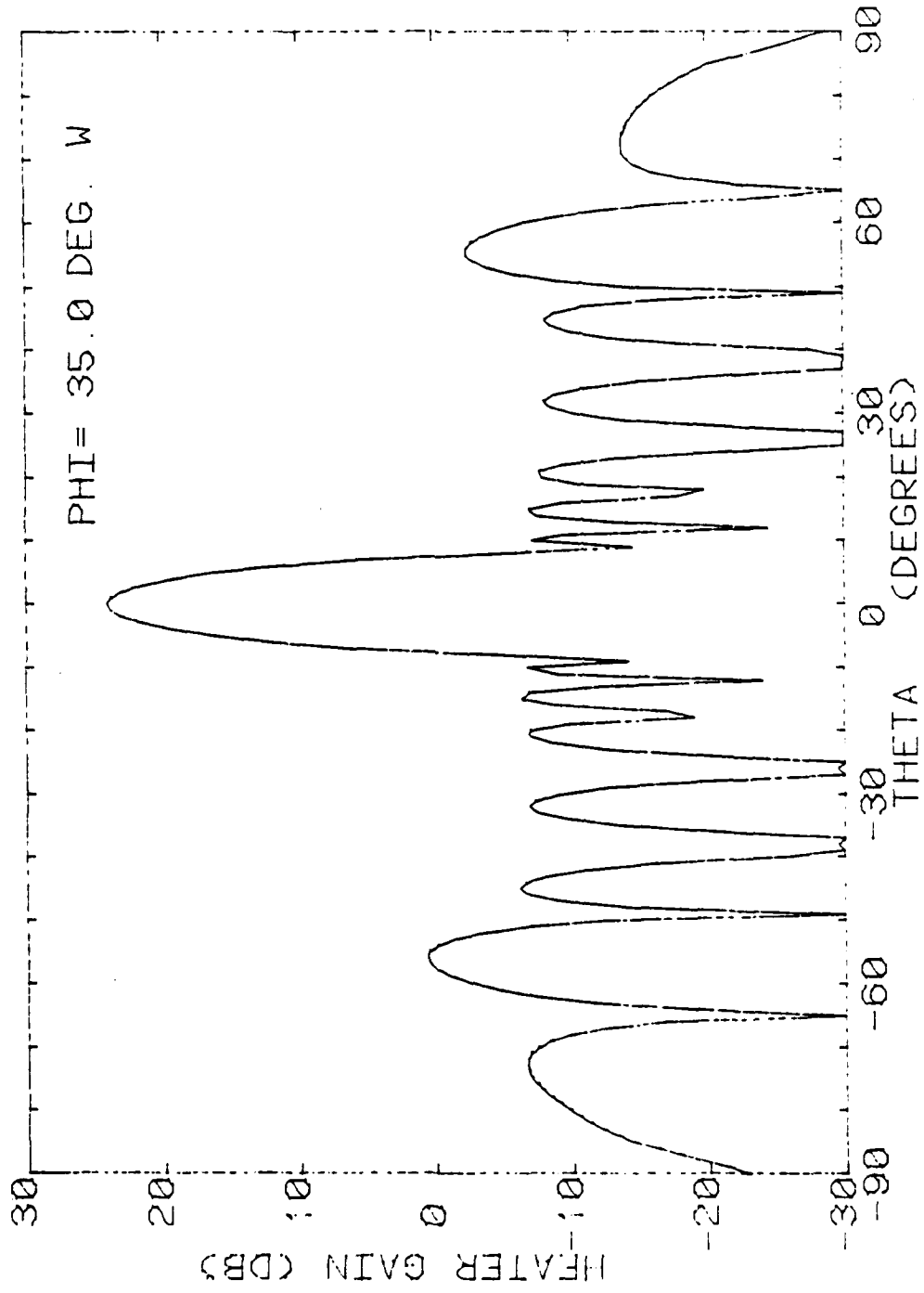


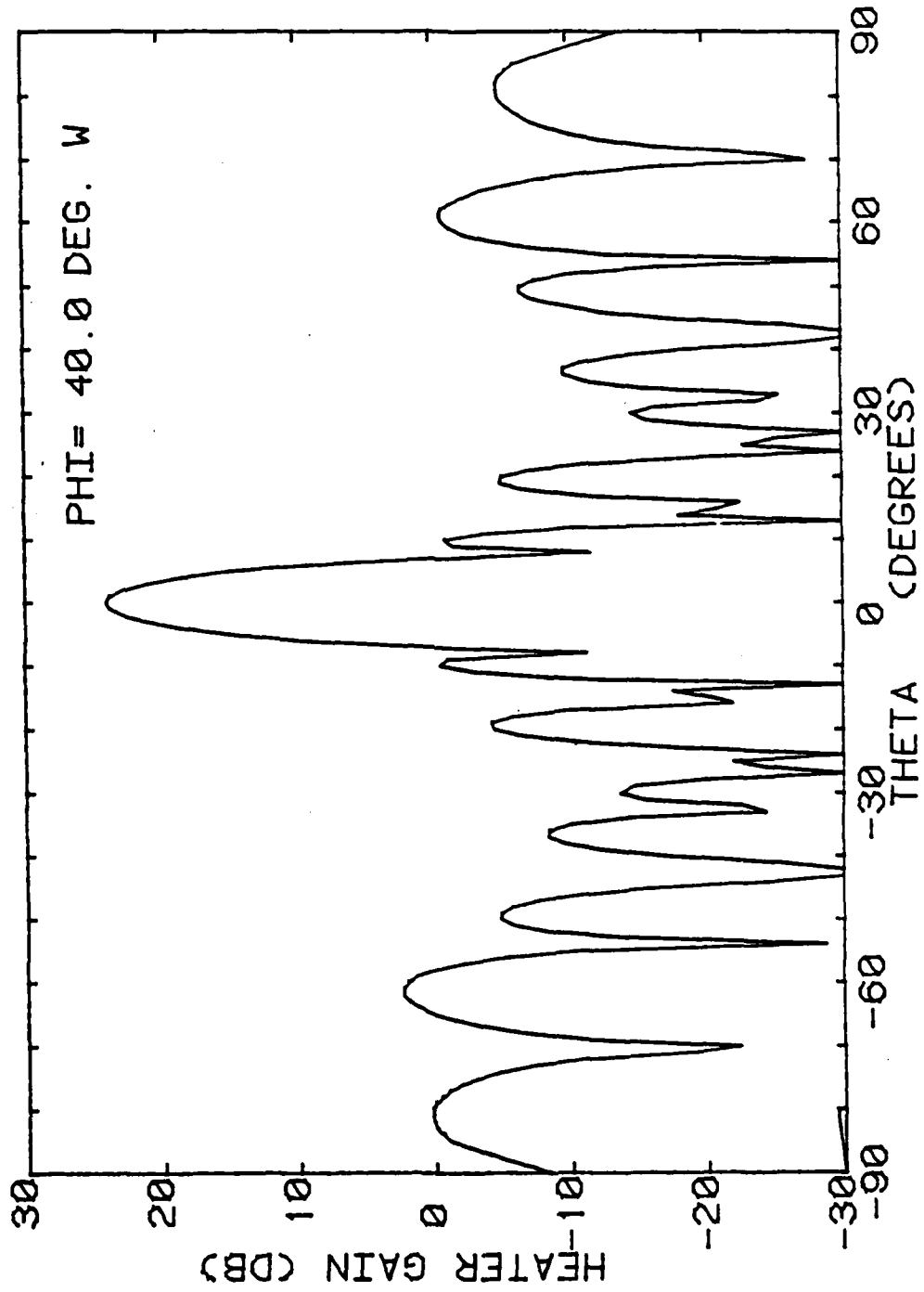


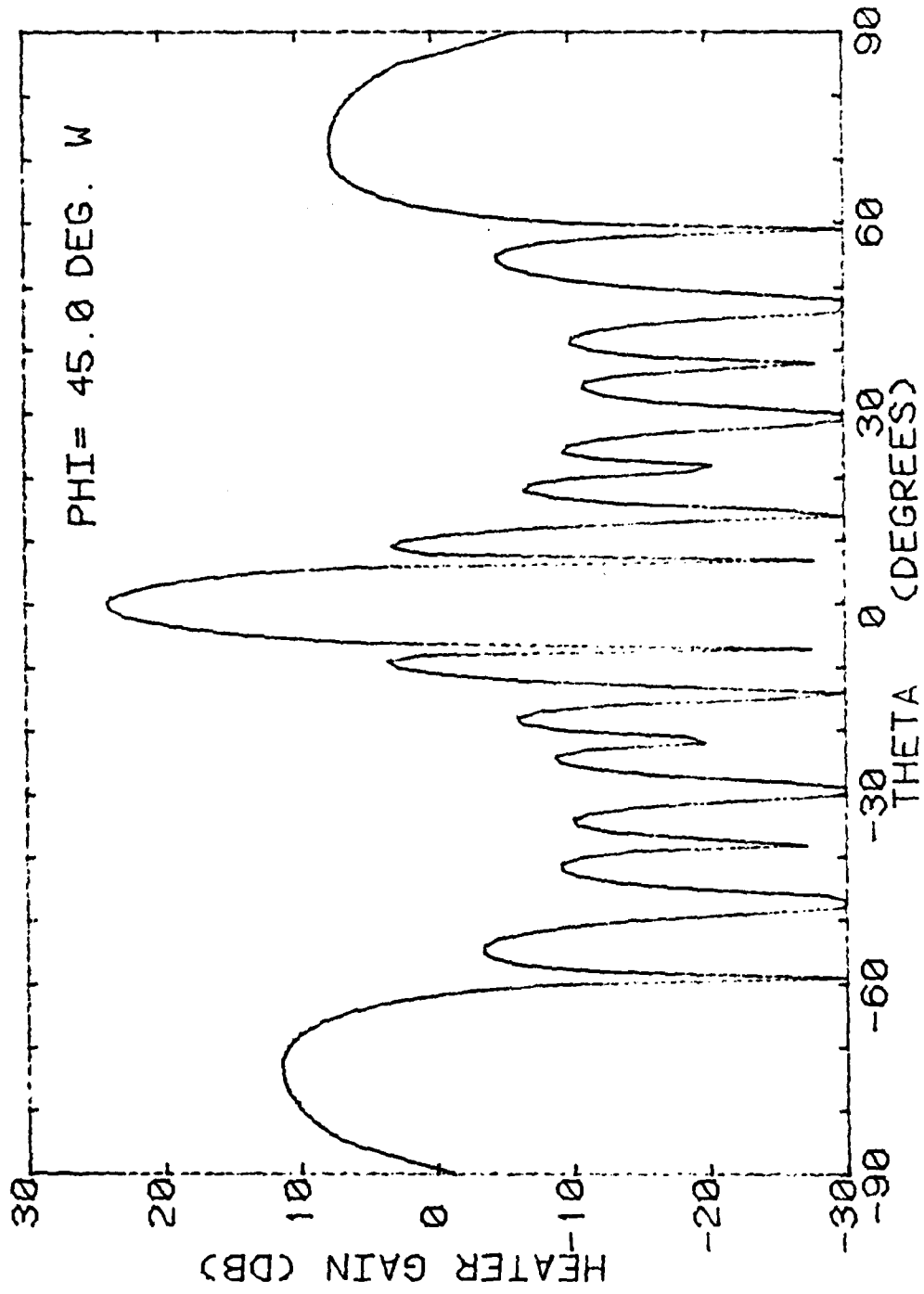


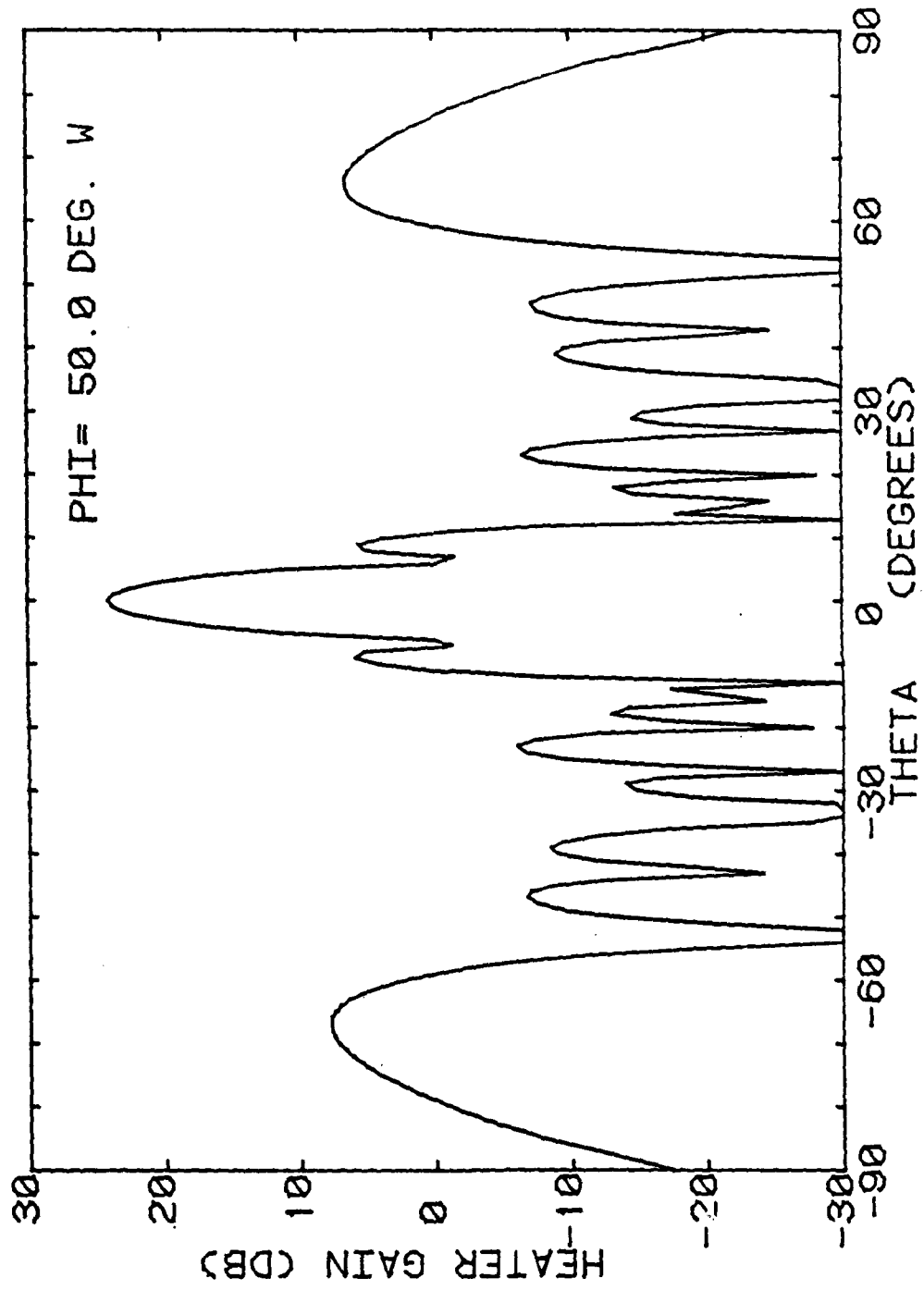


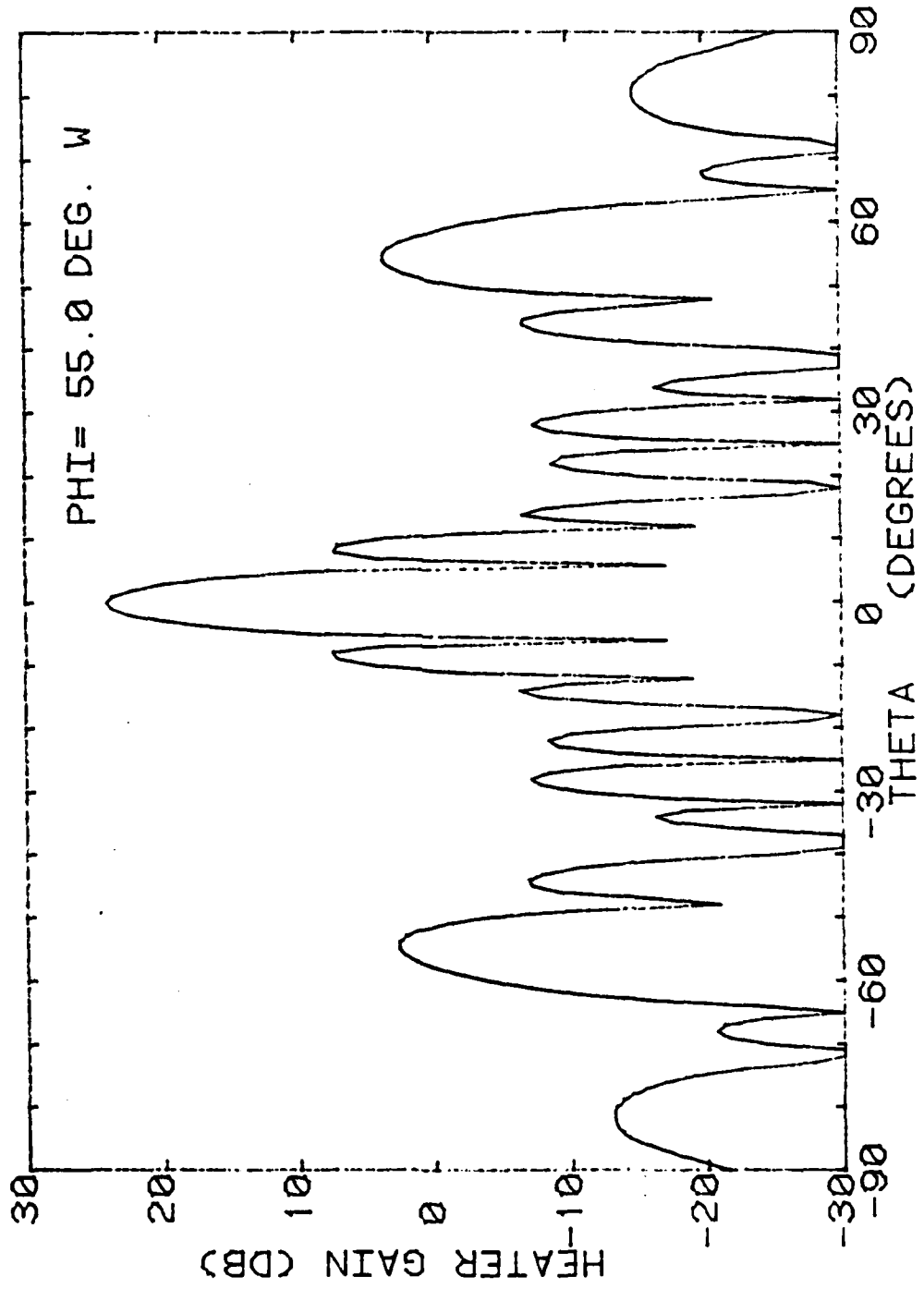


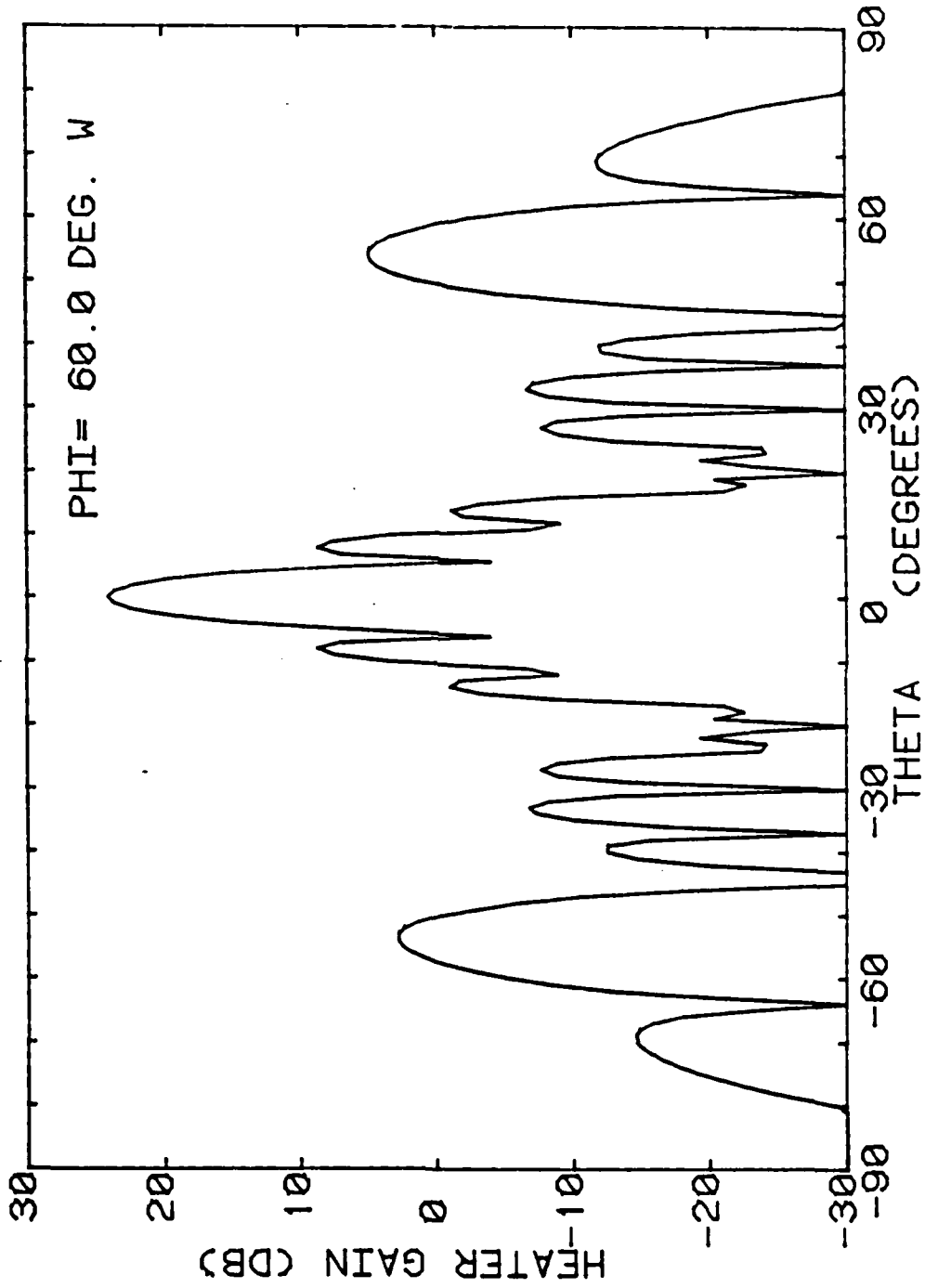


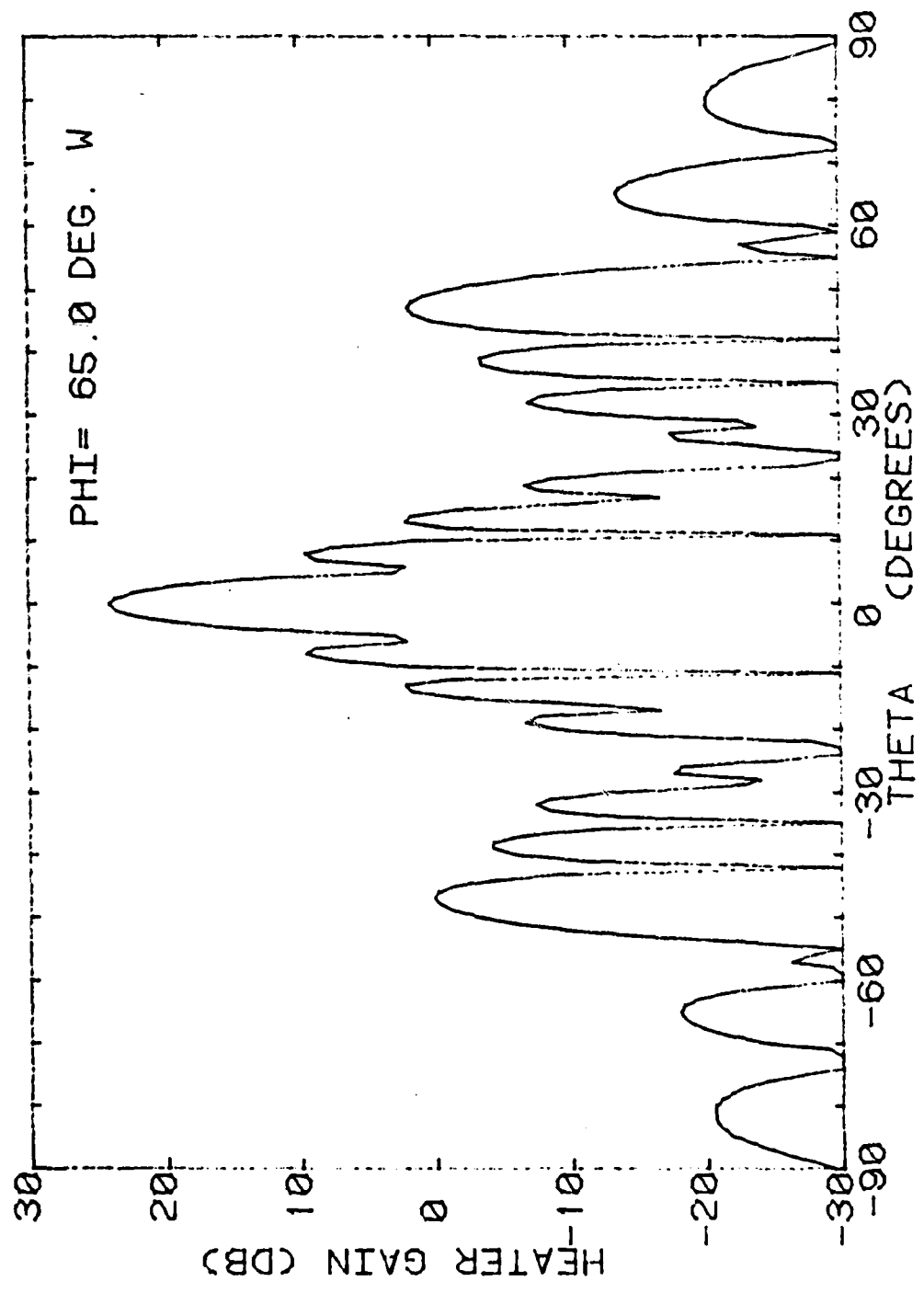


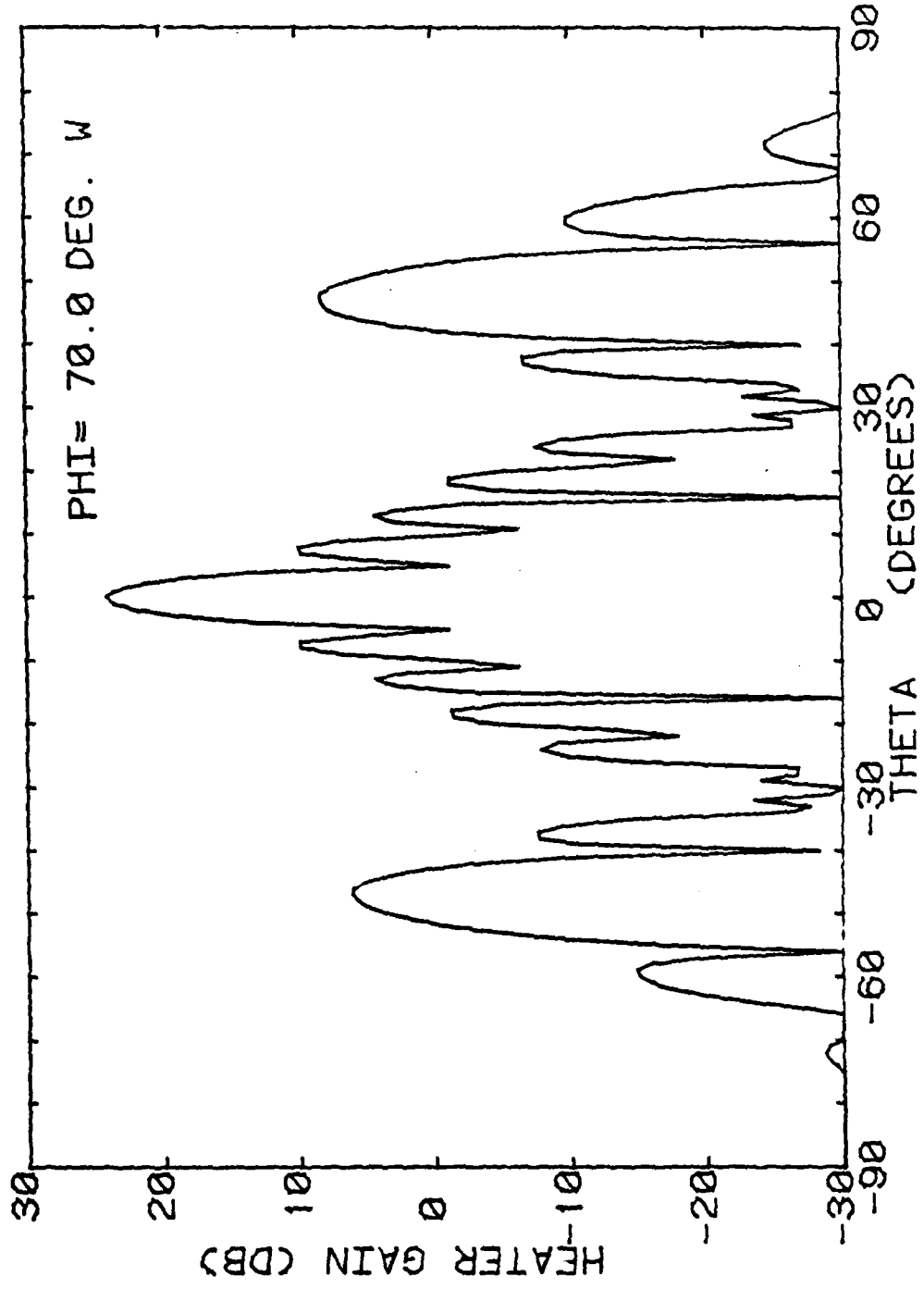


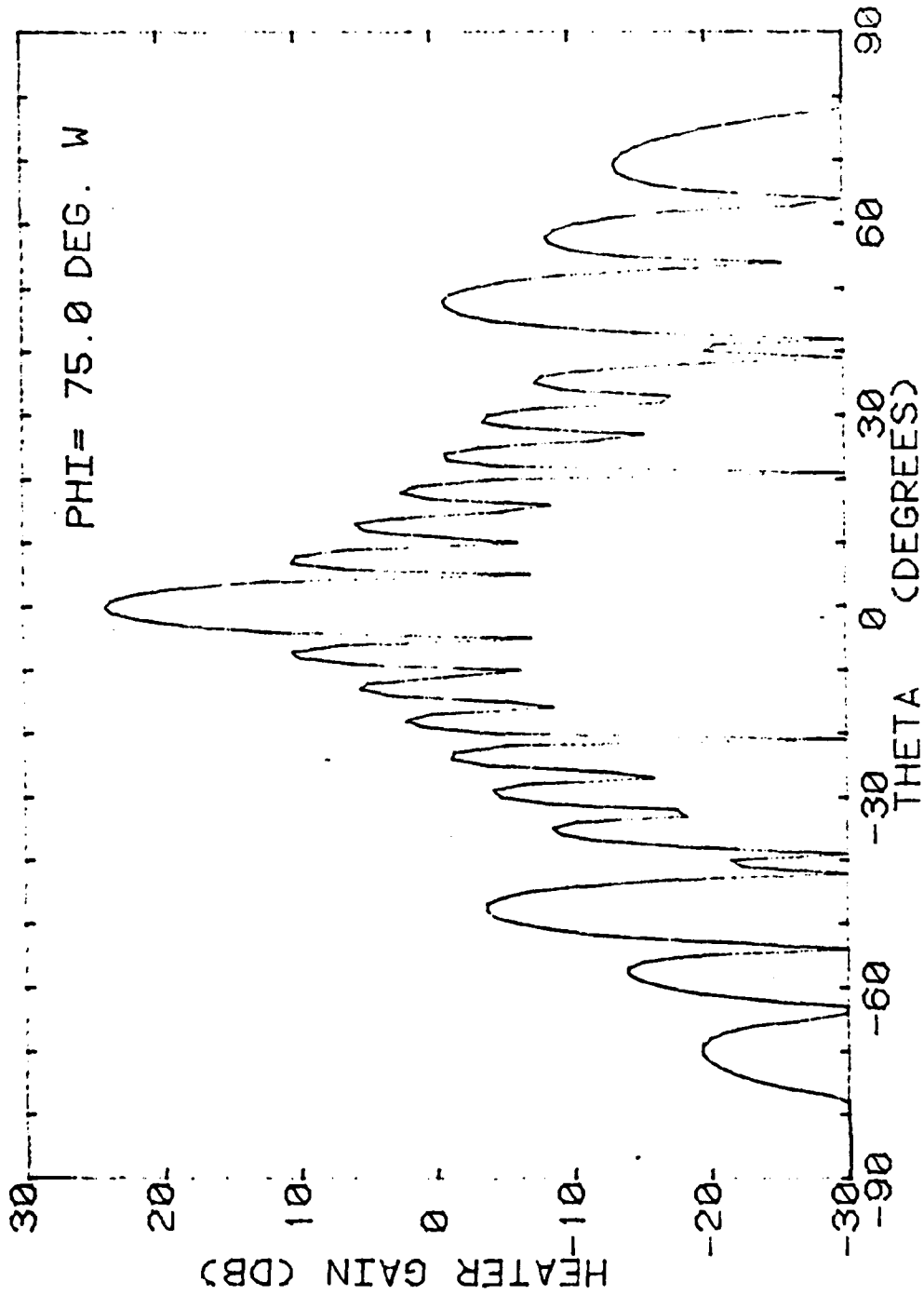


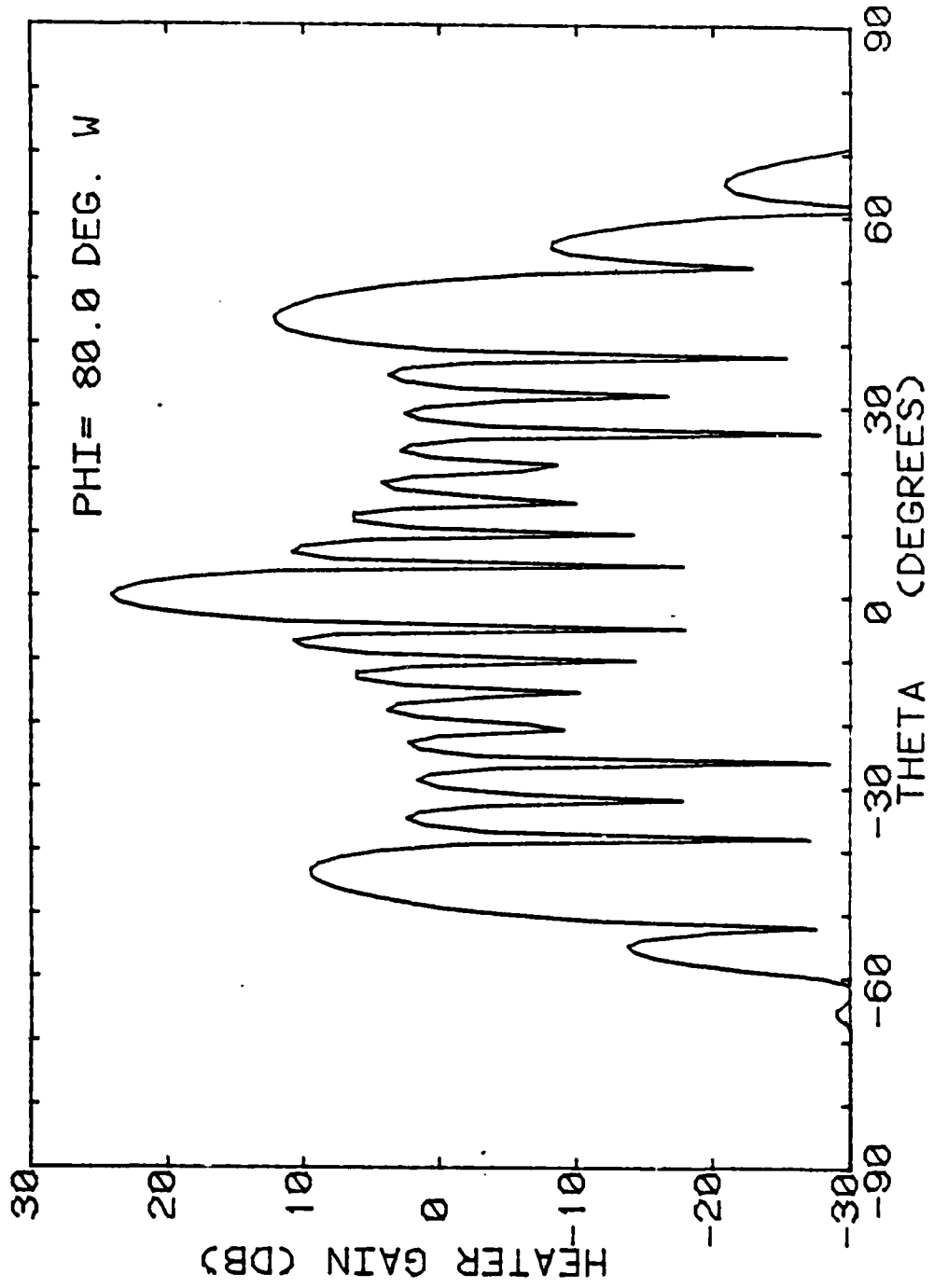


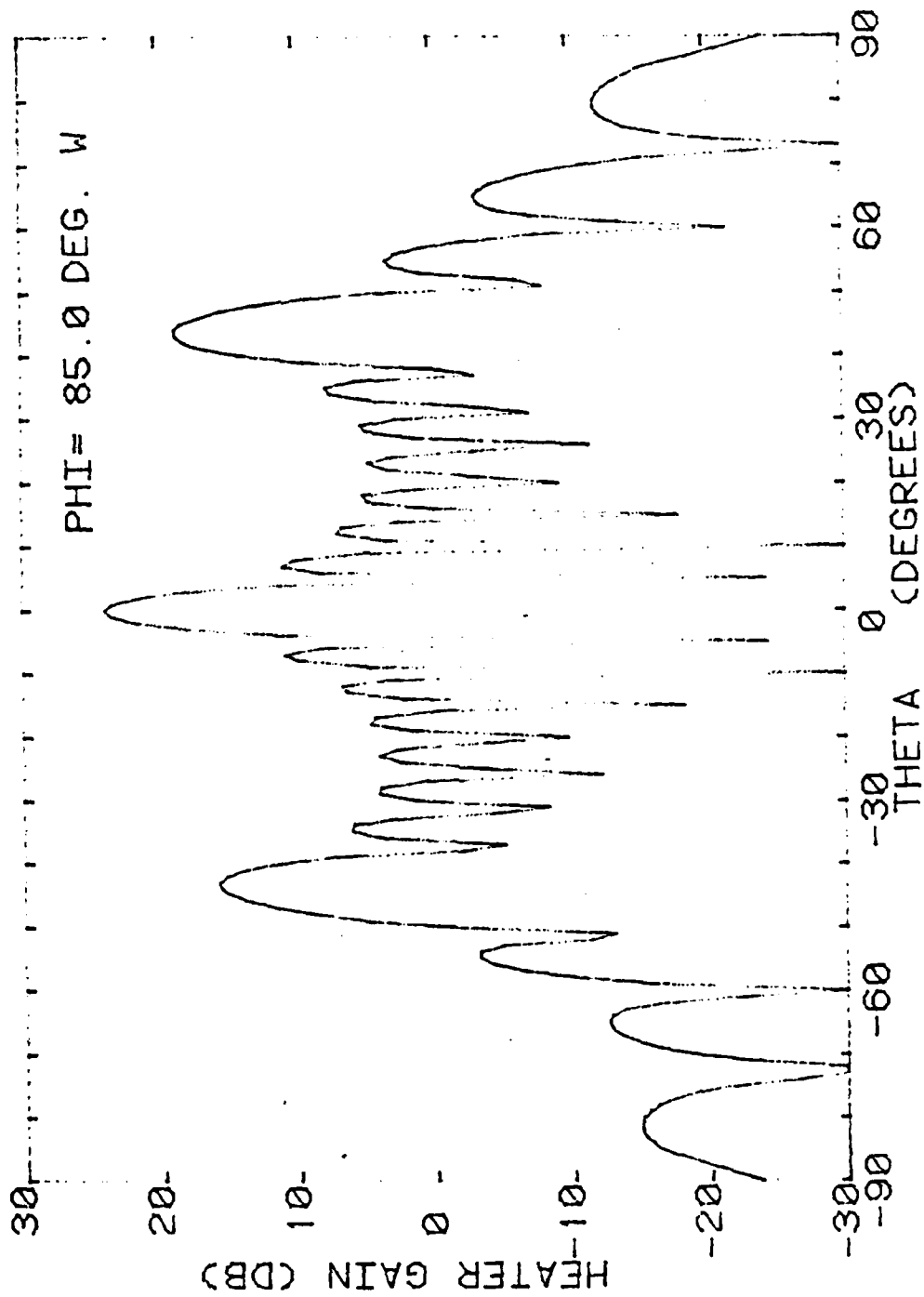


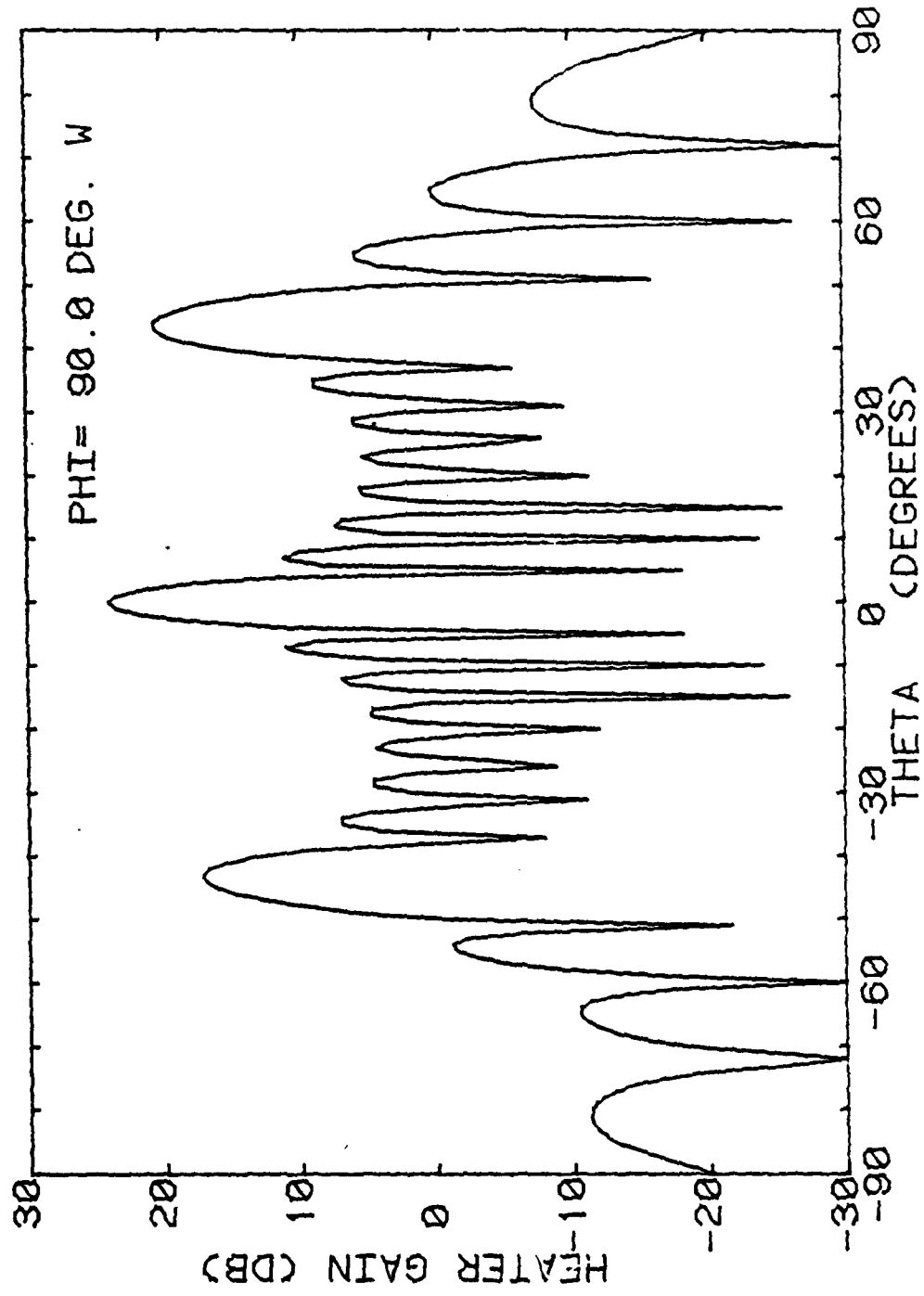


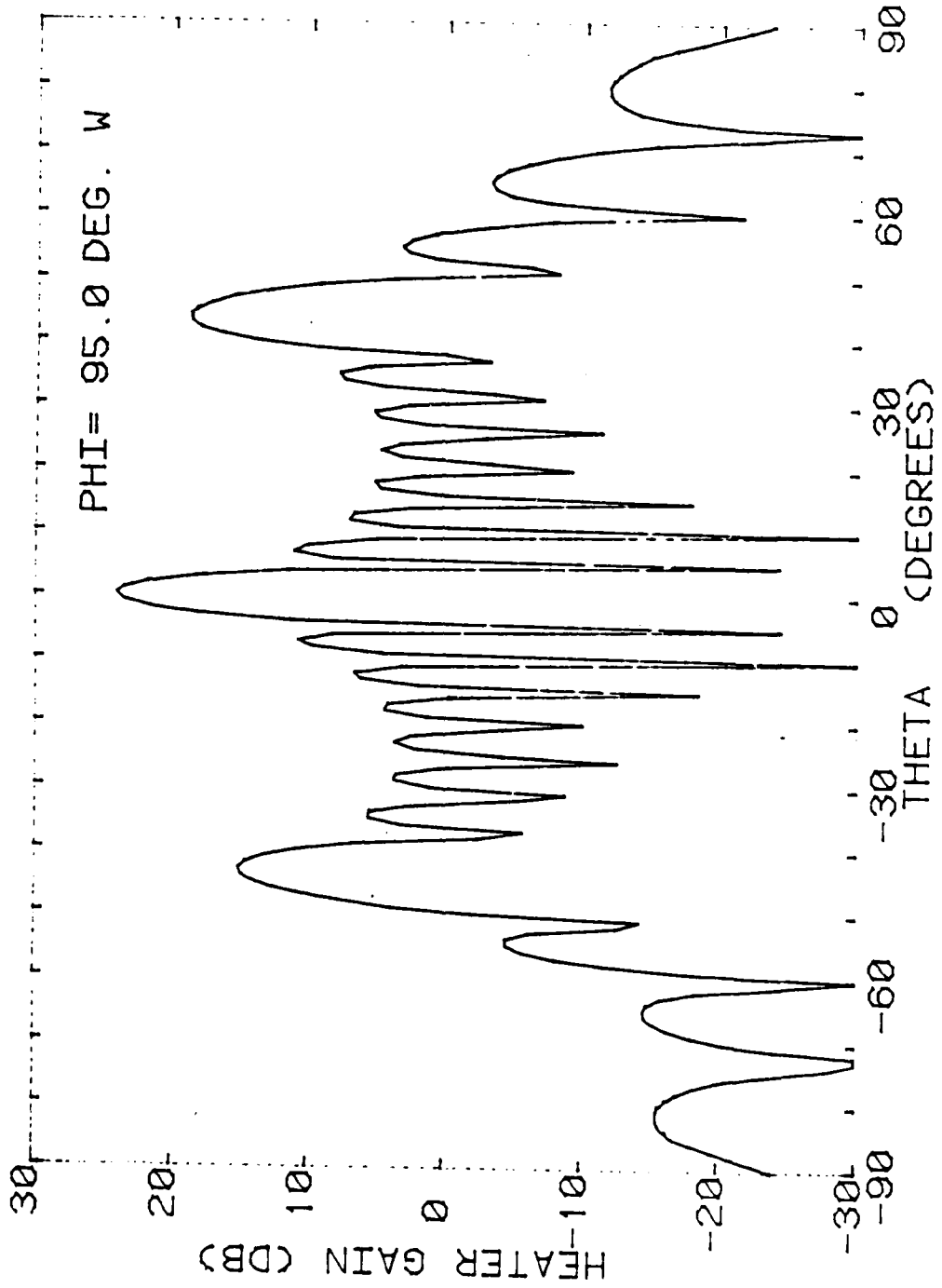












AD-A126 809

EFFECT OF HF HEATING ARRAY DIRECTIVITY PATTERN ON THE
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UNIVERSITY PARK IONOSPHERE RESEARCH L.

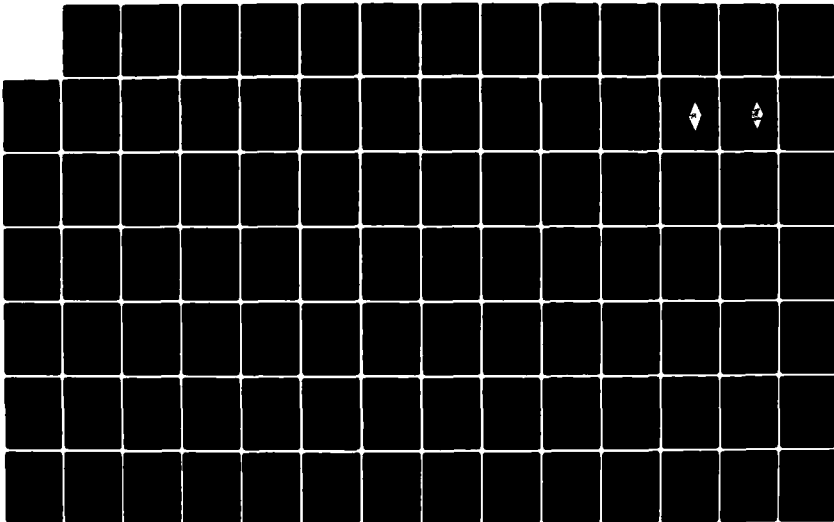
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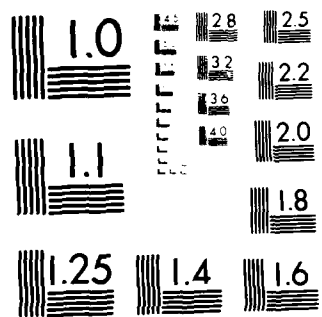
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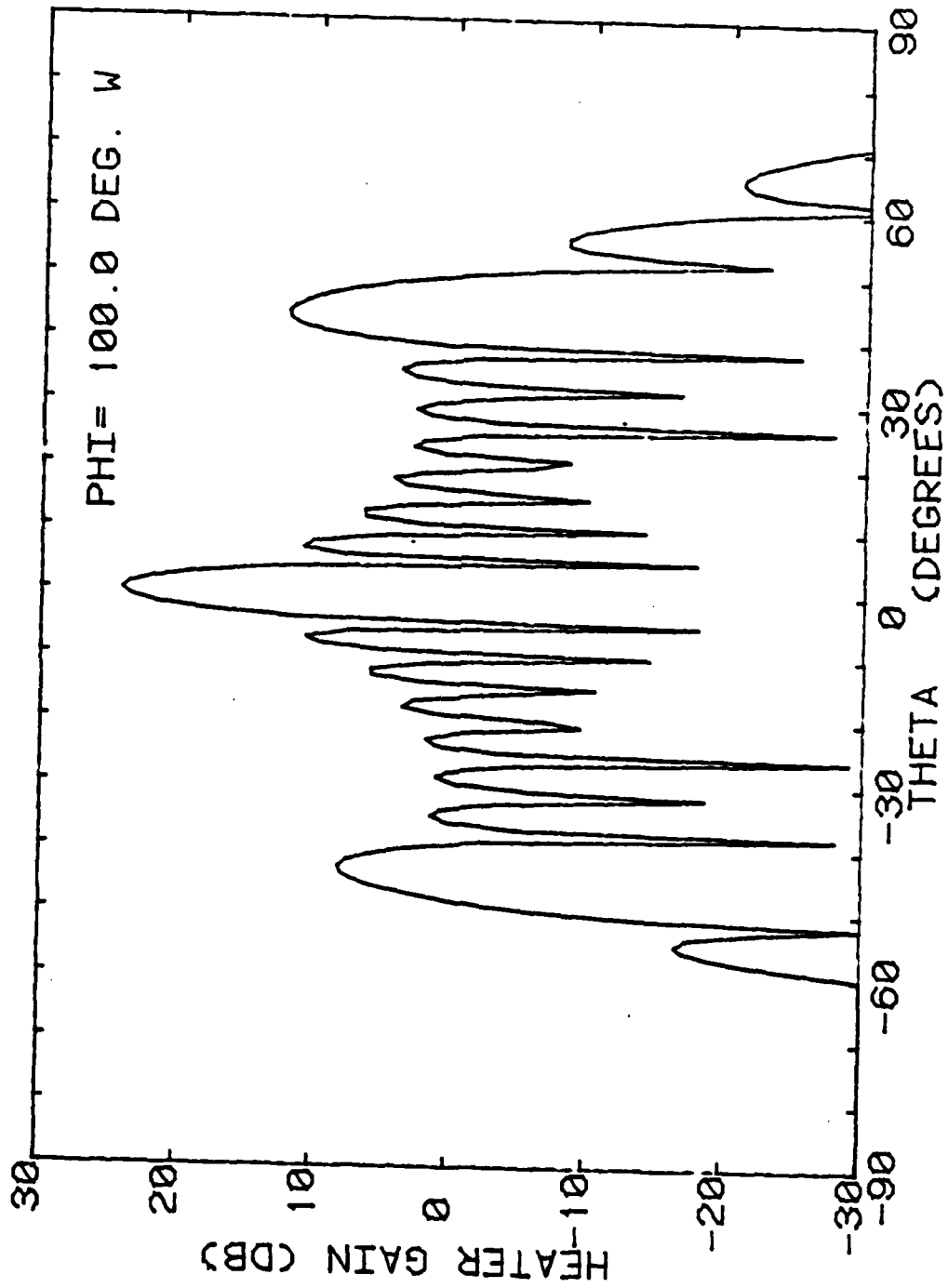
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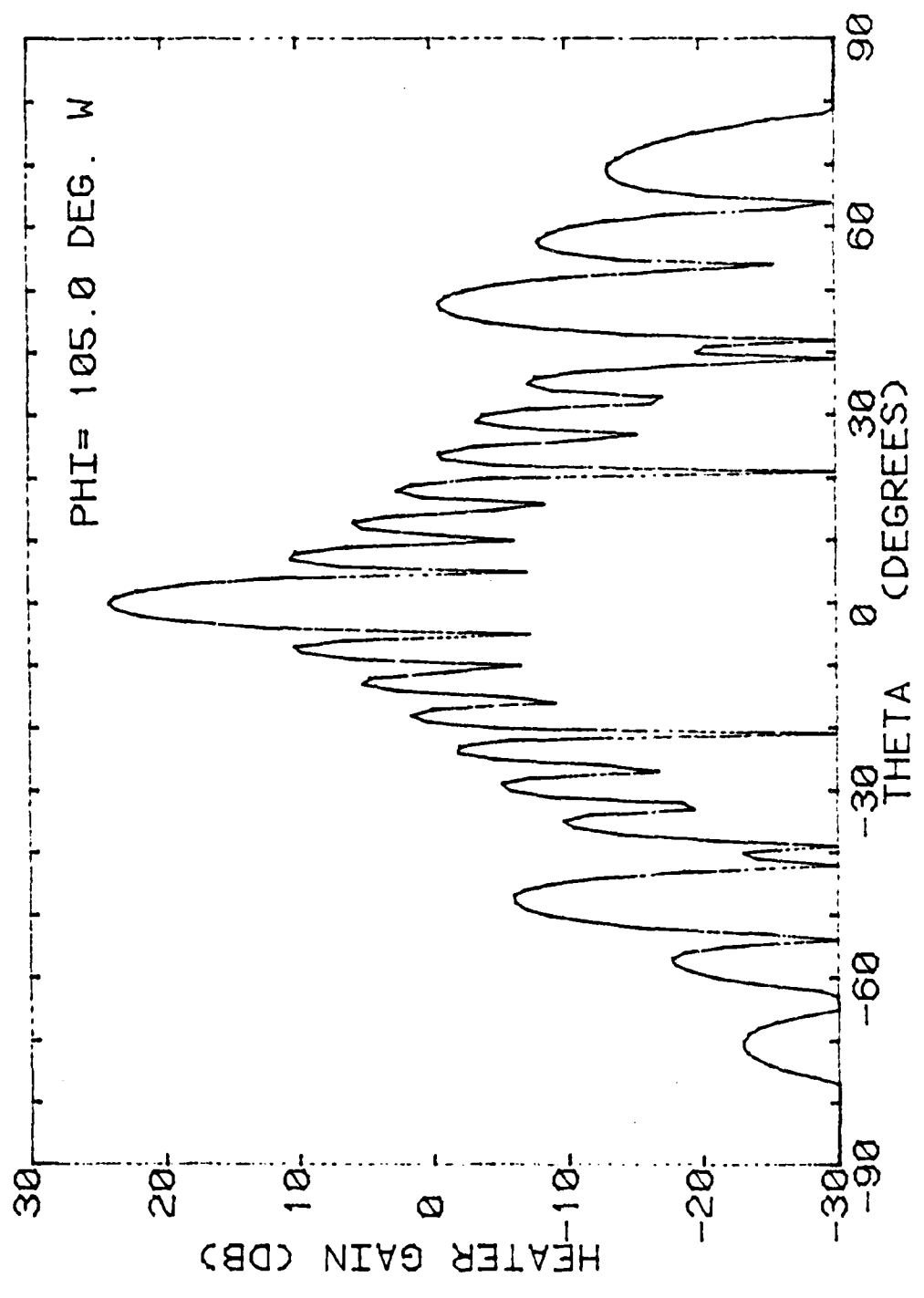
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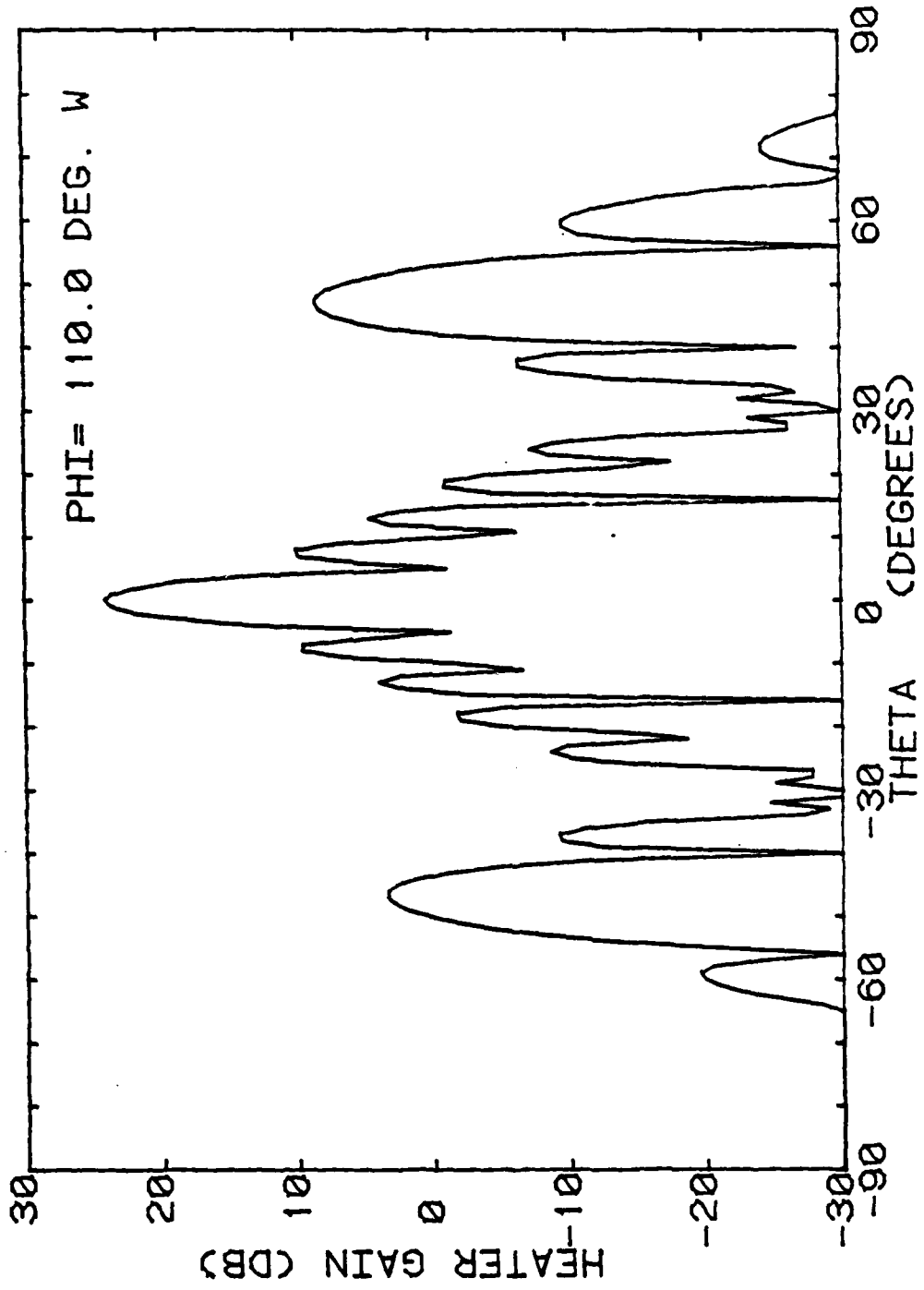


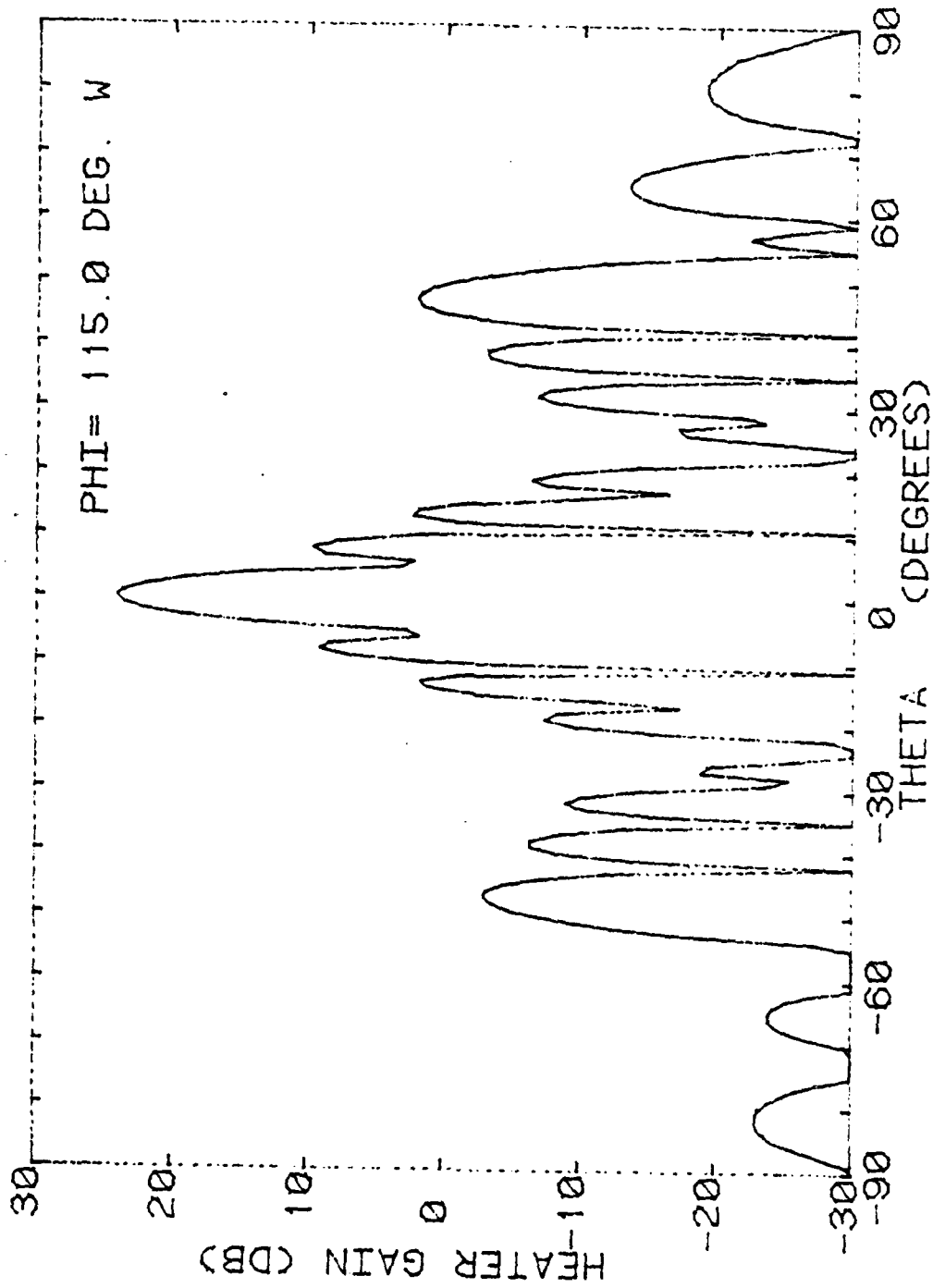


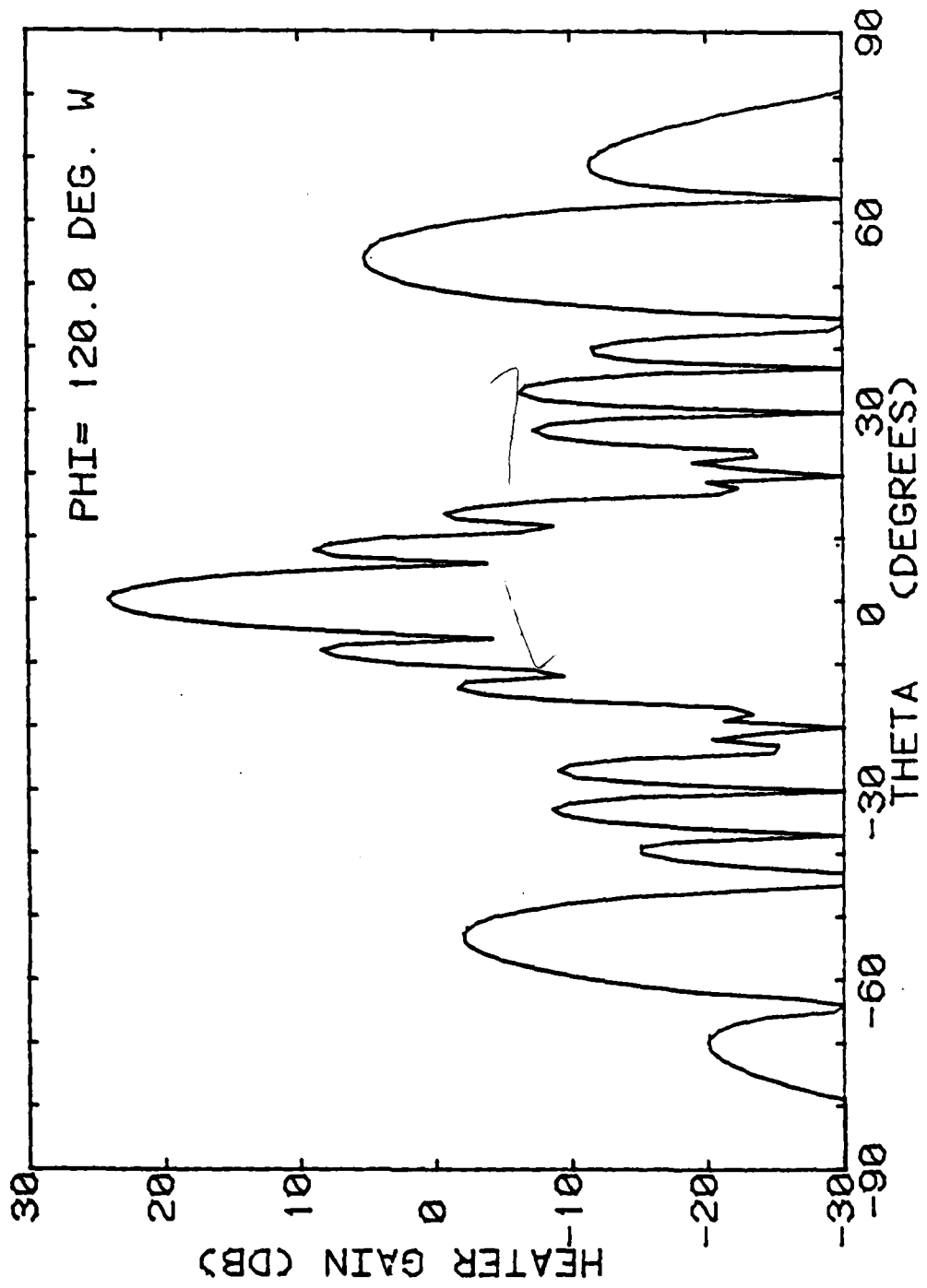
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

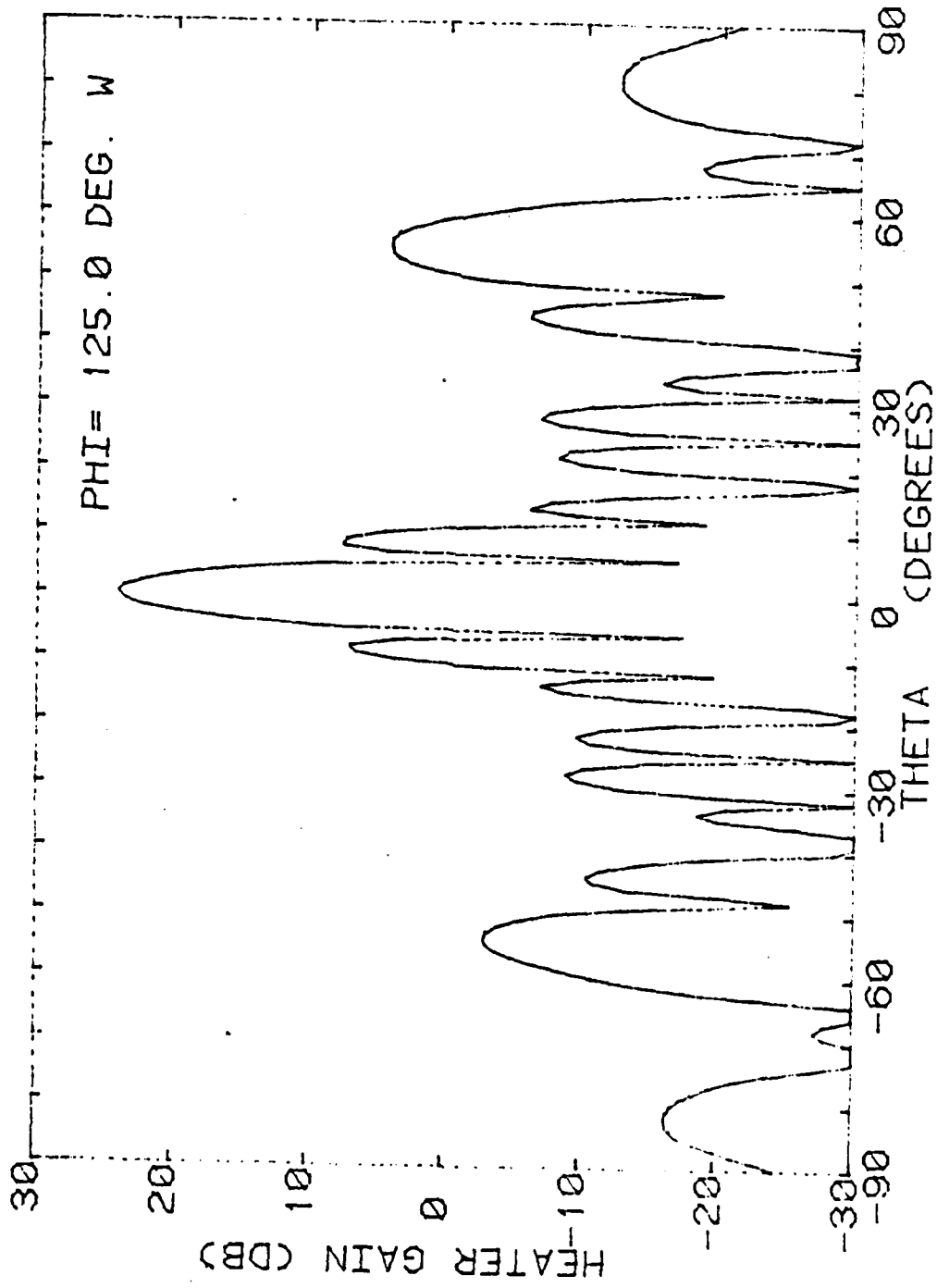


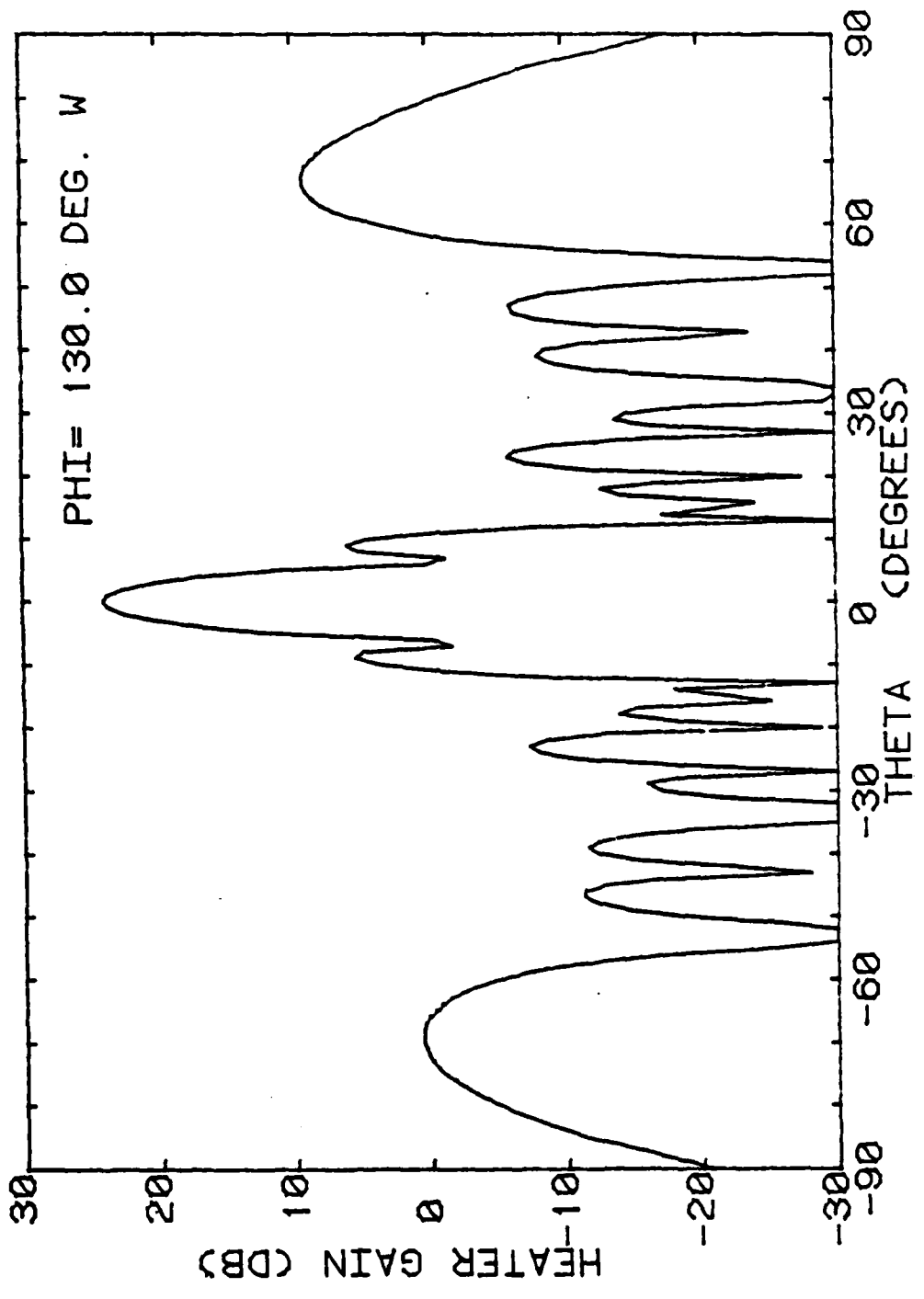


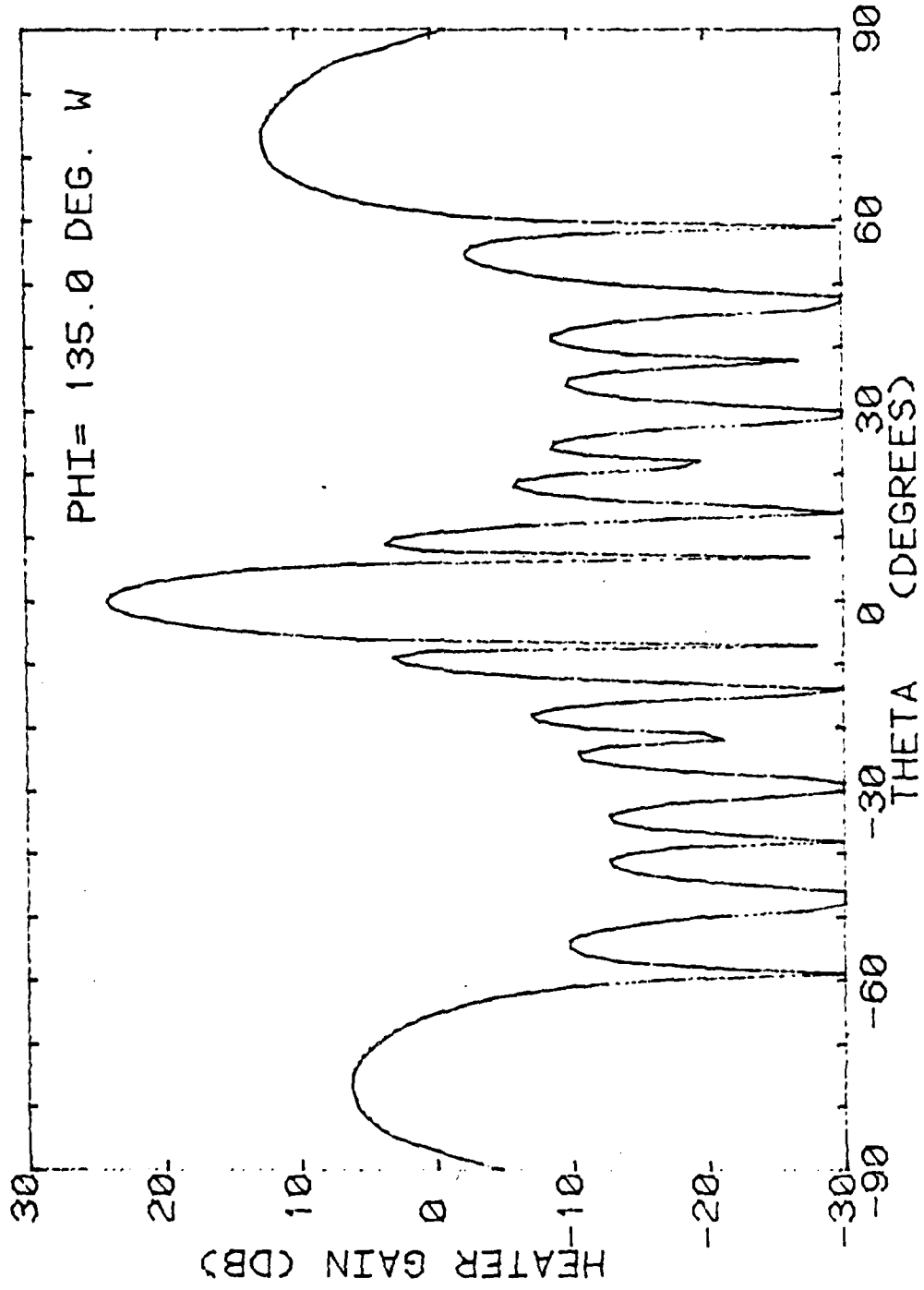


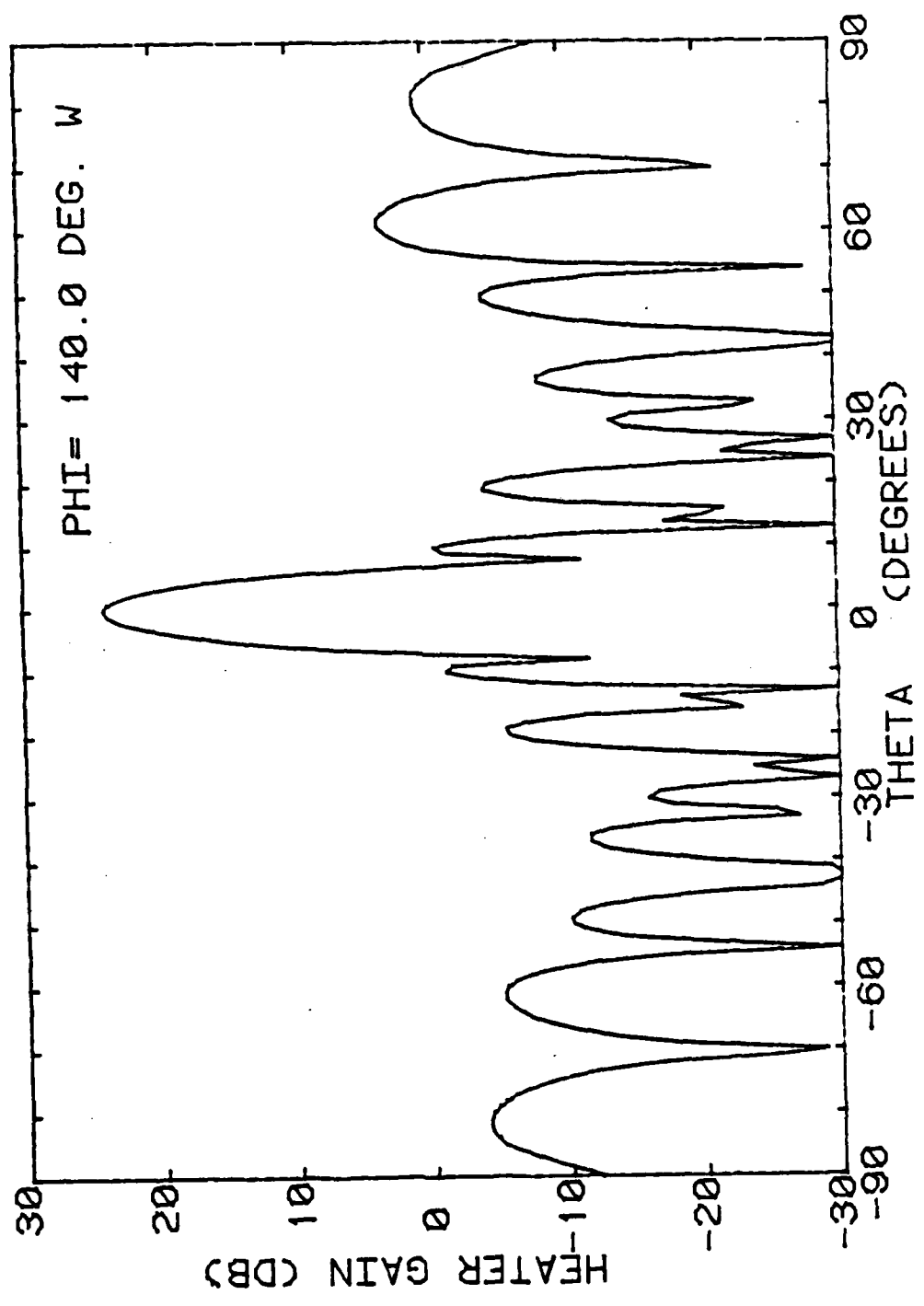


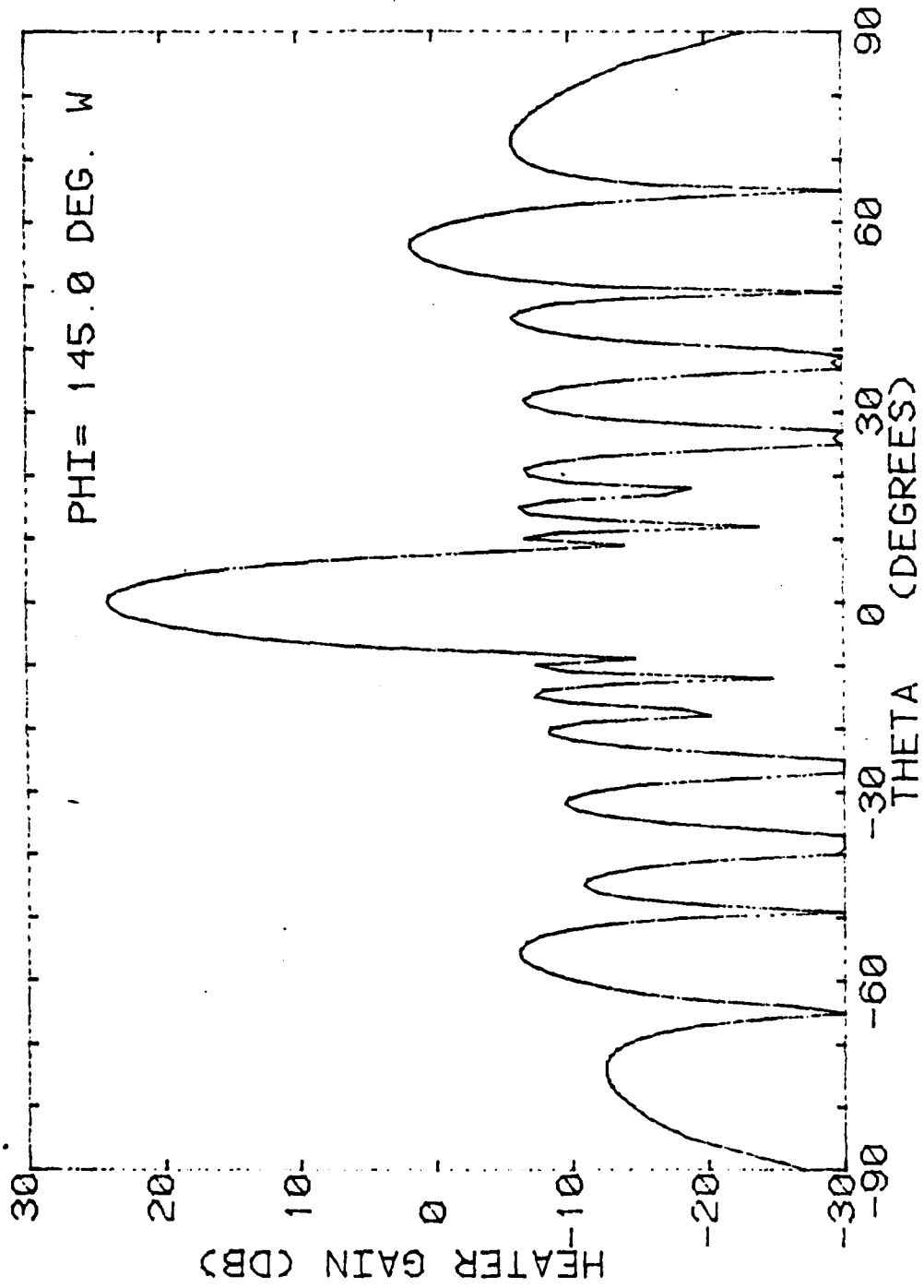


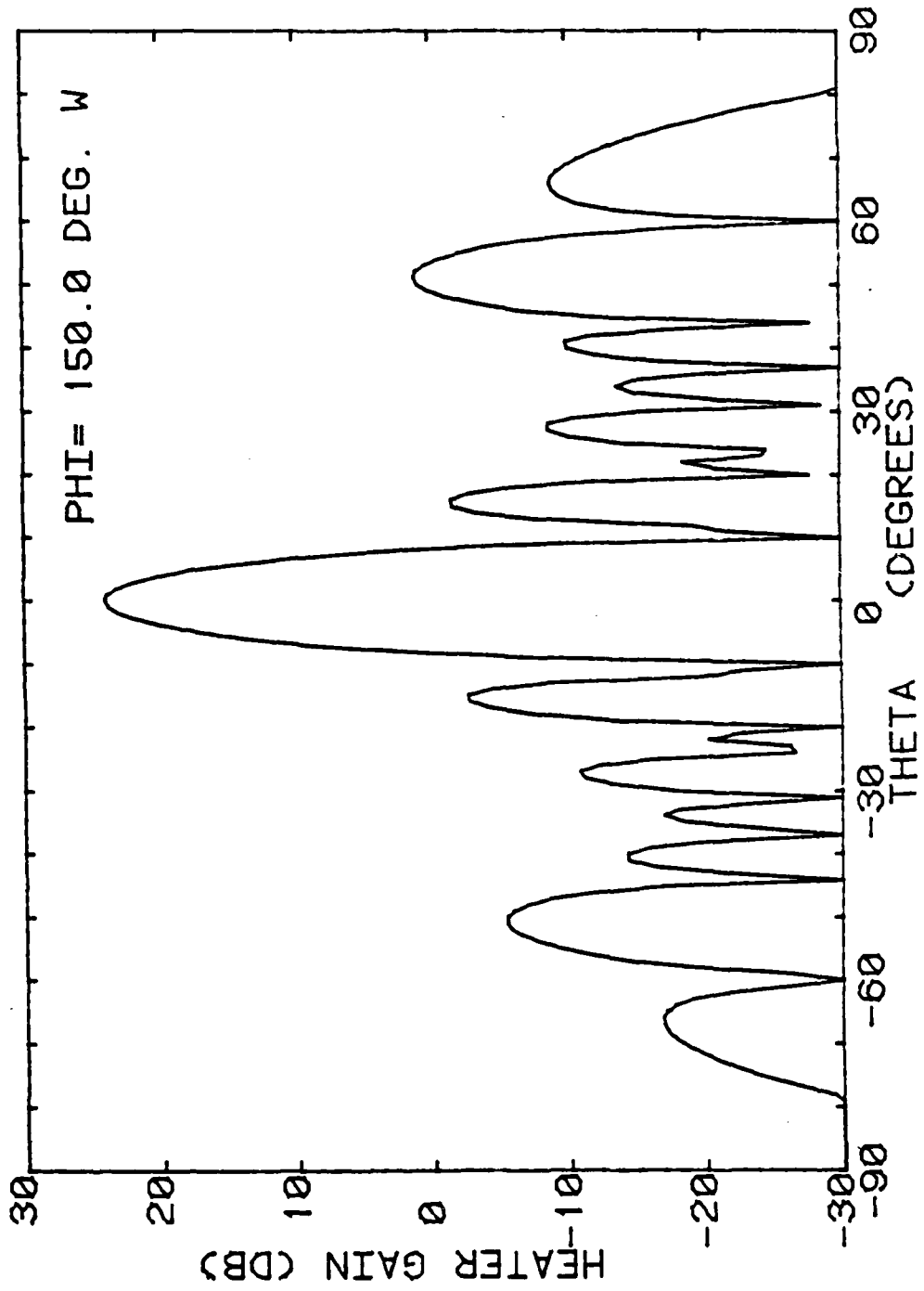


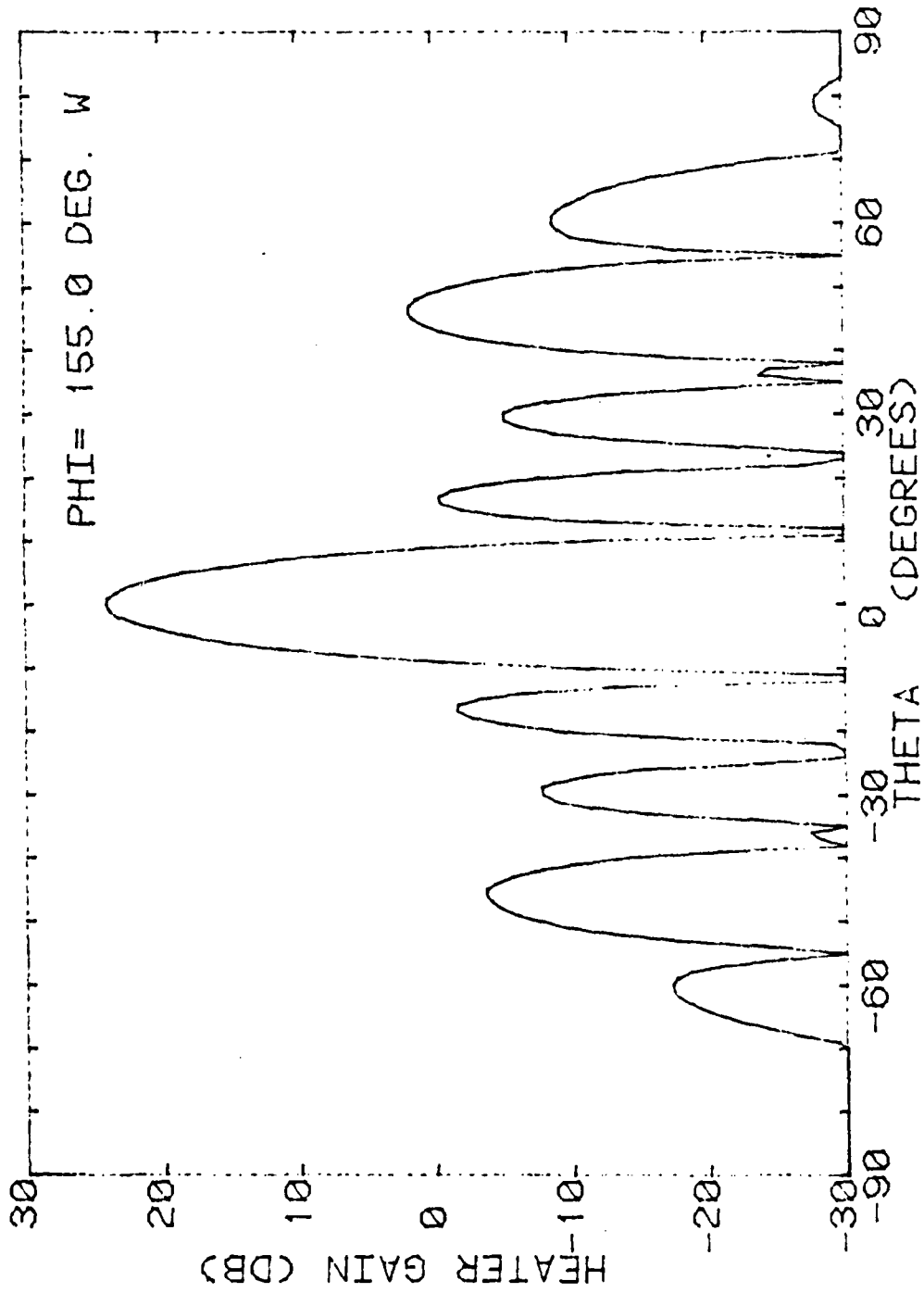


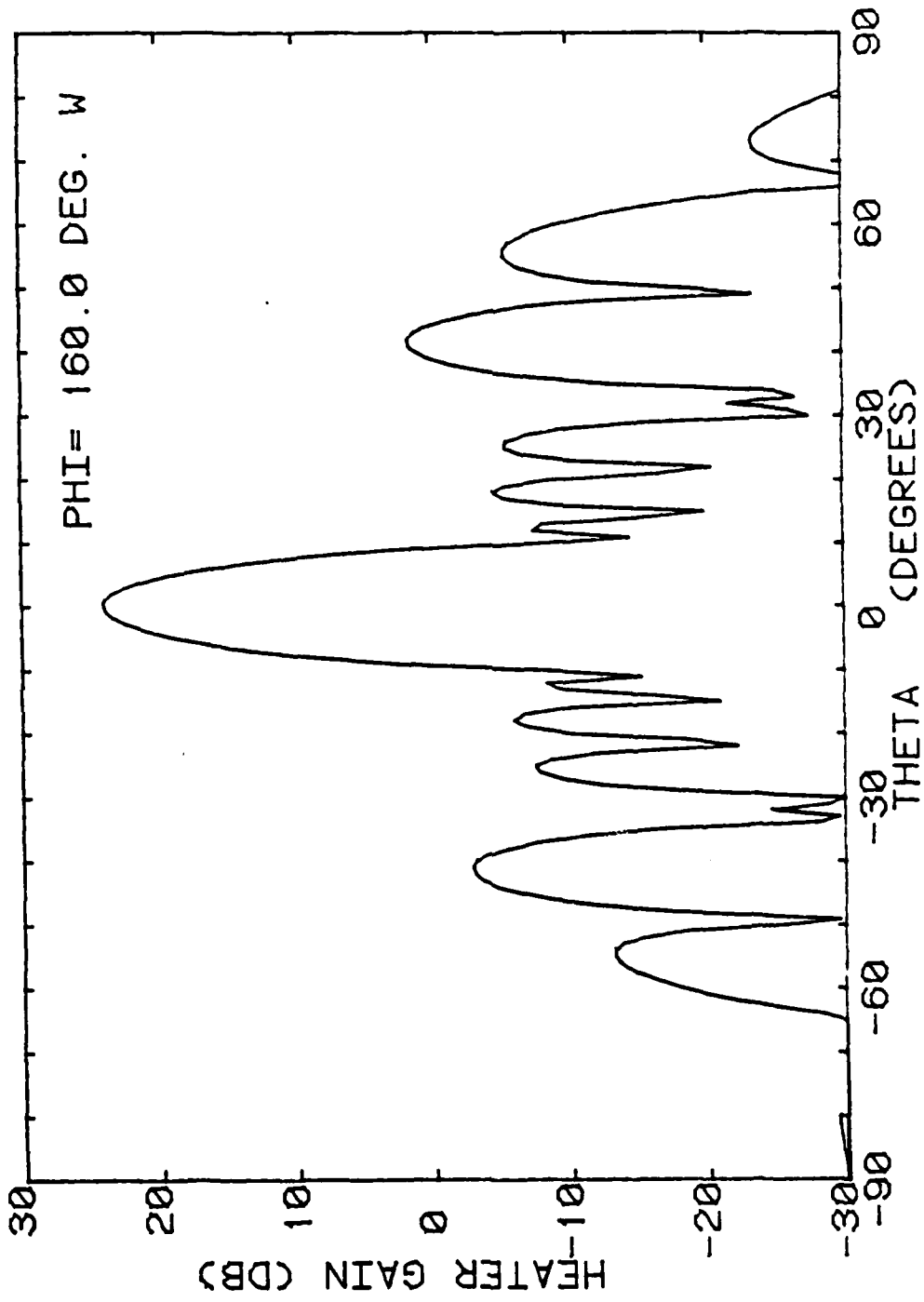


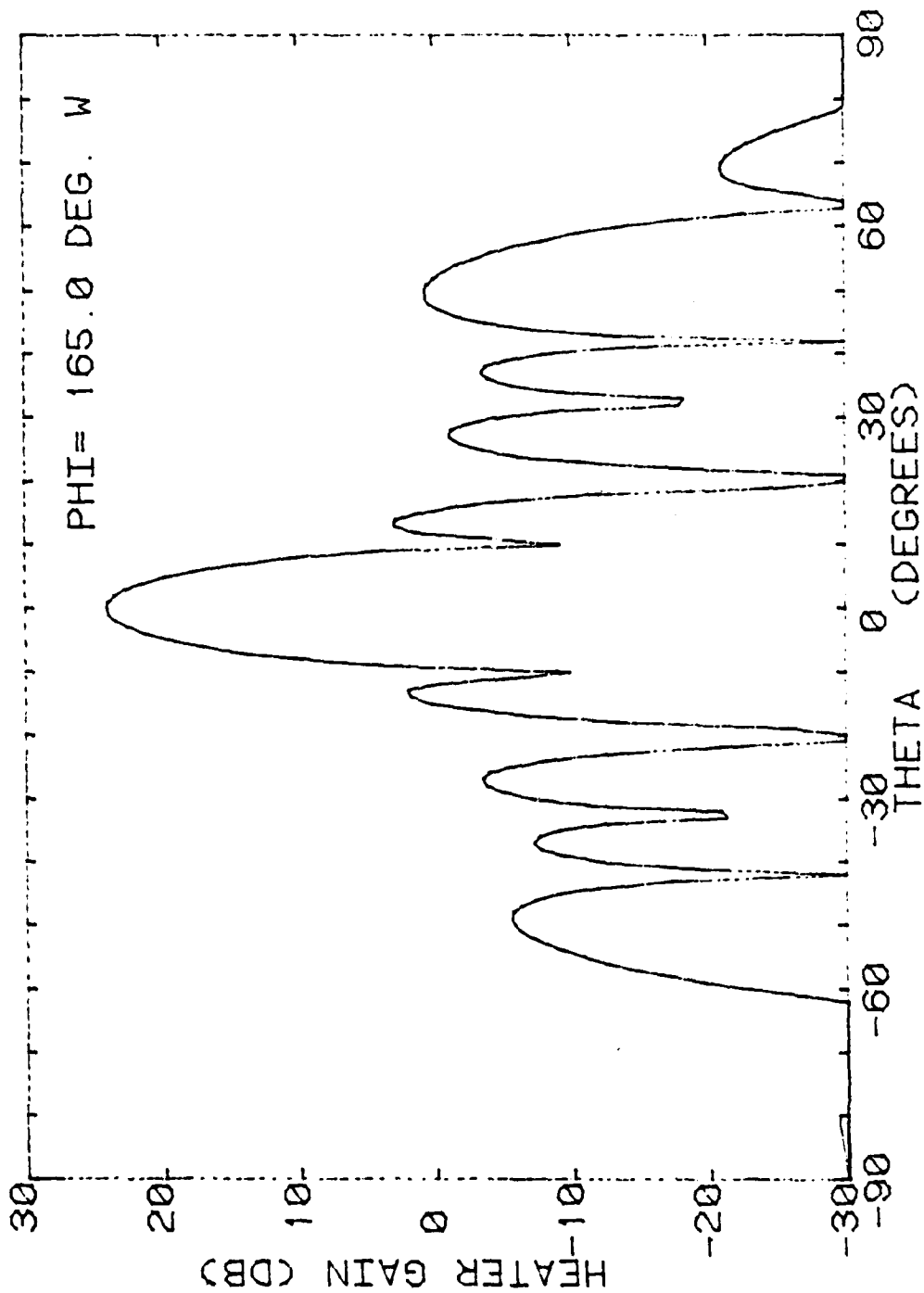


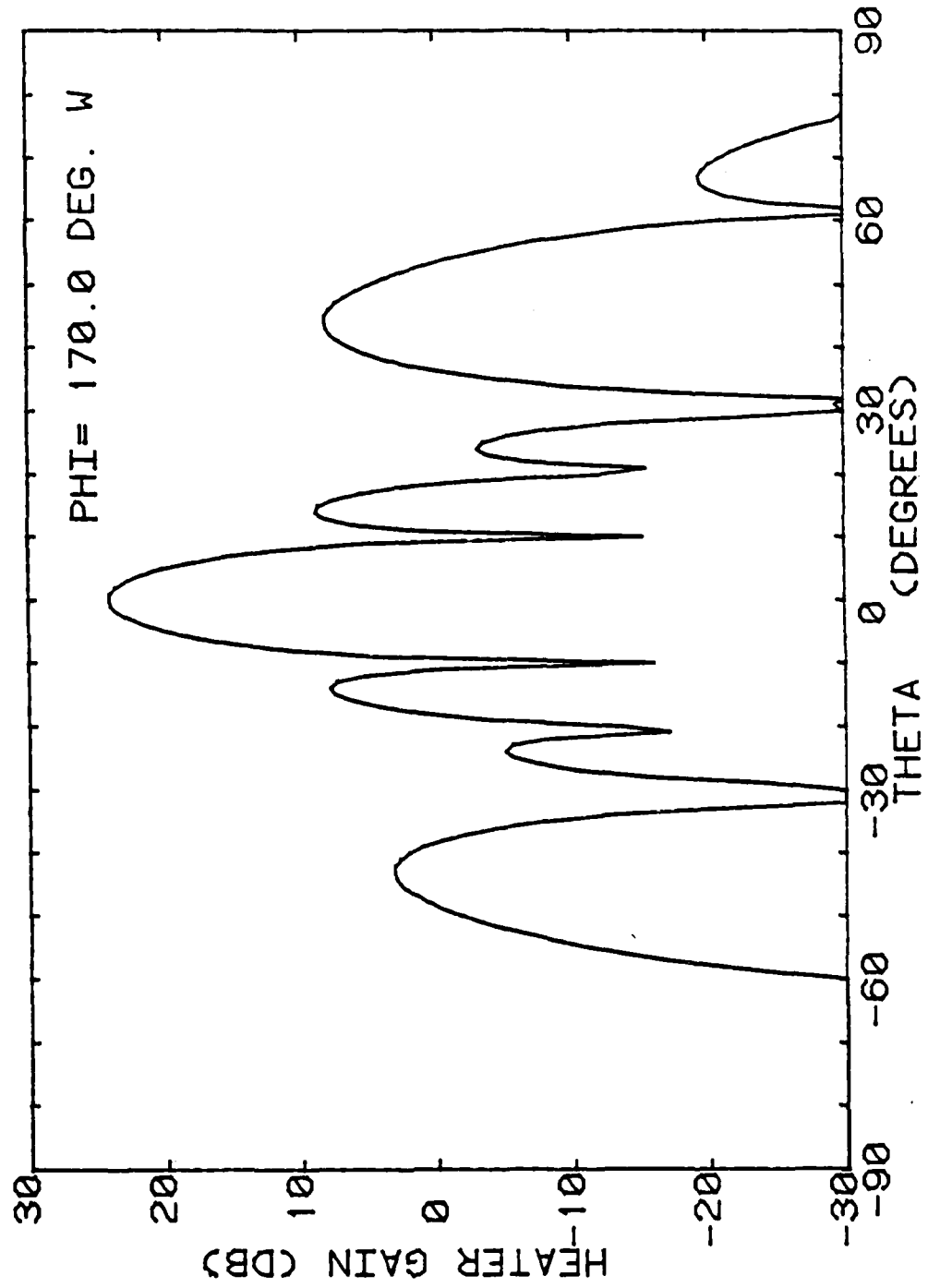


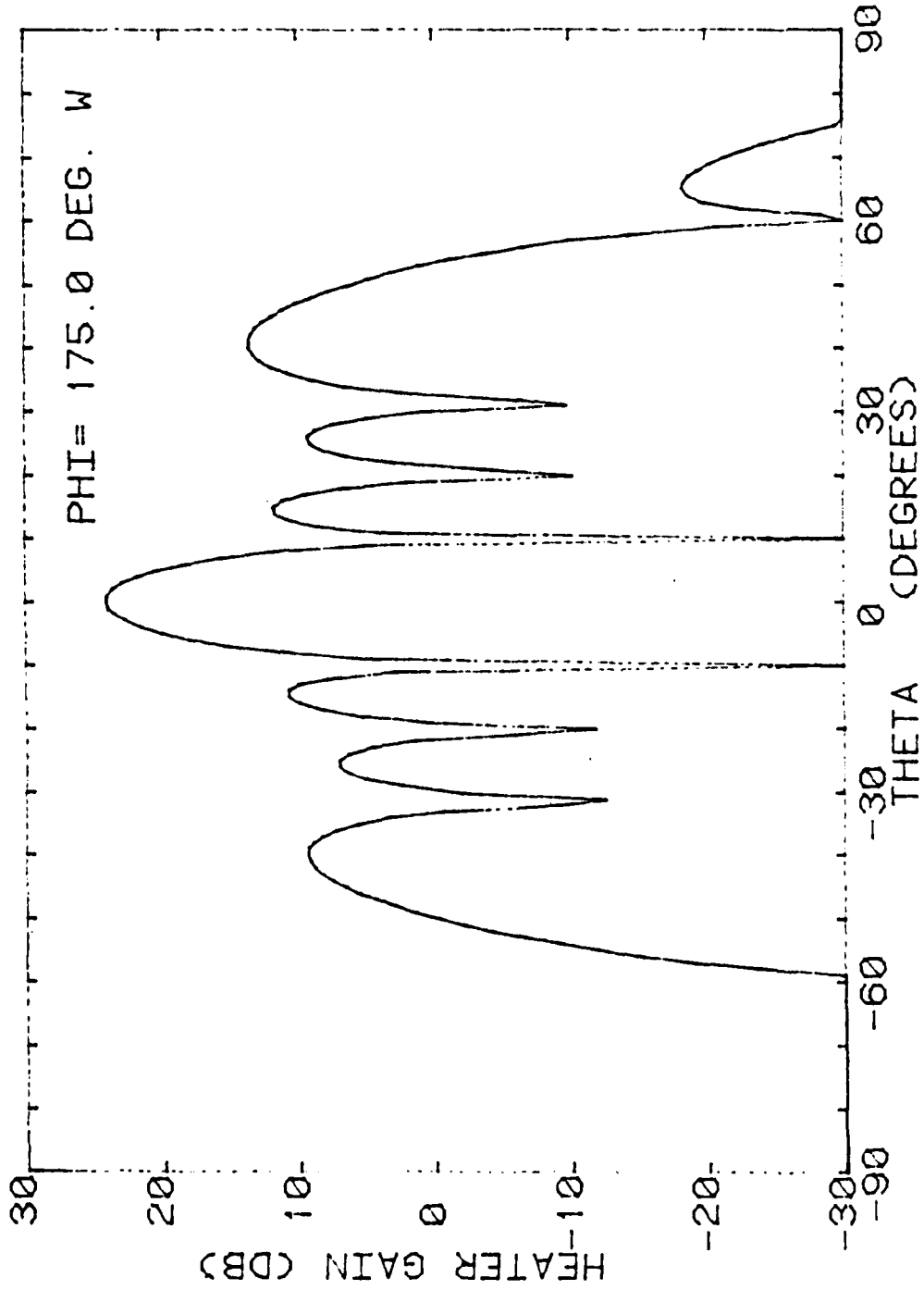












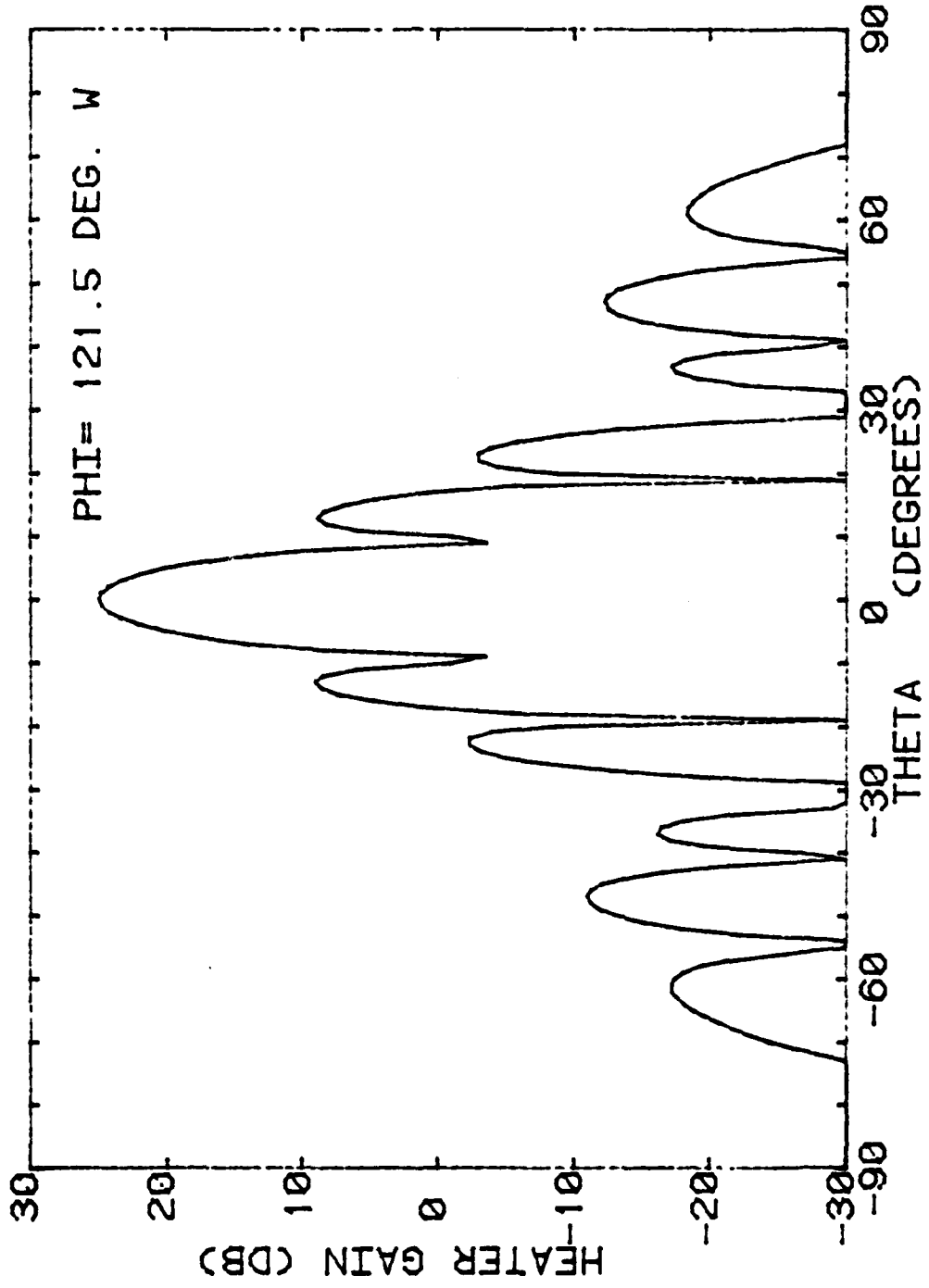


Figure 1-12.a Directive gain pattern in direction of Los Canos (3.17 Mhz)

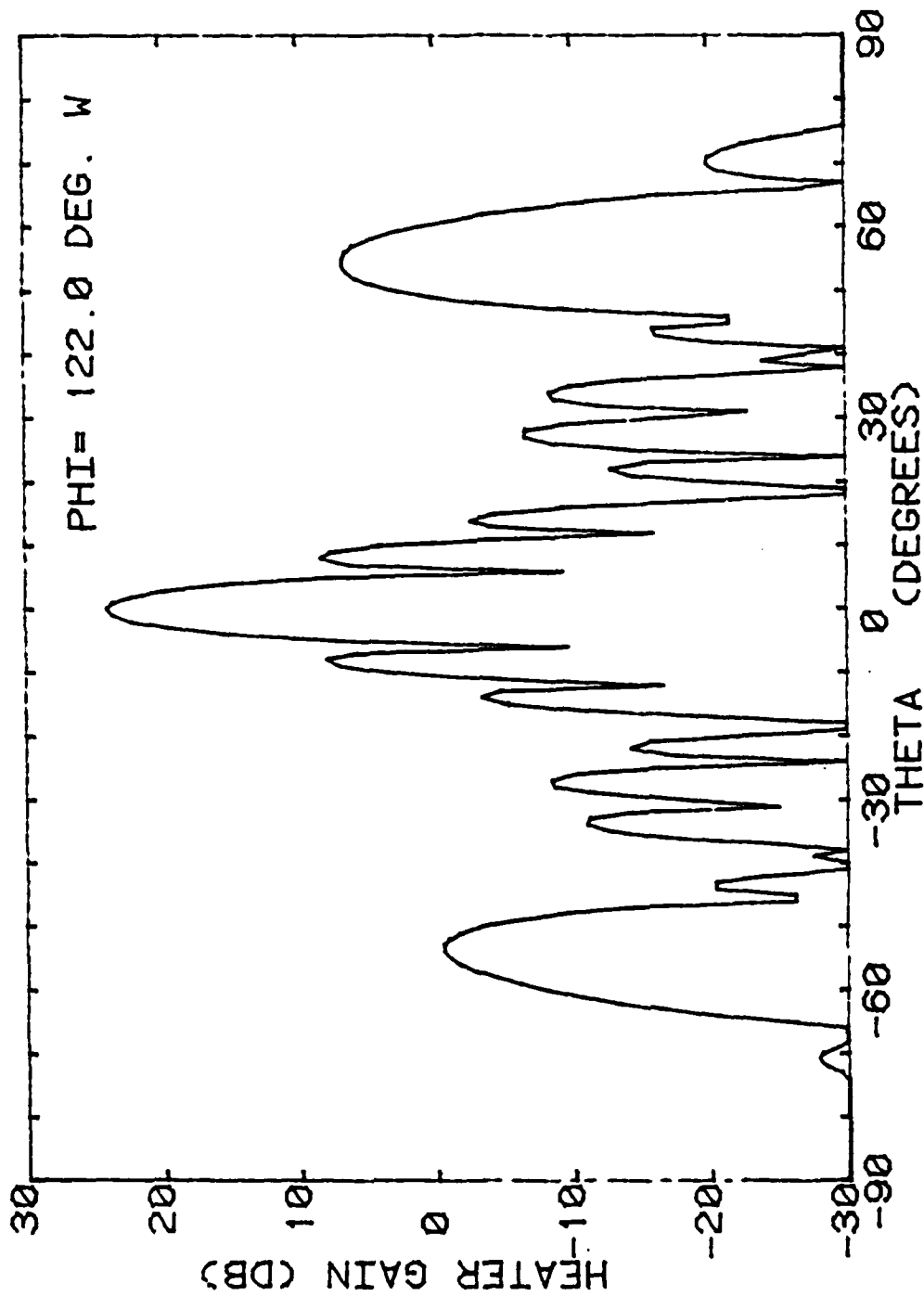


Figure 1-12.b Directive gain pattern in direction of Los Canos (5.1MHz)

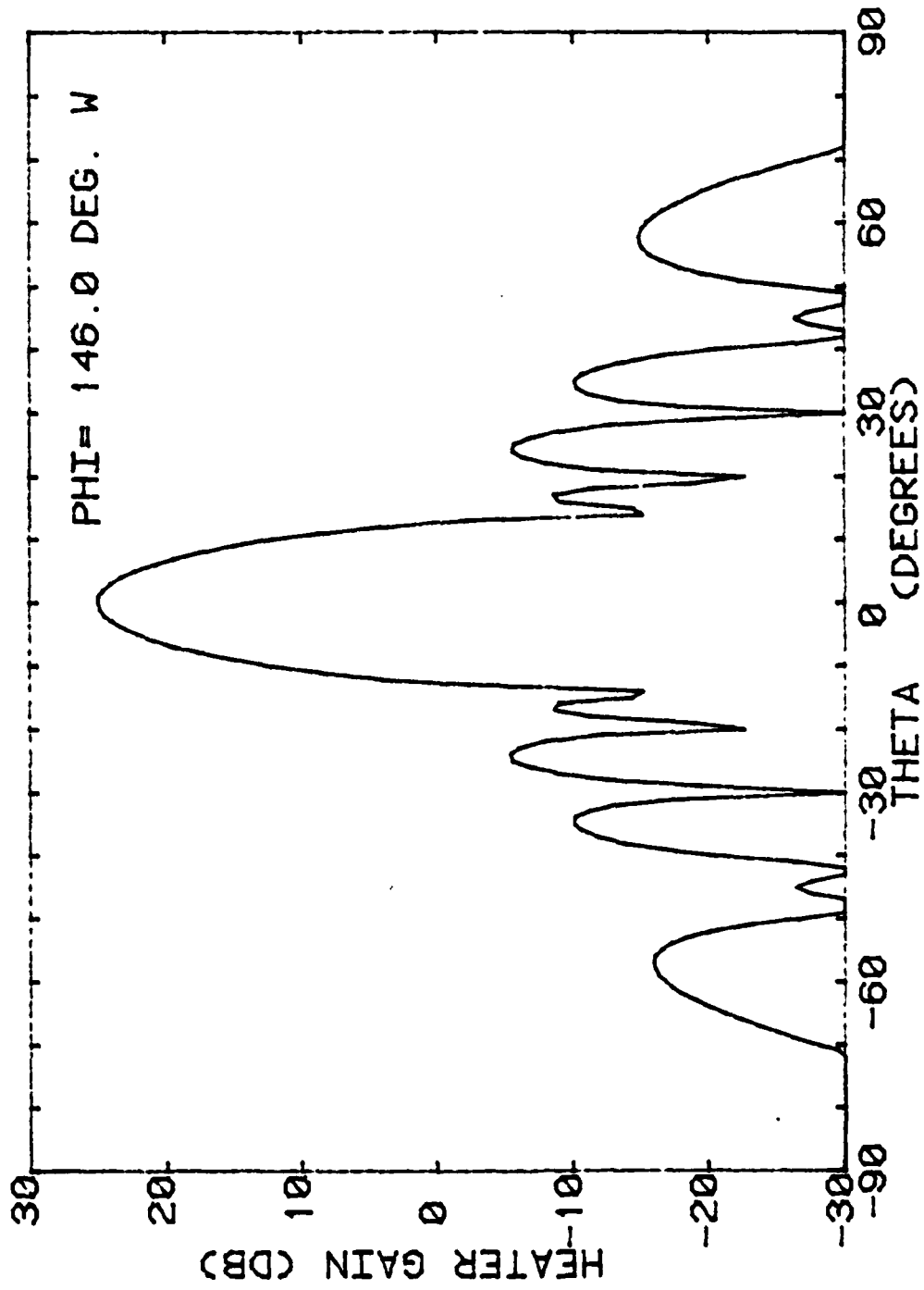


Figure 1-13.a Directive gain pattern in direction of Arecibo Observatory (3.17 Mhz)

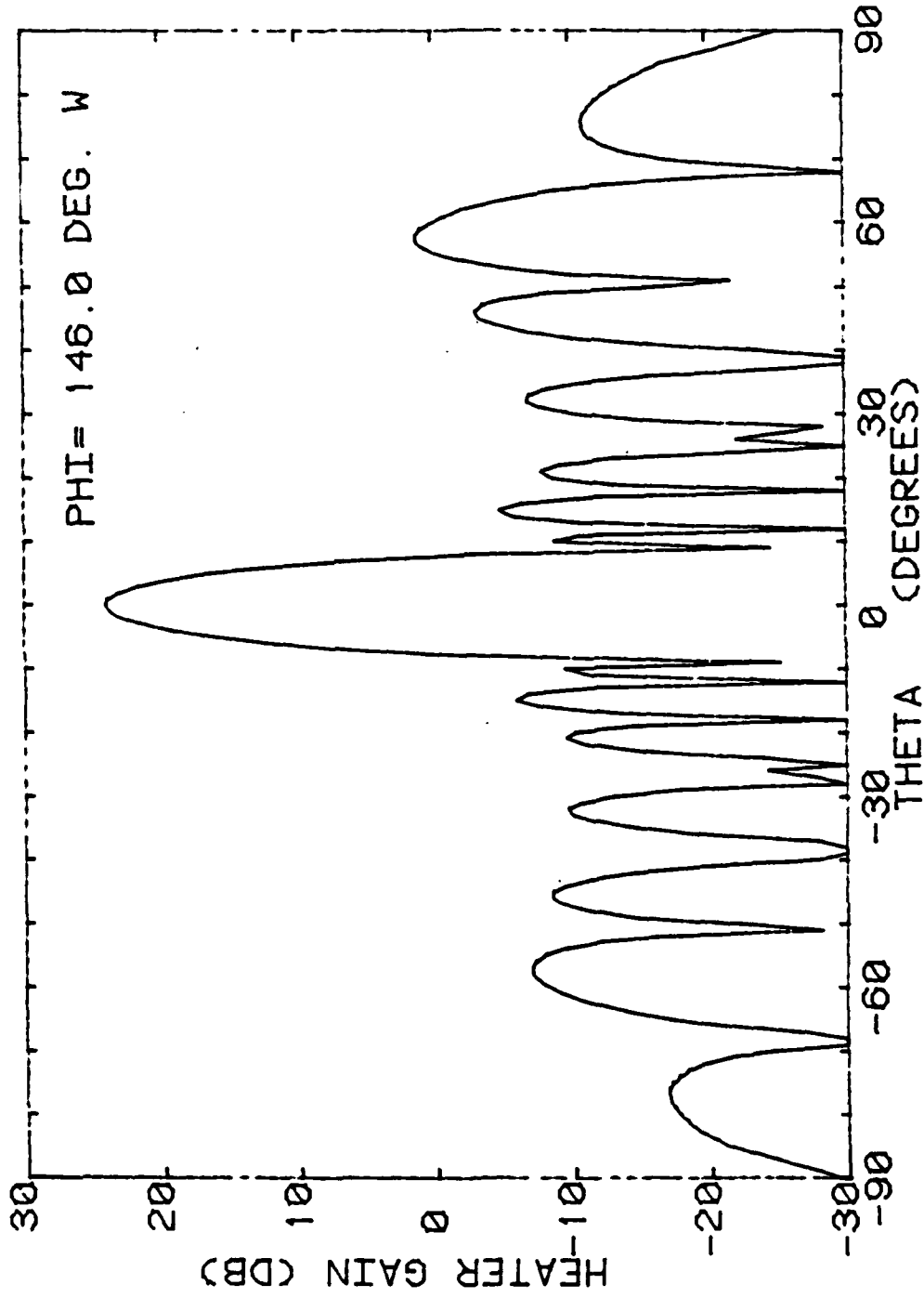


Figure 1-13.b Directive gain pattern in direction of Arecibo Observatory (5.1 MHz)

Grating lobes (lobes which have the same intensity as the main beam²) in the antenna factor will occur when both the numerator and denominator of both terms of equation (1-15) are zero. This will occur when equation (1-20) is satisfied.

$$\begin{aligned} \beta(d/2) \sin\theta \sin\phi &= 0 \text{ or } \pi \\ \beta(d/2) \sin\theta \cos\phi &= 0 \text{ or } \pi \end{aligned} \tag{1-20}$$

For the A.O. array $\beta d/2$ is equal to 2.82 and 4.54 for 3.17 and 5.1 MHz respectively. Since $\sin\theta \sin\phi$ and $\sin\theta \cos\phi$ are never larger than 1, the 3.17 MHz pattern does not and should not have grating lobes. However, grating lobes will be present in the 5.1 MHz pattern because 4.54 is larger than π .

These grating lobes will occur for the angles given in table II. As can be seen in the plots of figure (1-11) major lobes do occur at these angles. They are attenuated when they are multiplied by the elemental pattern during the calculations of the total array pattern.

<u>θ(deg)</u>	<u>ϕ(deg)</u>
43.8	0
43.8	90
43.8	180
43.8	270
78.1	45
78.1	135
78.1	225
78.1	315

Table II. Location of Grating Lobes in 5.1 MHz pattern

ELF/VLF ARRAY MODEL

Having established a directive gain pattern, it remains to relate the pattern to the heating of the ionosphere. Richardson⁸ has shown that the largest change in conductivity caused by the heating occurs

at approximately a 70 km altitude. As a zero order approximation, the heating pattern can be projected on a plane located at a 70 km altitude. The location and relative intensity of the major heated regions can be found. By placing elementary dipoles with the same relative amplitude of current at the respective heated regions, a field intensity at a receiving site on the ground can be calculated.

A correction factor is needed to project the pattern onto a 70 km altitude plane. The pattern shows the relative distribution of the power on a spherical surface of radius "R." Since the distance to a plane increases when "theta" is greater than zero, the power density on the plane will decrease from that indicated by the pattern. The power is being spread over a larger spherical surface as "R" is increased. The projection of the pattern on a plane surface requires multiplying the pattern by an attenuation factor of $\cos^2\theta$. This attenuation is plotted as a function of "theta" in figure (1-14).

Programs 6 and 7 in Appendix I were used to compute a pattern on a square section of a plane (122 km north and south by 122 km east and west of the main beam) at a 70 km altitude. The data were then plotted using Statistical Analysis System (SAS).^(9,10) Figures (1-15) and (1-16) show the relative power density on a 70 km altitude plane for 3.17 MHz and 5.1 MHz respectively. Only levels above that of an isotropic radiator (0 db) were plotted.

The 122 km dimension of the plotted data corresponds to an angle of "theta" equal to 60.2 degrees. The major lobes created by the antenna factor grating lobes at 78.1 degrees are not seen in figure (1-16). These lobes are for the most part attenuated to the zero reference level by the long propagation path. Table III gives the

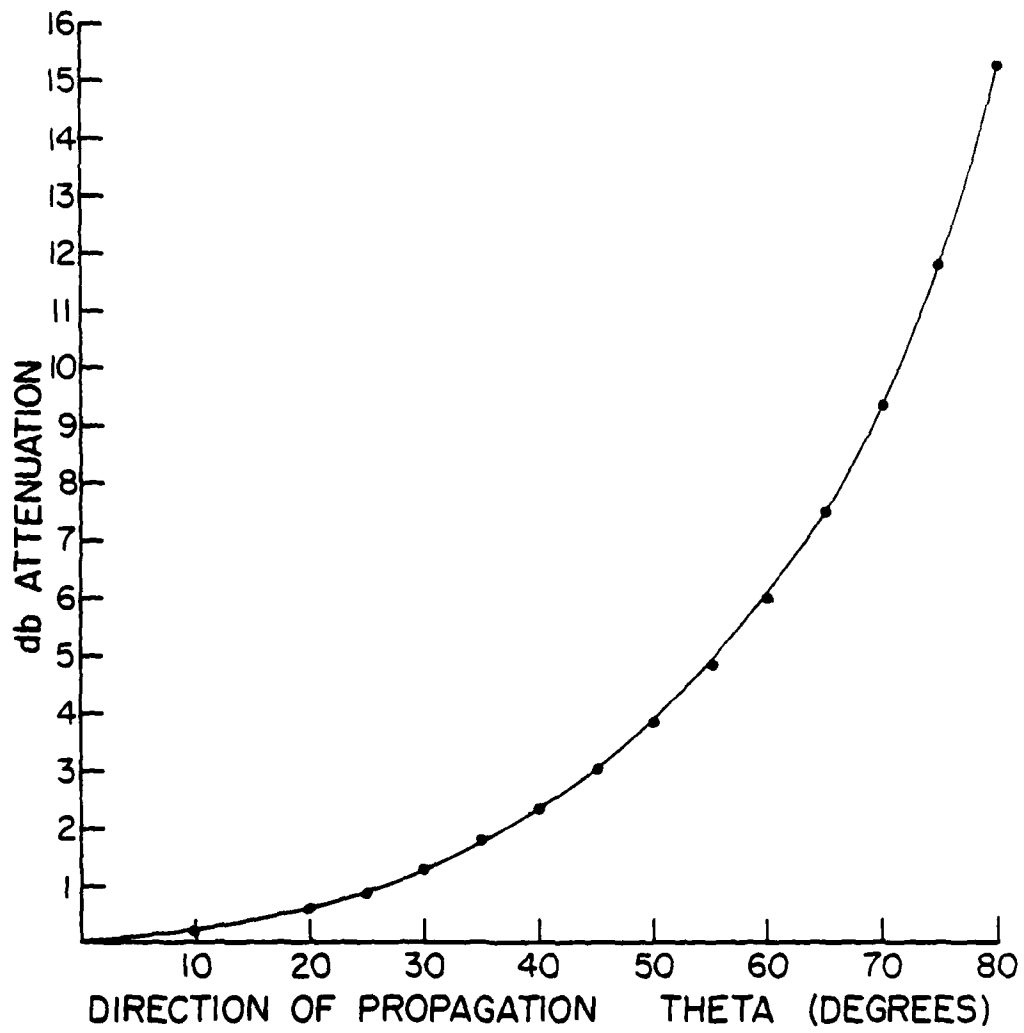


Figure 1-14 Propagation loss due to power spreading

RELATIVE POWER AT 70 KM

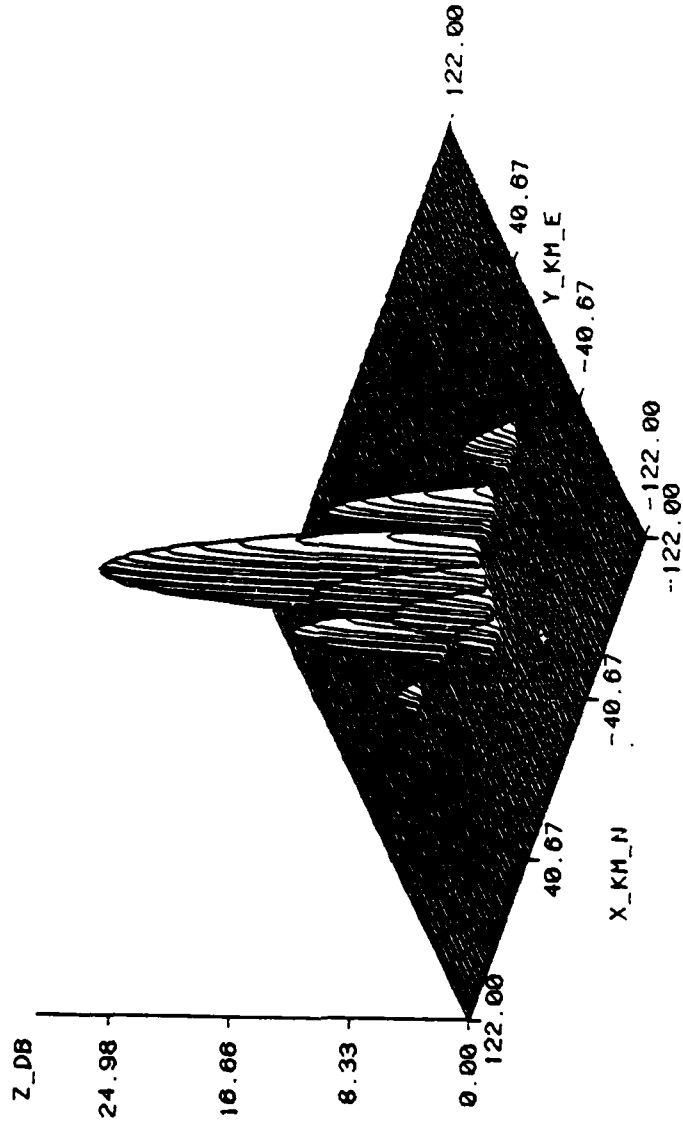


Figure 1-15 Relative HF power above isotropic on a 70 km altitude plane (3.17 MHz)

RELATIVE POWER AT 70 KM

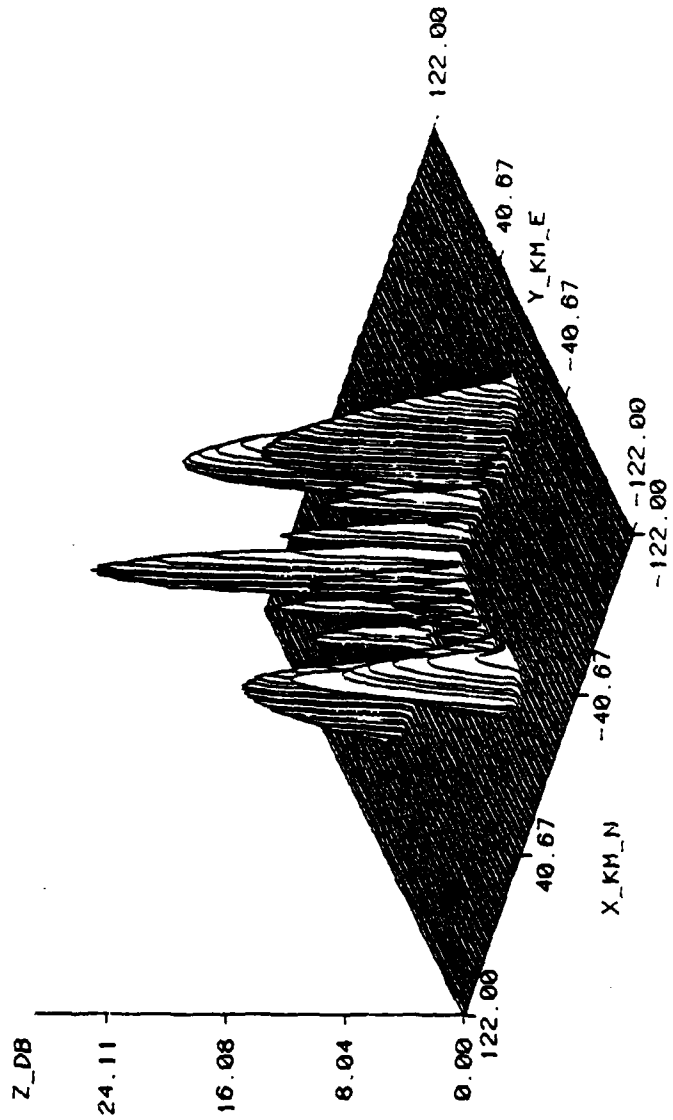


Figure 1-16 Relative HF power above isotropic on a 70 km altitude plane (5.1 MHz)

(deg)	(deg)	Directive Gain (db)	Path Attenuation (db)	Relative Power Density at 70 km altitude (db)	Location Center x (km) y (km)
77	45	6.251	-12.96	-6.71	214.4 214.4
71	135	7.568	- 9.75	-2.18	143.8 143.8
72	225	12.486	-10.20	2.29	152.3 152.3
73	315	11.399	-10.68	.72	161.9 161.9

Table III. Grating lobes location and power density on 70 km altitude plane.

location and relative power density of these lobes on the 70 km altitude plane.

Data on the lobes shown in figures (1-15) and (1-16) are given in tables IV and V. The current was assumed to be proportional to the square root of the power density. To find the average current per unit length for each lobe, the current was integrated over the area of the plane disturbed by the lobe and divided by the length of the region. The current distribution on the plane was approximated using a pyramid with a quadrilateral as a base. The length and width of the heated region are the diagonals of the quadrilateral base; the peak current is the altitude. The volume of the pyramid is equal to one third of the area of the base times the altitude.¹⁰ The area of the quadrilateral base is one half of the product of the diagonals times the sine of the angle between the diagonals.¹¹ So the formula for calculating the average current per unit length becomes equation (1-21).

$$I_{av} = (1/3)[(1/2)a \cdot b \sin 90](I_p/a) = (1/6) b I_p \quad (1-21)$$

a = length (diagonal)
 b = width (diagonal)
 I_p = peak current (altitude)

In this zero order approximation each of the lobes is represented as an elementary current element source. The source has a current equal to the average current calculated in equation (1-21), a length equal to the length of the lobe, and is located at the x,y coordinates of the peak power density for the lobe on the 70 km altitude plane. The location, length, and average current are summarized in tables IV and V.

Location x(km) y(km)		P _d Relative Power Density (db)	a Length (km)	b Width (km)	I _p Peak Current (10P _d /20)	I _{av} Average Current (1/6 a·b·I _p)a
-63	0	3.022	24	12	1.416	2.832
-30	0	10.87	22	18	3.495	7.485
0	0	24.983	40	20	17.748	59.16
30	0	10.215	22	16	3.242	8.645
62	0	1.295	15	7	1.161	1.355
0	-38	1.624	19	7	1.207	1.408
0	-25	5.875	26	9	1.967	2.951
0	-14	11.239	32	9	3.647	5.471
0	14	11.239	32	9	3.647	5.471
0	25	5.875	26	9	1.967	2.951
0	38	1.624	16	7	1.206	1.407

Table IV. Lobe Statistics for Frequency = 3.17 MHz

Location		P _d Relative Power Density	a Length (km)	b Width (km)	I _p Peak Current (10P _d /20)	I _{av} Average Current (1/6 a·b·I _p)/a
x(km)	y(km)	(db)				
-60.5	0	15.519	54	14	5.970	13.93
-34.0	0	10.141	14	14	3.214	7.499
-18.0	0	12.205	12	10	4.076	6.793
0	0	24.113	24	12	16.056	32.113
18.0	0	11.134	12	10	3.603	6.006
33.0	0	8.306	14	10	2.530	4.217
59.0	0	11.279	43	14	3.664	8.549
0	-65	14.301	26	28	5.189	24.213
0	-48	5.331	15	8	1.847	2.463
0	-38	3.715	12	6	1.534	1.534
0	-30	3.586	12	5	1.511	1.259
0	-22	4.825	14	5	1.743	1.452
0	-15	6.969	16	5	2.231	1.859
0	-9	11.079	20	6	3.581	3.581
0	9	11.079	20	6	3.581	3.581
0	15	6.969	17	5	2.231	1.859
0	22	4.825	15	5	1.743	1.452
0	30	3.586	14	5	1.511	1.259
0	38	3.715	14	6	1.534	1.534
0	48	5.331	18	8	1.847	2.463
0	65	14.301	28	28	5.189	24.213

Table V. Lobe Statistics for Frequency = 5.1 MHz.

The magnetic field due to a current element is given in equation⁵ (1-22). The source is located at the origin and along the Z' axis. H_{ϕ}' is the magnetic field intensity in the source coordinate system X', Y', Z' . Since H_{ϕ}' is a vector and there are a number of sources at different locations whose fields need to be superimposed at the observation point, it would be beneficial to translate the fields to the observation frame of reference, X, Y, Z .

$$H_{\phi}' = [(Idl)/4\pi r'] \sin\theta' e^{-j\beta r'} [j\beta + (1/r')] \quad (1-22)$$

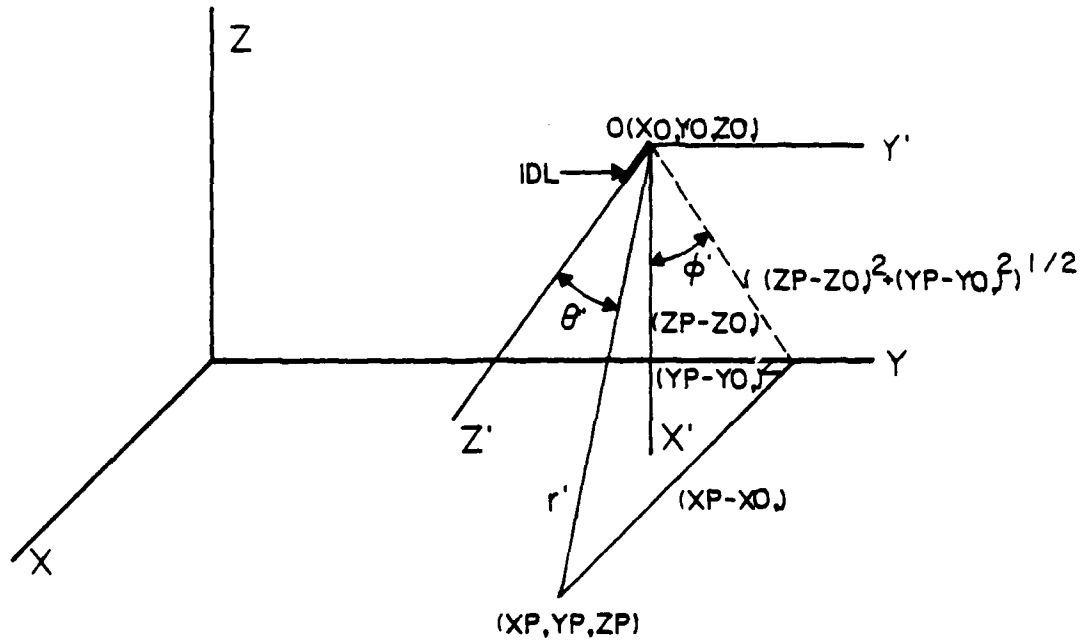
The source and observation coordinate systems are shown in figure (1-17). The source is located at point $O(X_0, Y_0, Z_0)$ and along the Z' -axis, which is parallel to the X -axis in the observation point coordinate system. The Y - and Y' -axis are also parallel and the X' -axis is in the negative z direction. From the geometry of the figure the relationships given in equation (1-23) can be found. In addition, using the transformation from spherical coordinates to Cartesian coordinates, equation¹² (1-24), the expression for the magnetic field, equation (1-22), can be transformed to the observation point coordinates.

$$\begin{aligned} X' &= XP - X_0 \\ Y' &= YP - Y_0 \\ Z' &= ZP - Z_0 \\ r' &= (XP - X_0)^2 + (YP - Y_0)^2 + (ZP - Z_0)^2)^{1/2} \end{aligned} \quad (1-23)$$

$$\sin\theta' = \frac{[(ZP - Z_0)^2 + (YP - Y_0)^2]^{1/2}}{r'}$$

$$\begin{aligned} H_y &= H_{y'} = H_{\phi}'(x') / \sqrt{x'^2 + y'^2} \\ -H_z &= H_{x'} = -H_{\phi}'(y') / \sqrt{y'^2 + x'^2} \\ H_x &= H_{z'} = 0 \end{aligned} \quad (1-24)$$

The phase term $e^{-j\beta r'}$ is important when performing the superposition of the fields from all of the sources at the observation



OBSERVATION COORDINATES X,Y,Z
 SOURCE COORDINATES X',Y',Z'

Figure 1-17 Relative orientation of observation and source coordinates

point. Small differences in the value of r' can be magnified by causing a significant change in the term's value. Thus it would affect the summation of the real and imaginary parts of all the sources.

An additional term must be added to $\beta r'$ to maintain the proper relationship between the sources. This is because the HF heating pulse must travel different path lengths to the source region. The difference in path lengths causes a time delay between the sources, equation (1-25). This delay can be expressed in terms of an additional path length ΔR , equation (1-26). This allows the phase term, $e^{-j\beta r'}$, in equation (1-22) to be expressed as $e^{-j\beta(r'+\Delta R)}$. By combining the phase delay, equations (1-23) and (1-24) into equation (1-22), an expression for the magnetic field intensity at the point of observation and in terms of the observation point coordinate system can be found, equation (1-27).

$$\text{Time delay} = \frac{(Z_0^2 + Y_0^2 + X_0^2)^{1/2} - r_0}{c} \quad (1-25)$$

$$\begin{aligned} \text{Phase delay} &= \frac{(Z_0^2 + Y_0^2 + X_0^2)^{1/2} - r_0}{c} = (2\pi/\lambda)[(Z_0^2 + Y_0^2 + X_0^2)^{1/2} - r_0] \\ &= \beta \Delta R \end{aligned} \quad (1-26)$$

$$\begin{aligned} \vec{H} &= \frac{Idl[(Z_P - Z_0)^2 + (Y_P - Y_0)^2]^{1/2}}{4\pi[(X_P - X_0)^2 + (Y_P - Y_0)^2 + (Z_P - Z_0)^2]^{1/2}} e^{-j\beta[(X_P - X_0)^2 + (Y_P - Y_0)^2 + \\ & \quad (Z_P - Z_0)^2]^{1/2} + (Z_P^2 + Y_0^2 + X_0^2)^{1/2} - r_0} \left[\frac{(X_P - X_0)}{[(X_P - X_0)^2 + (Y_P - Y_0)^2]^{1/2}} \hat{a}_y + \right. \\ & \quad \left. \frac{(Y_P - Y_0)}{[(X_P - X_0)^2 + (Y_P - Y_0)^2]^{1/2}} \hat{a}_z \right] \times \left[j\beta + \frac{1}{[(X_P - X_0)^2 + (Y_P - Y_0)^2 + (Z_P - Z_0)^2]^{1/2}} \right] \end{aligned} \quad (1-27)$$

Programs 8 and 9 Appendix I were written to calculate the strength of the magnetic field at an observation point due to the two source patterns of figures (1-15) and (1-16). For each of the two cases a current element was placed at the location of the lobes, and a total magnetic field was calculated at an observation point corresponding to Los Canos. The calculations were carried out for the frequencies listed in table VI. These frequencies correspond to the frequencies used during the ELF/VLF experiments conducted in Puerto Rico. Figure (1-18) shows the result of the calculation. It is a plot of relative magnetic field strength as a function of frequency.

<u>Frequency</u> (kHz)	<u>Frequency</u> (kHz)
.479386	2.5
1.0	2.793296
1.25	3.144654
1.506024	3.448276
2.0	4.0
2.293578	4.464286
	5.0

Table VI. Experimental Frequencies

In order to determine the effect of the lobes on the value of the magnetic field at the observation point, a calculation was done with only the main lobe acting as the source. The plot of the relative field strength as a function of frequency is given in figure (1-19). A comparison of figures (1-18) and (1-19) shows that the lobes have a significant effect on determining the frequency response of the ELF/VLF radiating source. The location of the relative maximums and minimums in both 5.1 MHz and 3.17 MHz generated ELF/VLF response have shifted in frequency. A significant reduction in the field strength occurs between 2.5 to 4.5 kHz for the 5.1 MHz generated Y component.

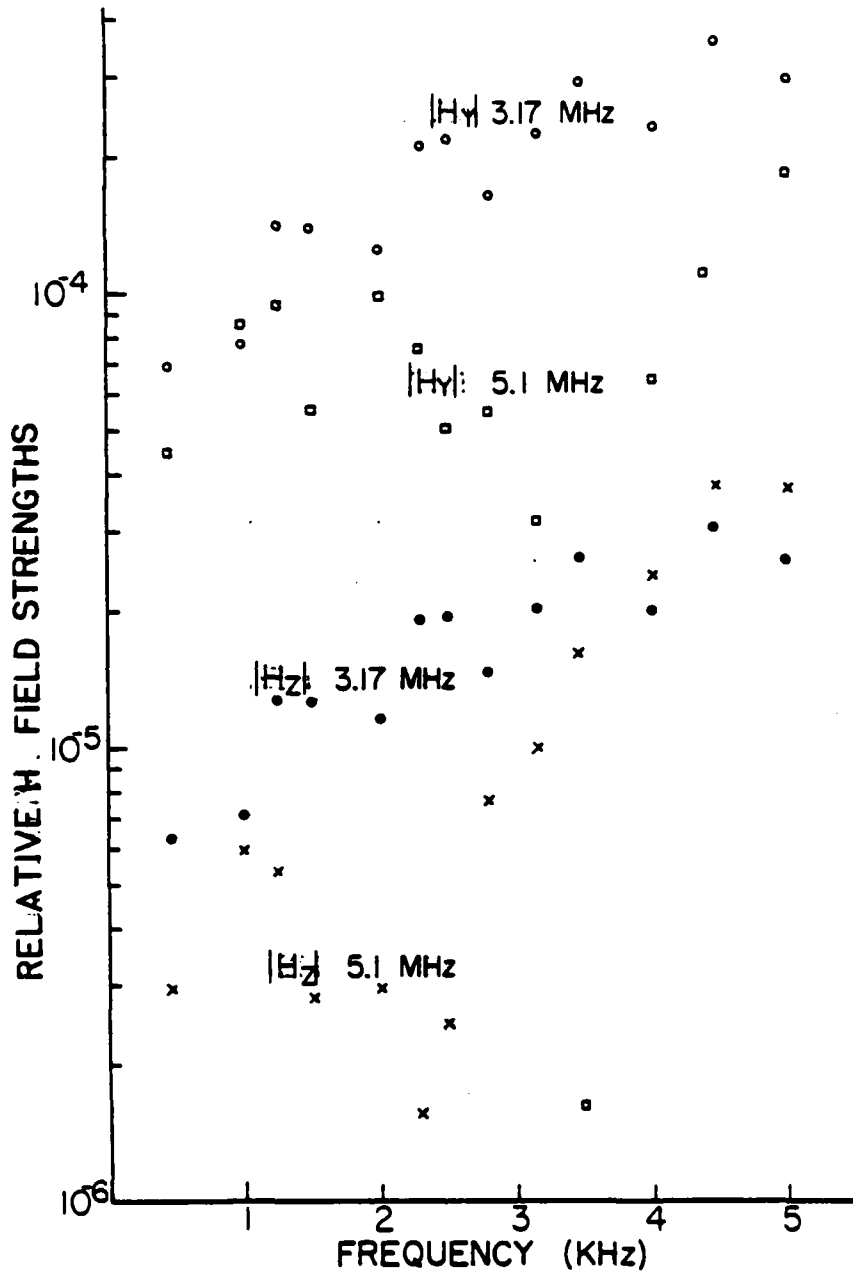


Figure 1-18 Current element array VLF/ELF response

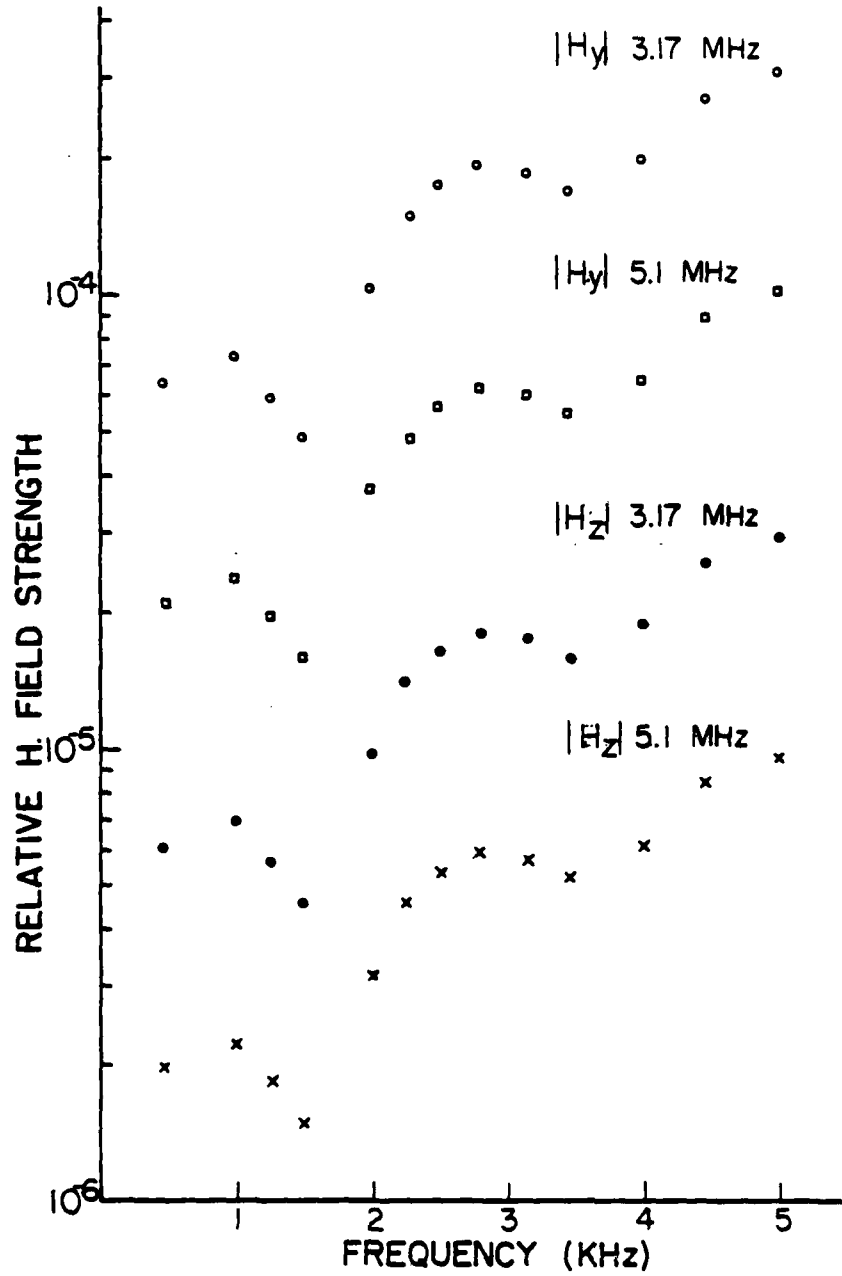


Figure 1-19 Main beam current element VLF/ELF response

In addition to computing the relative field strengths for the test frequencies, a calculation was made in 100 Hz frequency steps from from 500 Hz to 5 kHz. The result is plotted in figure (1-20). As can readily be seen from the figure, two deep minimums occur for the 5.1 MHz generated ELF/VLF. One occurs between 600 Hz and 700 Hz, and the other occurs between 3400 Hz and 3600 Hz. The 3.17 MHz generated ELF/VLF has only one deep minimum, which is located between 700 Hz and 900 Hz.

A calculation was made for an alternate receiving site. This site is located at Salinas, Puerto Rico, 17.98° N and 66.30° W geographic latitude and longitude respectively. The frequency response results for the two HF heating patterns are shown in figure (1-21). Comparison of figures (1-20) and (1-21) shows the changes in the response due to the different propagation paths. The first striking difference is the disappearance of the null in between 3 and 4 KHz in the 5.1 MHz pattern generated VLF. Second, the relative maximums and minimums for the Salinas location have been shifted to a lower frequency. In general, the relative field strengths are lower for the Salinas site due to the increase in propagation distance.

CONCLUSION

This completes the description of the zero order approximation. In summary, a pattern for the Arecibo Observatory has been calculated using the technique of pattern multiplication and AMP. The calculated pattern for the "PHI" equal "0" plane compares with the experimentally measured pattern. The pattern shows that there is enough power in the side lobes and grating lobes to cause significant heating at a 70 km

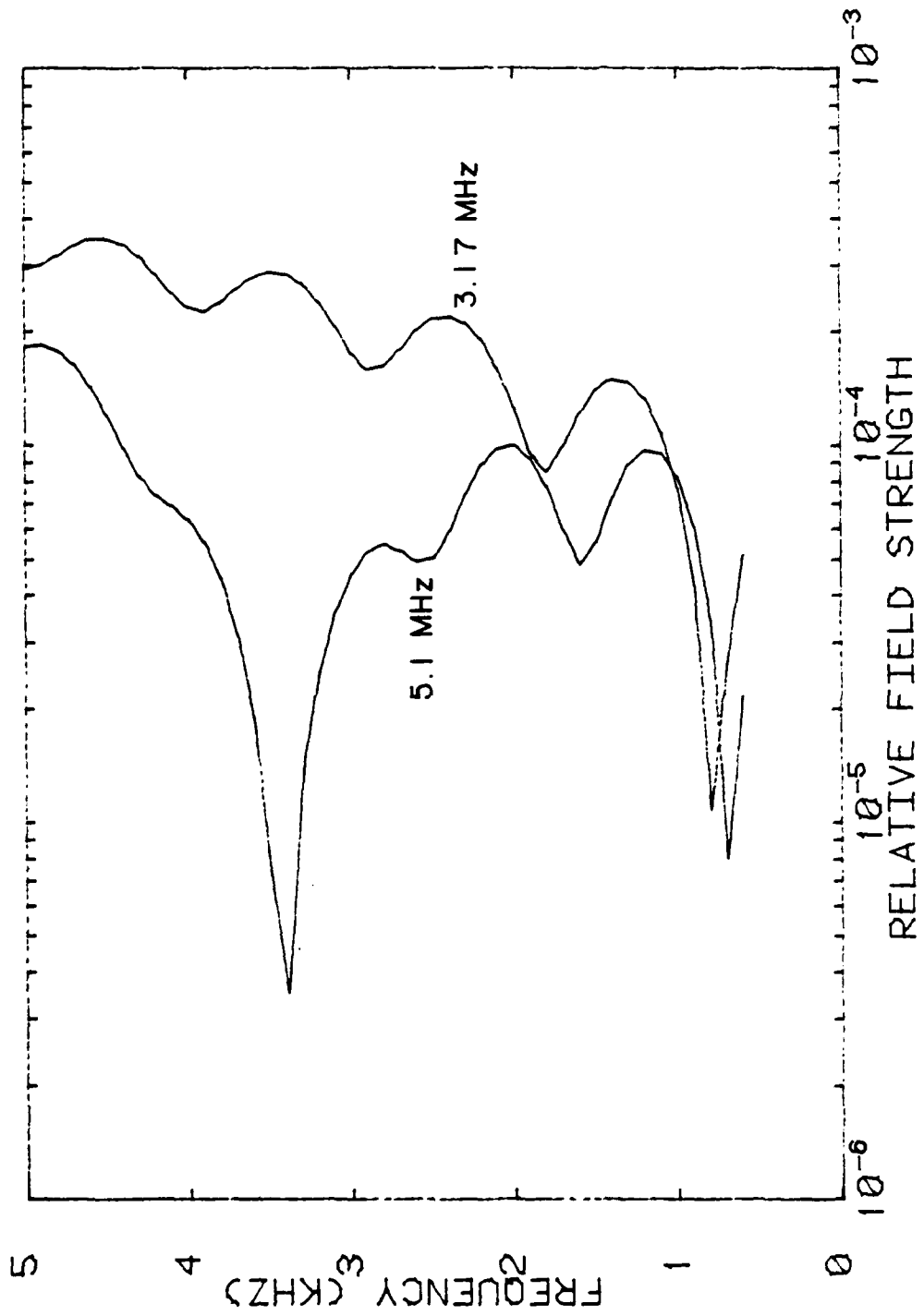


Figure 1-20 Current element array VLF/ELF response. Y component of magnetic field

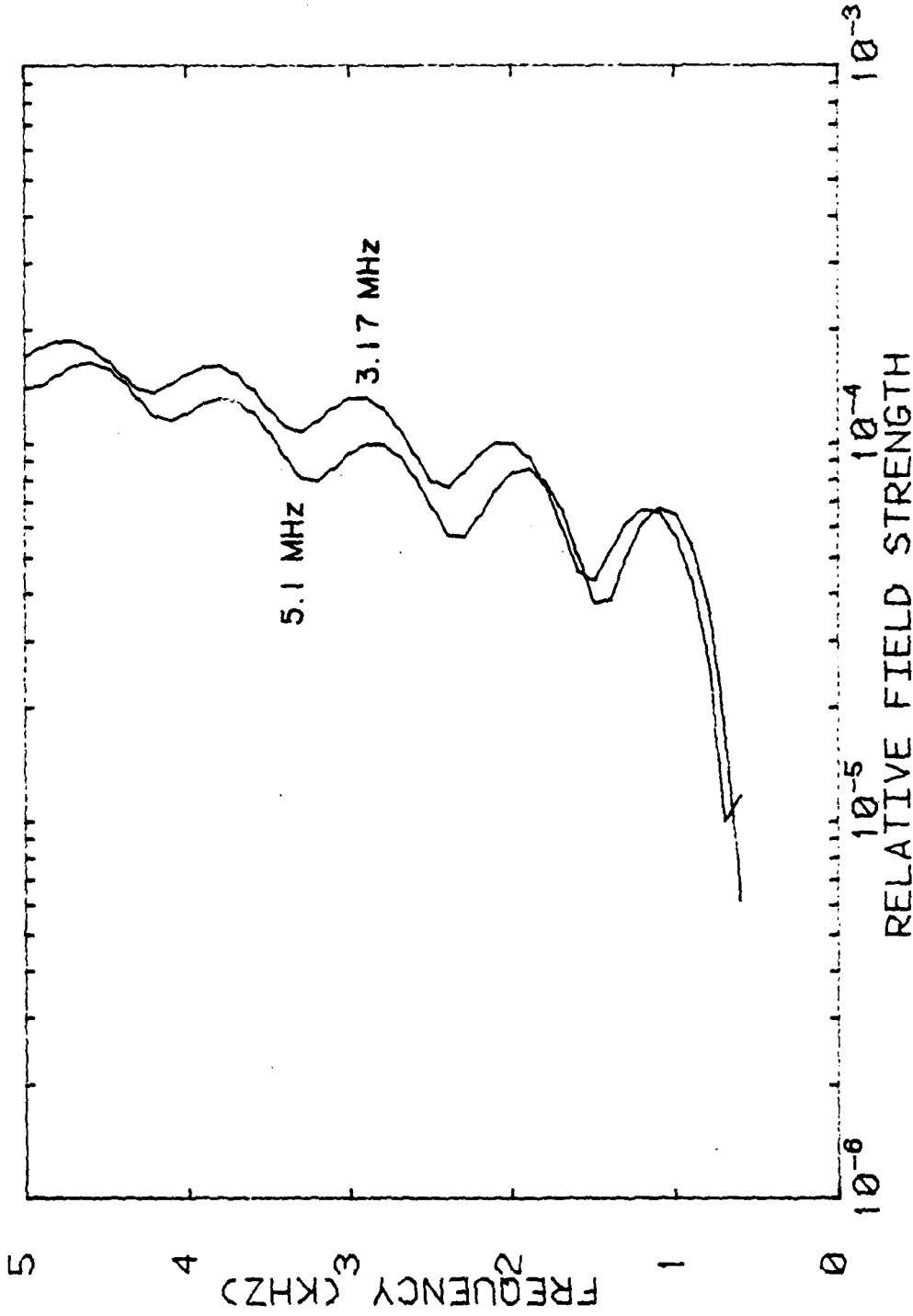


Figure I-21 Current element array VLF/ELF response at Salinas. Y component of magnetic field

altitude. Using the HF antenna pattern, a zero order approximation of the model for the ELF/VLF radiating system was determined. The frequency responses of the ELF/VLF radiation system for observation points corresponding to Los Canos and Salinas were calculated. The calculations determined that the regions heated by the side lobes and grating lobes have a significant effect on the strength of the received signal.

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Appendix I
Computer Programs

Program I

AMP data file

Program II

Total Array Pattern Simpson Integration, 3.17 MHz

	// EXEC FWCG	7.
	//SYSIN DD *	0000010
	DIMENS(UN A(145))	4.
	AX=0.	5.
	HX=1.570297	6.
	AY=0.	7.
	RY=6.283185	8.
C	NHT MUST BE EVEN AND GREATER THAN 4. NHT+1 IS # OF THETA ANGLES.	8.5
	NHT=90	9.
C	NHP MUST BE EVEN AND GREATER THAN 4. NHP+1 IS # OF PHI ANGLES	9.5
	NHP=144	10.
	TOT=0.	11.
	HT=(RX-AX)/NHT	12.
	HP=(RY-AY)/NHP	13.
	X=AX	14.
	Y=AY	15.
	DO 300 J=1,145	16.
	A(J)=0.	17.
300	CONTINUE	18.
C	NI=# OF ANGLES THETA=4. (FIRST AND LAST TWO OF SERIES PLUS SECOND IN LOOP	18.2
	NI=NHT-3	18.3
C	NJ=# OF ANGLES PHI AT WHICH INTEGRALS IN THETA ARE EVALUATED.	18.5
	NJ=NHP+1	18.6
	DI 200 J=1,NJ	19.
	C1=FLIAT(J)	20.
	A(J)=A(J)+PWR(X,Y)	21.
	DO 100 I=1,NI,2	22.
	C=FLIAT(I)	23.
	X=AX+C*HT	24.
	A(J)=A(J)+4.*PWR(X,Y)	25.
	X=AX+(C+1.)*HT	26.
	A(J)=A(J)+2.*PWR(X,Y)	27.
100	CONTINUE	28.
	X=AX+(NHT-1)*HT	28.5
	A(J)=A(J)+4.*PWR(X,Y)	28.6
	X=AX+NHT*HT	29.
	A(J)=A(J)+PWR(X,Y)	30.
	X=AX	31.
	Y=AY+C1*HP	32.
200	CONTINUE	33.
	TOT=TOT+A(1)	34.
	NP=NHP-2	34.5
	DI 400 J=2,NP,2	35.
	TOT=TOT+4.*A(J)	36.
	TOT=TOT+2.*A(J+1)	37.
400	CONTINUE	38.
	III=III+4.*A(NHP)	38.6
	III=III+A(NJ)	39.
	ANS=(III+II)*HP/4.	40.
	WRITE(6,600) ANS,(A(I),I=1,145)	41.
600	FORMAT(' THE TOTAL INTEGRAL IS ',1PE15,/,15ZF 1,10(1PE10,/,2X))	42.
	STOP	43.
	END	44.
	LINK(III,PWR(X,Y))	45.
	REAL,46 PWR,X,Y,PI	46.
	PI=3.141592653589793	47.
	X1=X	48.
	III=(A-(X/PI))*PI	49.
	PHI=(Y/PI)*PI	50.
	PWR=A(1+III*PI)*PI*(1+PHI*PI)*PI	51.

	14.54,-1.63,-3.29,-1.67,-3.36,-3.69,-1.22, .09,-2.45,-4.22,-2.25,-6	108.
	1.16,-6.42,-1.03,-2.6,-4.12,-5.25000,-5.360,-5.03,-8.21,-2.69,-.92,-	109.
	13.95,-6.48,-3.51,-5.25,-8.15,-4.18,-1.60,-6.00,-1.61,-6.19,-1.91,-	110.
	17.14,-3.91,-2.07,-5.73,-8.93,-6.90,-7.90,-8.17,-4.88,-2.11,-8.85,-	111.
	110.33,-5.64,-8.92,-9.25,-5.49,-3.38,-7.57,-11.73,-6.4,-9.95,-10.76	112.
	1,-6.34,-4.10,-5.45,-13.08,-7.19,-10.97,-11.48,-7.22,-4.86,-9.28,-1	113.
	13.99,-8.00,-11.97,-12.61,-8.13,-5.66,-9.96,-14.54,-8.84,-12.95,-13	114.
	1.72,-9.09,-6.52,-10.55,-14.6000,-9.70,-13.90,-14.81,-10.09,-7.44,	115.
	1-11.05,-14.52,-10.59,-16.83,-15.85,-11.15,-8.43,-11.51,-14.33,-11.	116.
	154,-15.77,-16.87,-12.28,-9.81,-12.04,-16.30,-12.60,-16.79,-17.91,-	117.
	113.52,-10.73,-12.80,-14.64,-13.90,-18.01,-19.11,-16.99,-12.21/	118.
	DATA 122-14.19,-15.73,-15.77,-19.78,-20.86,-16.98,-14.26,-17.54,-1	119.
	18.90,-19.51,-23.4,-24.41,-20.76,-18.15,-0.0,0.0,0.0,0.0,0.0,0.	120.
	107	121.
	I1=1	122.
	DI 300 I=1.34	123.
	DI 400 J=1.7	124.
	FF(J,I)=I(J,I)	125.
400	CONTINUE	126.
300	CONTINUE	127.
	DI 500 I=35.37	128.
	DI 600 J=1.7	129.
	IT=1-34	130.
	FF(J,I)=I2(J,IT)	131.
600	CONTINUE	132.
500	CONTINUE	133.
C	WRITE(6,2000) ((FF(I,J),I=1,7),J=1,37)	134.
C	2000 FORMAT(1,37(1,7)(F7.2,4X),7))	135.
	J1=1	136.
	DI 100 I=2.8	137.
	I3=1	138.
	IF (APHI(I) .GT. PHI) GO TO 1000	139.
	I1=I1+1	140.
100	CONTINUE	141.
1000	DI 200 J=2.36	142.
	J3=J	143.
	IF (ATHETA(J) .GT. THETA) GO TO 1100	144.
	J1=J1+1	145.
200	CONTINUE	146.
	J3=36	147.
	J1=J3-1	148.
1100	FRACT=(THETA-ATHETA(J1))/(ATHETA(J3)-ATHETA(J1))	149.
	FRACP=(PHI-APHI(I1))/(APHI(I3)-APHI(I1))	150.
	IF (I3 .EQ. 8) I3=1	151.
	FF1=FRACP*(FF(I3,J1)-FF(I1,J1))+FF(I1,J1)	152.
	FF2=FRACP*(FF(I3,J3)-FF(I1,J3))+FF(I1,J3)	153.
	ELF=FRACT*(FF2-FF1)+FF1	154.
	ELFE=ELF/10.	155.
	ELF=10.**ELFE	156.
C	WRITE(6,700) ELF,A(THETA(J3),ATHETA(J1)),APHI(I3),APHI(I1)	157.
C	700 FORMAT(1,'ELEMENTAL FACTOR=',F6.2,' I',4(4X),F6.2))	158.
	RETURN	159.
	END	160.
	//DATA,INPHI DI 6	161.

Program III

Total Array Pattern Simpson Integration, 5.1 MHz

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// EXEC FWCG
//JP SERVICE=DFFER
//SYSIN DD *
0000010
DIMENSION A(145)
AX=0.
RX=1.570297
AY=0.
RY=6.283185
C NHT MUST BE EVEN AND GREATER THAN 4. NHT+1 IS # OF THETA ANGLES.
NHT=90
C NHP MUST BE EVEN AND GREATER THAN 4. NHP+1 IS # OF PHI ANGLES
NHP=144
TOT=0.
HT=(RX-AX)/NHT
HP=(RY-AY)/NHP
X=AX
Y=AY
DO 300 J=1,145
A(J)=0.
300 CONTINUE
C NI=# OF ANGLES THETA=4. (FIRST AND LAST TWO OF SERIES PLUS SECOND IN LOOP
NI=NHT-3
C NJ=# OF ANGLES PHI AT WHICH INTEGRALS IN THETA ARE EVALUATED.
NJ=NHP+1
DO 200 J=1,NJ
C1=FLIAT(J)
A(J)=A(J)+PWR(X,Y)
DO 100 I=1,NI,2
C=FLIAT(I)
X=AX+C*HT
A(J)=A(J)+4.*PWR(X,Y)
X=AX+(C+1)*HT
A(J)=A(J)+2.*PWR(X,Y)
100 CONTINUE
X=AX+(NHT-1)*HT
A(J)=A(J)+4.*PWR(X,Y)
X=AX+NHT*HT
A(J)=A(J)+PWR(X,Y)
X=AX
Y=AY+C1*HP
200 CONTINUE
TOT=TOT+A(I)
NP=NHP-2
DO 400 J=2,NP,2
TIT=TIT+4.*A(J)
TII=TII+2.*A(J+1)
400 CONTINUE
TIII=TIII+4.*A(NHP)
TII=TII+A(NJ)
ANS=TIT*HT*HP/9.
WRITE(6,600) ANS,(A(I),I=1,145)
600 FORMAT(' THE TOTAL INTEGRAL IS =',1PE15,7.15/(' ',10(1PE10,3.2X))
STOP
END
FUNCTION PWR(X,Y)
REAL * PWR,X,Y,PI
PI=3.141592653589793
XI=X
PHI=(Y/PI)*PI00.

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PWR=AF*(THETA,PHI)*E*(THETA,PHI)*SIN(X)
C WRITE(6,100) PWR
C 100 FORMAT(' ',PWR=' ',1P10.3)
RETURN
END
FUNCTION AF(THETA,PHI)
THETAR=(THETA/180.)*3.14159
PHIR=(PHI/180.)*3.14159
C RFTA=2*PI*(E/C)*R5/2. R5=01STANCE BETWEEN RADIATORS.
RFTA=4.539001
RFTA4=4.*RFTA
RETAH=M.*RFTA
STHETA=SIN(THETAR)
SPHI=SIN(PHIR)
CPHI=COS(PHIR)
C AFT1=(SIN(RFTA4*STHETA*SPHI)/SIN(RFTA*STHETA*SPHI))*(SIN(RETAH*STHETA*CPHI)/SIN(RFTA*STHETA*CPHI))
C IF (ABS(THETA-0.) .LE. .2 .OR. ABS(THETA-180.) .LE. .2 .OR. ABS(PHI-0.) .LE. .2 .OR. ABS(PHI-180.) .LE. .2) GO TO 100
GO TO 200
100 AFT1=4.
GO TO 300
200 AFT1=ABS(SIN(RFTA4*STHETA*SPHI)/SIN(RFTA*STHETA*SPHI))
300 IF (ABS(THETA-0.) .LE. .2 .OR. ABS(THETA-180.) .LE. .2 .OR. ABS(PHI-180.) .LE. .2 .OR. ABS(PHI-270.) .LE. .2) GO TO 400
GO TO 500
400 AFT2=8.
GO TO 600
500 AFT2=ABS(SIN(RETAH*STHETA*CPHI)/SIN(RFTA*STHETA*CPHI))
C USE .434294 TO CONVERT NATURAL LOG TO BASE 10
600 CONTINUE
C 600 DRIFT1=20.*.434294*ALOG(AFT1)
C DRIFT2=20.*.434294*ALOG(AFT2)
C WRITE(6,700) THETA,PHI,DRIFT1,DRIFT2
C 700 FORMAT(' ',THETA=' ',F6.2,' DEG', PHI=' ',F6.2,' DEG', 4 ELEMENT=' ',F7.
C 12,' OR 8 ELEMENT=' ',F7.2,' OR')
C AFT=ABS(AFT)
C IF (ABS(AFT) .LT. 1.E-10) GO TO 10
C AF=20.*.434294*ALOG(AFT)
C AF=DRIFT1+DRIFT2
AF=AFT*AF
RETURN
C 10 AF=-99.
C RETURN
END
FUNCTION E*(THETA,PHI)
DIMENSION EE(9,37),APHI(10),A(10),A(10),A(10),A(10),A(10),A(10),A(10),A(10),A(10)
DATA A(1) /10.,60.,90.,110.,130.,150.,170.,190.,210.,230.,250.,270.,290.,310.,330.,350.,370.,390.,410.,430.,450.,470.,490.,510.,530.,550.,570.,590.,610.,630.,650.,670.,690.,710.,730.,750.,770.,790.,810.,830.,850.,870.,890.,910.,930.,950.,970.,990./
DATA A(2) /11.783,11.3,10.8,10.3,9.8,9.3,8.8,8.3,7.8,7.3,6.8,6.3,5.8,5.3,4.8,4.3,3.8,3.3,2.8,2.3,1.8,1.3,0.8,0.3,0.2,0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.1,1.2,1.3,1.4,1.5,1.6,1.7,1.8,1.9,2.0,2.1,2.2,2.3,2.4,2.5,2.6,2.7,2.8,2.9,3.0,3.1,3.2,3.3,3.4,3.5,3.6,3.7,3.8,3.9,4.0,4.1,4.2,4.3,4.4,4.5,4.6,4.7,4.8,4.9,5.0,5.1,5.2,5.3,5.4,5.5,5.6,5.7,5.8,5.9,6.0,6.1,6.2,6.3,6.4,6.5,6.6,6.7,6.8,6.9,7.0,7.1,7.2,7.3,7.4,7.5,7.6,7.7,7.8,7.9,8.0,8.1,8.2,8.3,8.4,8.5,8.6,8.7,8.8,8.9,9.0,9.1,9.2,9.3,9.4,9.5,9.6,9.7,9.8,9.9,10.0,10.1,10.2,10.3,10.4,10.5,10.6,10.7,10.8,10.9,11.0,11.1,11.2,11.3,11.4,11.5,11.6,11.7,11.8,11.9,12.0,12.1,12.2,12.3,12.4,12.5,12.6,12.7,12.8,12.9,13.0,13.1,13.2,13.3,13.4,13.5,13.6,13.7,13.8,13.9,14.0,14.1,14.2,14.3,14.4,14.5,14.6,14.7,14.8,14.9,15.0,15.1,15.2,15.3,15.4,15.5,15.6,15.7,15.8,15.9,16.0,16.1,16.2,16.3,16.4,16.5,16.6,16.7,16.8,16.9,17.0,17.1,17.2,17.3,17.4,17.5,17.6,17.7,17.8,17.9,18.0,18.1,18.2,18.3,18.4,18.5,18.6,18.7,18.8,18.9,19.0,19.1,19.2,19.3,19.4,19.5,19.6,19.7,19.8,19.9,20.0,20.1,20.2,20.3,20.4,20.5,20.6,20.7,20.8,20.9,21.0,21.1,21.2,21.3,21.4,21.5,21.6,21.7,21.8,21.9,22.0,22.1,22.2,22.3,22.4,22.5,22.6,22.7,22.8,22.9,23.0,23.1,23.2,23.3,23.4,23.5,23.6,23.7,23.8,23.9,24.0,24.1,24.2,24.3,24.4,24.5,24.6,24.7,24.8,24.9,25.0,25.1,25.2,25.3,25.4,25.5,25.6,25.7,25.8,25.9,26.0,26.1,26.2,26.3,26.4,26.5,26.6,26.7,26.8,26.9,27.0,27.1,27.2,27.3,27.4,27.5,27.6,27.7,27.8,27.9,28.0,28.1,28.2,28.3,28.4,28.5,28.6,28.7,28.8,28.9,29.0,29.1,29.2,29.3,29.4,29.5,29.6,29.7,29.8,29.9,30.0,30.1,30.2,30.3,30.4,30.5,30.6,30.7,30.8,30.9,31.0,31.1,31.2,31.3,31.4,31.5,31.6,31.7,31.8,31.9,32.0,32.1,32.2,32.3,32.4,32.5,32.6,32.7,32.8,32.9,33.0,33.1,33.2,33.3,33.4,33.5,33.6,33.7,33.8,33.9,34.0,34.1,34.2,34.3,34.4,34.5,34.6,34.7,34.8,34.9,35.0,35.1,35.2,35.3,35.4,35.5,35.6,35.7,35.8,35.9,36.0,36.1,36.2,36.3,36.4,36.5,36.6,36.7,36.8,36.9,37.0,37.1,37.2,37.3,37.4,37.5,37.6,37.7,37.8,37.9,38.0,38.1,38.2,38.3,38.4,38.5,38.6,38.7,38.8,38.9,39.0,39.1,39.2,39.3,39.4,39.5,39.6,39.7,39.8,39.9,40.0,40.1,40.2,40.3,40.4,40.5,40.6,40.7,40.8,40.9,41.0,41.1,41.2,41.3,41.4,41.5,41.6,41.7,41.8,41.9,42.0,42.1,42.2,42.3,42.4,42.5,42.6,42.7,42.8,42.9,43.0,43.1,43.2,43.3,43.4,43.5,43.6,43.7,43.8,43.9,44.0,44.1,44.2,44.3,44.4,44.5,44.6,44.7,44.8,44.9,45.0,45.1,45.2,45.3,45.4,45.5,45.6,45.7,45.8,45.9,46.0,46.1,46.2,46.3,46.4,46.5,46.6,46.7,46.8,46.9,47.0,47.1,47.2,47.3,47.4,47.5,47.6,47.7,47.8,47.9,48.0,48.1,48.2,48.3,48.4,48.5,48.6,48.7,48.8,48.9,49.0,49.1,49.2,49.3,49.4,49.5,49.6,49.7,49.8,49.9,50.0,50.1,50.2,50.3,50.4,50.5,50.6,50.7,50.8,50.9,51.0,51.1,51.2,51.3,51.4,51.5,51.6,51.7,51.8,51.9,52.0,52.1,52.2,52.3,52.4,52.5,52.6,52.7,52.8,52.9,53.0,53.1,53.2,53.3,53.4,53.5,53.6,53.7,53.8,53.9,54.0,54.1,54.2,54.3,54.4,54.5,54.6,54.7,54.8,54.9,55.0,55.1,55.2,55.3,55.4,55.5,55.6,55.7,55.8,55.9,56.0,56.1,56.2,56.3,56.4,56.5,56.6,56.7,56.8,56.9,57.0,57.1,57.2,57.3,57.4,57.5,57.6,57.7,57.8,57.9,58.0,58.1,58.2,58.3,58.4,58.5,58.6,58.7,58.8,58.9,59.0,59.1,59.2,59.3,59.4,59.5,59.6,59.7,59.8,59.9,60.0,60.1,60.2,60.3,60.4,60.5,60.6,60.7,60.8,60.9,61.0,61.1,61.2,61.3,61.4,61.5,61.6,61.7,61.8,61.9,62.0,62.1,62.2,62.3,62.4,62.5,62.6,62.7,62.8,62.9,63.0,63.1,63.2,63.3,63.4,63.5,63.6,63.7,63.8,63.9,64.0,64.1,64.2,64.3,64.4,64.5,64.6,64.7,64.8,64.9,65.0,65.1,65.2,65.3,65.4,65.5,65.6,65.7,65.8,65.9,66.0,66.1,66.2,66.3,66.4,66.5,66.6,66.7,66.8,66.9,67.0,67.1,67.2,67.3,67.4,67.5,67.6,67.7,67.8,67.9,68.0,68.1,68.2,68.3,68.4,68.5,68.6,68.7,68.8,68.9,69.0,69.1,69.2,69.3,69.4,69.5,69.6,69.7,69.8,69.9,70.0,70.1,70.2,70.3,70.4,70.5,70.6,70.7,70.8,70.9,71.0,71.1,71.2,71.3,71.4,71.5,71.6,71.7,71.8,71.9,72.0,72.1,72.2,72.3,72.4,72.5,72.6,72.7,72.8,72.9,73.0,73.1,73.2,73.3,73.4,73.5,73.6,73.7,73.8,73.9,74.0,74.1,74.2,74.3,74.4,74.5,74.6,74.7,74.8,74.9,75.0,75.1,75.2,75.3,75.4,75.5,75.6,75.7,75.8,75.9,76.0,76.1,76.2,76.3,76.4,76.5,76.6,76.7,76.8,76.9,77.0,77.1,77.2,77.3,77.4,77.5,77.6,77.7,77.8,77.9,78.0,78.1,78.2,78.3,78.4,78.5,78.6,78.7,78.8,78.9,79.0,79.1,79.2,79.3,79.4,79.5,79.6,79.7,79.8,79.9,80.0,80.1,80.2,80.3,80.4,80.5,80.6,80.7,80.8,80.9,81.0,81.1,81.2,81.3,81.4,81.5,81.6,81.7,81.8,81.9,82.0,82.1,82.2,82.3,82.4,82.5,82.6,82.7,82.8,82.9,83.0,83.1,83.2,83.3,83.4,83.5,83.6,83.7,83.8,83.9,84.0,84.1,84.2,84.3,84.4,84.5,84.6,84.7,84.8,84.9,85.0,85.1,85.2,85.3,85.4,85.5,85.6,85.7,85.8,85.9,86.0,86.1,86.2,86.3,86.4,86.5,86.6,86.7,86.8,86.9,87.0,87.1,87.2,87.3,87.4,87.5,87.6,87.7,87.8,87.9,88.0,88.1,88.2,88.3,88.4,88.5,88.6,88.7,88.8,88.9,89.0,89.1,89.2,89.3,89.4,89.5,89.6,89.7,89.8,89.9,90.0,90.1,90.2,90.3,90.4,90.5,90.6,90.7,90.8,90.9,91.0,91.1,91.2,91.3,91.4,91.5,91.6,91.7,91.8,91.9,92.0,92.1,92.2,92.3,92.4,92.5,92.6,92.7,92.8,92.9,93.0,93.1,93.2,93.3,93.4,93.5,93.6,93.7,93.8,93.9,94.0,94.1,94.2,94.3,94.4,94.5,94.6,94.7,94.8,94.9,95.0,95.1,95.2,95.3,95.4,95.5,95.6,95.7,95.8,95.9,96.0,96.1,96.2,96.3,96.4,96.5,96.6,96.7,96.8,96.9,97.0,97.1,97.2,97.3,97.4,97.5,97.6,97.7,97.8,97.9,98.0,98.1,98.2,98.3,98.4,98.5,98.6,98.7,98.8,98.9,99.0,99.1,99.2,99.3,99.4,99.5,99.6,99.7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.1,183.2,183.3,183.4,183.5,183.6,183.7,183.8,183.9,184.0,184.1,184.2,184.3,184.4,184.5,184.6,184.7,184.8,184.9,185.0,185.1,185.2,185.3,185.4,185.5,185.6,185.7,185.8,185.9,186.0,186.1,186.2,186.3,186.4,186.5,186.6,186.7,186.8,186.9,187.0,187.1,187.2,187.3,187.4,187.5,187.6,187.7,187.8,187.9,188.0,188.1,188.2,188.3,188.4,188.5,188.6,188.7,188.8,188.9,189.0,189.1,189.2,189.3,189.4,189.5,189.6,189.7,189.8,189.9,190.0,190.1,190.2,190.3,190.4,190.5,190.6,190.7,190.8,190.9,191.0,191.1,191.2,191.3,191.4,191.5,191.6,191.7,191.8,191.9,192.0,192.1,192.2,192.3,192.4,192.5,192.6,192.7,192.8,192.9,193.0,193.1,193.2,193.3,193.4,193.5,193.6,193.7,193.8,193.9,194.0,194.1,194.2,194.3,194.4,194.5,194.6,194.7,194.8,194.9,195.0,195.1,195.2,195.3,195.4,195.5,195.6,195.7,195.8,195.9,196.0,196.1,196.2,196.3,196.4,196.5,196.6,196.7,196.8,196.9,197.0,197.1,197.2,197.3,197.4,197.5,197.6,197.7,197.8,197.9,198.0,198.1,198.2,198.3,198.4,198.5,198.6,198.7,198.8,198.9,199.0,199.1,199.2,199.3,199.4,199.5,199.6,199.7,199.8,199.9,200.0,200.1,200.2,200.3,200.4,200.5,200.6,200.7,200.8,200.9,201.0,201.1,201.2,201.3,201.4,201.5,201.6,201.7,201.8,201.9,202.0,202.1,202.2,202.3,202.4,202.5,202.6,202.7,202.8,202.9,203.0,203.1,203.2,203.3,203.4,203.5,203.6,203.7,203.8,203.9,204.0,204.1,204.2,204.3,204.4,204.5,204.6,
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1.4,1.36,2.,-2.17,-1.04,-2.55,-1.52,0.93,0.93,1.62,-3.34,-3.95,-3.2
16,-2.33,.55,.46,1.21,-4.42,-4.93,-4.47,-3.18,0.15,-.04,.77,-5.64,-
15.97,-5.59,-4.13,-.27,-.57,.24,-7.0,-7.06,-6.42,-5.17,-.70,-1.1600
1,-.22,-8.53,-8.19,-8.19,-6.34,-1.14,-1.74,-.76,-10.22,-9.40,-9.700
1,-7.63,-1.59,-2.35,-1.46,-12.05,-10.46,-11.46,-9.07,-2.06,-2.29,-1
1.04,-13.40,-11.3,-13.10,-10.68,-2.56,-3.65,-2.57,-15.46,-12.00,-14
1.8700,-12.47,-3.1,-4.34,-3.22,-16.27,-12.65,-16.68,-14.40,-3.68,-5
1.04,-3.84,-16.19,-13.05,-17.62,-16.39,-6.42,-5.76,-4.59,-15.54,-13
1.32,-18.11,-18.16,-5.04,-6.5,-5.32,-16.78,-13.54,-18.06,-19.32,-5.
1860000,-7.26,-6.04,-14.15,-13.79,-17.8,-19.66,-6.81,-8.07,-6.91,-1
13.78,-16.15,-17.61,-19.5,-19.93,-8.94,-7.81,-13.76,-14.71,-17.7,-19
1.330,-9.30,-9.95,-8.87/
DATA T2/-14.23,-15.65,-18.25,-19.58,-11.05,-11.22,-10.21,-15.57,-1
17.35,-19.69,-20.72,-13.52,-13.13,-12.22,-19.12,-21.19,-23.37,-24.1
17,-18.01,-17.03,-16.23,700.0/
DATA T3/3.83,3.83,3.80,3.85,3.75,3.84,3.68,3.82,3.58,3.76,3.47,3.6
18.3,32000,3.57,3.16,3.44,2.97,3.27,2.76,3.07,2.52,2.84,2.25,2.5600
1.1,96.2,24.1,64.1,89.1,29.1,49.02,1.05,0.52,0.56,.10,.03,-.36,-.5
15,-.84,-1.18,-1.35,-1.85,-1.89,-2.56,-2.45,-3.30,-3.05,-4.06,-3.68
1.44,84,-4.36,-5.61,-5.08,-6.37,-5.85,-7.09,-6.70,-7.76,-7.64,-8.40
1.48,69,-9.01,-9.89,-9.66,-11.33,-10.43,-13.13,-11.49,-15.66,-13.24
1,-20.2200,-17.07,0.0.0/
I1=1
IF I PHI .LT. 10.) PHI=PHI+360.
DO 300 I=1,33
DO 400 J=1,4
EF(J,I)=T1(J,I)
400 CONTINUE
EF(5,I)=T3(1,I)
DO 450 J=5,7
EF(J+1,I)=T1(J,I)
450 CONTINUE
EF(9,I)=T3(2,I)
300 CONTINUE
DO 500 I=34,37
DO 600 J=1,6
IT=I-33
EF(J,I)=T2(J,IT)
600 CONTINUE
EF(5,I)=T3(1,I)
DO 650 J=5,7
EF(J+1,I)=T2(J,IT)
650 CONTINUE
EF(9,I)=T3(2,I)
500 CONTINUE
WRITE(6,2000) ((EF(I,J),I=1,9),J=1,4)
C 2000 FORMAT(' ',37(' ',9('7.2',4X),/))
I1=1
DO 100 I=2,10
I3=1
IF (APH(I) .GT. PH(I)) GO TO 1000
I1=I+1
100 CONTINUE
1000 DO 200 I=2,36
I4=J
IF (A(IH)-A(J) .GT. (PH(I4) GO TO 1100
J1=J+1
200 CONTINUE
I3=I6
I1=I3-1

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1100 FRAC1=(ATHETA-A1HETA(J1))/7*(ATHETA(J3)-ATHETA(J1))
      IF (I1 .EQ. 13) WRITE(6,800) PHI
      FRAC2=(PHI-APHI(I1))/(APHI(I3)-APHI(I1))
      IF(I3 .EQ. 10) I4=1
      FF1=FRAC2*(FF(I3,J1)-FF(I1,J1))+FF(I1,J1)
      FF2=FRAC2*(FF(I3,J3)-FF(I1,J3))+FF(I1,J3)
      ELF=FRAC2*(FF2-FF1)+FF1
      FLF=FLF/10.
      FLF=10.*ELFF
C     WRITE(6,700) FLF,ATHETA(J3),ATHETA(J1),APHI(I3),APHI(I1)
C     700  FORMAT(' ',ELEMENTAL FACTOR='F6.2', 1H',4(3X,F6.2))
800  FORMAT(' ',F10.3,' PHI NOT IN RANGE 10 DEG TO 370 DEG')
      RETURN
      END
//DATA,INPUT DD *

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Program IV

Directive Gain Pattern Calculation and Plotting, 3.17MHz

	//SCR EXEC PGM=IFERR14	2.
	//SCR DD DISP=(OLD,DELETE),VOL=REF=VOL001,	3.
	// DSN=MFN,118490,KJC,PL01,OUTP01	4.
	// EXEC EXCI	5.
	/*JP SERVICE=DEFERK	6.
	/*JP FULLSKIP5	7.
	//SYSIN DD *	8.
	CUJMMJM /BLOCK1/XVAL(1R1),YVAL(1R1),YRCD(4),[XRCI(8)]	9.
C	4 CHARACTERS PER [INTEGER] N [INTEGER] ARKAYS. SEE BLOCK DATA SURPRING	10.
	DIMENSION ATHA(91),ADR(91),CHECK(5),CHEKP(5)	11.
	CHECK(1)=0.	12.
	CHECK(2)=32.5	13.
	CHECK(3)=55.	14.
	CHECK(4)=87.5	15.
	CHECK(5)=90.	16.
	CHEKP(1)=90.	17.
	CHEKP(2)=270.	18.
	CHEKP(3)=90.	19.
	CHEKP(4)=130.	20.
	CHEKP(5)=250.	21.
	DD 400 J=11.19	22.
	JINC=1	23.
	DD 1003 I=1.181	24.
	XVAL(I)=0.	25.
1003	YVAL(I)=0.	26.
	J1=J-1	27.
	PHI=FLDAT(J1)*5.0+90.	28.
C	PHI=CHEKP(J)	29.
	PHIL=PHI-90.	30.
	DD 500 I=1.91	31.
	ATHA(I)=0.	32.
	ADR(I)=0.	33.
500	CONTINUE	34.
	DI 2000 J2=1.2	35.
	THETA=0.	36.
	DI 100 I=1.91	37.
C	THETA=CHECK(I)	38.
C	FIND TOTAL FIELD. R.62 IS FACTOR TO NORMALIZE TO GAIN OVER ISOTROPIC	39.
	DR=AF(THETA,PHI)+FLF(THETA,PHI)-R.62	40.
	ATHA(I)=THETA	41.
	ADR(I)=DR	42.
	THETA=THETA+1.	43.
100	CONTINUE	44.
	WRITE(6,200) (ATHA(I),PHI,ADR(I),I=1,91)	45.
200	FORMAT(' ',5(F6.2,1X,F6.2,1X,FR,3,2X))	46.
	WRITE(6,300)	47.
300	FORMAT(' ')	48.
	JP=91	49.
	NEND=NII+1	50.
	DI 1001 I=1.91	51.
	XVAL(JP)=ATHA(I)*JINC	52.
	YVAL(JP)=ADR(I)	53.
	JP=JP+JINC	54.
1001	CONTINUE	55.
	IF(JINC.EQ.1) JINC=-1	56.
	PHI=PHI+180	57.
	IF(PHI.GE.360.) PHI=PHI-360.	58.
2000	CONTINUE	59.
	WRITE(16,1006) (XVAL(I),YVAL(I),I=1,181)	60.
1006	FORMAT(' ',5(F6.2,1X,F6.2,1X,FR,3,2X))	61.

	COMMON /BLOCK1/XVAL(181),YVAL(181),YHCH(4),XHCCH(8)	182.
	DIMENSION XVVV(36),YVVV(36)	183.
	INTEGER*4 YSCALE,XSCALE	184.
C	NUM=# OF DIVISIONS ON X AXIS	185.
C	NUMD = # OF DIVISIONS ON Y AXIS	186.
C	XMIN = VALUE OF X AT ORIGIN	187.
C	XMAX = VALUE OF X AT END OF AXIS	188.
C	YMIN = VALUE OF Y AT ORIGIN	189.
C	YMAX = VALUE OF Y AT TOP OF Y AXIS	190.
C	NPNTS = # OF POINTS TO BE PLOTTED. MUST BE LESS THAN 81	191.
	CALL PLTTYPI(4662.6,37)	192.
	CALL START	193.
	CALL PLOT(0.0,0.0,3)	194.
	CALL PLOT(0.0,1.0,2)	195.
	CALL PLOT(0.0,7.0,3)	196.
	CALL PLOT(0.0,8.0,2)	197.
	CALL PLOT(11.0,0.0,3)	198.
	CALL PLOT(10.0,0.0,2)	199.
	CALL PLOT(1.0,0.0,3)	200.
	CALL PLOT(0.0,0.0,2)	201.
	CALL NEWPEN(1)	202.
C	DEFINE NEW ORIGIN FOR PLOT AXIS	203.
	CALL PLOT(2.22,1.88,-3)	204.
	CALL FACTOR(1.0)	205.
C	DRAW AXIS	206.
	ENTRY NXPLOT(NUM,NUMD,XMIN,XMAX,YMIN,YMAX,NPNTS)	207.
	CALL RECT(0.0,0.0,7.0,5.0)	208.
C	DRAW TIC MARKS ON AXIS. CSIZE=DIVISION SIZE IN INCHES X AXIS.	209.
C	DSIZE=DIVISION SIZE IN INCHES Y AXIS	210.
	CSIZE=7.0/FLOAT(NUM)	211.
	DSIZE=5.0/FLOAT(NUMD)	212.
	X1=0.0	213.
	Y1=0.0	214.
	Y2=Y1+.05	215.
	X2=X1+.05	216.
	DO 400 K=1,2	217.
	DO 200 J=1,NUM	218.
	XBASE=FLOAT(NUM-J)*CSIZE	219.
	X=XBASE	220.
	CALL PLOT(X,Y1,3)	221.
	CALL PLOT(X,Y2,2)	222.
200	CONTINUE	223.
	CALL PLOT(X1,Y1,3)	224.
	CALL PLOT(X2,Y1,2)	225.
	DO 300 J=1,NUMD	226.
	YBASE=FLOAT(NUMD-J)*DSIZE	227.
	CALL PLOT(X1,YBASE,3)	228.
	CALL PLOT(X2,YBASE,2)	229.
300	CONTINUE	230.
	X1=7.0	231.
	Y1=5.0	232.
	X2=X1-.05	233.
	Y2=Y1-.05	234.
400	CONTINUE	235.
C	PLOT SCALE ON Y AXIS	236.
C	UNITS = UNITS PER DIV ON Y AXIS	237.
	UNITS=(YMAX-YMIN)/FLOAT(NUMD)	238.
	YSCALE=AINT(A05(YMIN)/.5)	239.
	IF (YMIN .LT. 0) YSCALE=YSCALE*10	240.
	LL2=NUMD*1	241.

	DO 900 I=1,172	242.
	ULOC=DSI7F*(I-1)-.04	243.
	X=-.44	244.
	IF (YSCALE .GE. 0) X=-.307	245.
	CALL INIMMR(X,ULOC,.15,YSCALE,0,0)	246.
	YSCALE=YSCALE+AINT(UNITS+.5)	247.
900	CONTINUE	248.
	XT=-.5	249.
	YT=1.5	250.
	CALL LFTTR(XT,YT,.15, YHCO ,90,0,16)	251.
C	PIIT SCALES ON X AXIS	252.
C	UNITX UNITS PER DIV ON X AXIS	253.
	UNITX=((XMAX-XMIN)/FLDPT(NIM))	254.
	XSCALE=AINT(ABS(XMIN)+.5)	255.
	IF(XMIN .LT. 0) XSCALE=XSCALE*(0-1)	256.
C	LABEL X AXIS SCALES	257.
750	IT1=NIM+1	258.
	DO 700 I=1,IT1,3	259.
	ULOC=CSI7F*(I-1)-.125	260.
	IF (XSCALE .LT. 0) ULOC=ULOC-.15	261.
	CALL INIMMR(ULOC,-.24,.15,XSCALE,0,0)	262.
	XSCALE=XSCALE+AINT(UNITX+.5)*3	263.
700	CONTINUE	264.
	XT=1.0	265.
	YT=-.44	266.
	CALL LFTTR(XT,YT,.15, XHCO ,0,0,32)	267.
C	UNITS = UNITS PER DIV ON Y AXIS	268.
C	PLUT DATA	269.
	ENTRY PLINE(NPNTS)	270.
	DO 600 I=1,NPNTS	271.
	IF(XVAL(I) .LT. XMIN) XVAL(I)=XMIN	272.
	IF(XVAL(I) .GT. XMAX) XVAL(I)=XMAX	273.
	IF(YVAL(I) .LT. YMIN) YVAL(I)=YMIN	274.
	IF(YVAL(I) .GT. YMAX) YVAL(I)=YMAX	275.
600	CONTINUE	276.
C	WRITE(6,1001)(XVAL(I),YVAL(I),I=1,181)	277.
1001	FORMAT(' ',23(8(F7.2,' ',F7.2)/' '))	278.
	X=(XVAL(I)-XMIN)/(UNITX/CSI7F)	279.
	Y=(YVAL(I)-YMIN)/(UNITS/DSI7F)	280.
	CALL PLUT(X,Y,3)	281.
C	NPNTS = # OF POINTS TO BE PLOTFD	282.
	DO 500 I=2,NPNTS	283.
	X=(XVAL(I)-XMIN)/(UNITX/CSI7F)	284.
	Y=(YVAL(I)-YMIN)/(UNITS/DSI7F)	285.
	CALL PLUT(X,Y,2)	286.
500	CONTINUE	287.
C	PLUT RICE PAPER DATA	288.
C	DATA XVVV/-68.9,-52.8,-56.2,-62.3,-40.2,-38.0,-36.0,-28.6,-25.8,-2	289.
C	10.4,-16.2,-15.3,-13.8,-10.4,-6.0,-6.16,5.20,0.6,8.9,8.11,3.16,3.15	290.
C	1.8,17.7,20.2,24.6,25.8,28.6,31.6,34.1,36.1,38.0,40.5,42.4,49.4,53.6,	291.
C	DATA YVVV/7.11,-3.39,-23.89,15.61,15.61,11.61,-1.39,-1.89,2.11000,	292.
C	1,-29.39,-15.69,-7.89,-8.79,-29.89,0.11,19.51,23.11,24.11,8.11,-7.39	293.
C	1,-3.89,7.11,6.61,4.61,-12.89,2.31,4.61,-.89,-17.89,-1.49,7.11,13.1	294.
C	11,13.61,14.11,11.61,1.61	295.
C	INT 1002 I=1,36	296.
C	X=(XVVV(I)-XMIN)/(UNITX/CSI7F)	297.
C	Y=(YVVV(I)-YMIN)/(UNITS/DSI7F)	298.
C	CALL SYMMD(X,Y,208,6,0,0,-1)	299.
C	1002 CONTINUE	300.
C	WRITE(6,1001)(XVVV(I),YVVV(I),I=1,36)	301.

```
RETURN 303.  
END 304.  
BLOCK DATA 305.  
CUMMIN /HLICK1/XVAL(1H1),YVAL(1H1),LYCH(4),LXCH(8) 306.  
DATA LYRCD/'HEAT', 'ER G', 'AIN ', '(DH)'/ 307.  
DATA LXRCO/' ', ' ', 'THE', 'A ', '(DFG', 'REFS', ' ) 308.  
1/ 309.  
END 310.  
//DATA,FT37F001 DD VOLL=REF=MEN,IRR4490,KJC,LIR,D]SP=(NEW,KFFP), 311.  
// DSN=MEN,IRR4490,KJC,PLNT,INPIT,SPACE=(CYL,(1,1),RLSF), 312.  
// DCR=(RECFM=FB,LKFL=NO,HLKST17F=3120) 313.  
//DATA,INPIT DD * 314.
```


Program V

Directive Gain Pattern Calculation and Plotting, 5.1 MHz

```

//SCR EXEC PGM=IEFRR14
//SCR DD DISP=(OLD,DELETE),VOL=REF=VOL001,
// DSN=MFN,HR6490,KJC,PL0T,DIR1R11
// EXEC EXC0
/*JP SERVICE=IEFRR
/*JP FILE=SKIPS
//SYSIN DD *
COMMON /BLOCK1/XVAL(1R1),YVAL(1R1),IYHCO(4),IXHCO(8)
C 4 CHARACTERS PER INTEGER IN INTEGER ARRAYS. SEE BLOCK DATA SURPRIG
DIMENSION ATHA(91),ADH(91),CHECK(5),CHKP(5)
CHECK(1)=0.
CHECK(2)=32.5
CHECK(3)=55.
CHECK(4)=87.5
CHECK(5)=90.
CHKP(1)=90.
CHKP(2)=270.
CHKP(3)=90.
CHKP(4)=180.
CHKP(5)=250.
DO 400 J=1,5
JINC=1
DO 1003 I=1,181
XVAL(I)=0.
1003 YVAL(I)=0.
J1=J-1
PHI=FLOAT(J1)*10.+90.
C PHI=CHKP(J)
PHI1=PHI-90.
DO 500 I=1,91
ATHA(I)=0.
ADH(I)=0.
500 CONTINUE
DO 2000 J2=1,2
THETA=0.
DO 100 I=1,91
C THETA=CHECK(I)
C FIND TOTAL FIFLD. 9.82 IS FACTOR TO NORMALIZE TO GAIN OVER ISOTROPIC
DR=AF(THETA,PHI)+FLP(THETA,PHI)-9.82
ATHA(I)=THETA
ADH(I)=DR
THETA=THETA+1.
100 CONTINUE
WRITE(6,200) (ATHA(I),PHI,ADH(I),I=1,91)
200 FORMAT(' ',5('F6.2,1X',F6.2,1X,F8.3,2X'))
WRITE(6,300)
300 FORMAT(' ')
JP=91
NEND=NMT+1
DO 1001 I=1,91
XVAL(JP)=ATHA(I)*JINC
YVAL(JP)=ADH(I)
JP=JP+JINC
1001 CONTINUE
IF(JINC.EQ.1) JINC=-1
PHI=PHI+180
IF(PHI.GT.360.) PHI=PHI-360.
2000 CONTINUE
WRITE(6,1006) (XVAL(I),YVAL(I),I=1,181)
1006 FORMAT(' ',23('F7.2,1X',F7.2),/ ' ')

```

```

IF(J.GT.1) CALL NXYPLT(18.6,-90.,90.,-30.,30.,181)
IF(J.GT.1) GO TO 2100
CALL ANTPLT(18.6,-90.,90.,-30.,30.,181)
2100 Y=4.5H
X=4.00
CALL LETTER(X,Y,.15,'PHI=' ,0.0,5)
CALL NUMBER(X,Y,.15,PHI,0.0,1)
X=X+.75
Y=4.5H
CALL LETTER(X,Y,.15,'DEG. W',0.0,6)
CALL NEWPEN(3)
400 CONTINUE
CALL FINISH
1002 CONTINUE
STOP
END
FUNCTION AF(THETA,PHI)
THETA=(THETA/180.)*3.14159
PHI=(PHI/180.)*3.14159
C RETA=2*PI*(F/C)*85/2. R5=DISTANCE BETWEEN RADIATORS.
RETA=4.539601
RETA4=4.*RETA
RETA8=8.*RETA
STHETA=SIN(THETA)
SPHI=SIN(PHI)
CPHI=COS(PHI)
C AFT=(SIN(RETA4*STHETA*SPHI)/SIN(RETA*STHETA*SPHI))*(SIN(RETA8*STH
ITA*CPHI)/SIN(RETA*STHETA*CPHI))
IF(ABS(THETA-0.) .LE. .2 .OR. ABS(THETA-180.) .LE. .2 .OR. ABS(PH
I-0.) .LE. .2 .OR. ABS(PHI-180.) .LE. .2) GO TO 100
GO TO 200
100 AFT1=4.
GO TO 300
200 AFT1=ABS(SIN(RETA4*STHETA*SPHI)/SIN(RETA*STHETA*SPHI))
300 IF(ABS(THETA-0.) .LE. .2 .OR. ABS(THETA-180.) .LE. .2 .OR. ABS(PHI
-90.) .LE. .2 .OR. ABS(PHI-270.) .LE. .2) GO TO 400
GO TO 500
400 AFT2=8.
GO TO 600
500 AFT2=ABS(SIN(RETA8*STHETA*CPHI)/SIN(RETA*STHETA*CPHI))
C USE .434294 TO CONVERT NATURAL LOG TO BASE 10
600 DRAFT1=20.*.434294*ALOG(AFT1)
DRAFT2=20.*.434294*ALOG(AFT2)
C WRITE(6,700) THETA,PHI,DRAFT1,DRAFT2
700 FORMAT(' ',THEIA='F6.2','DEG. PHI='F6.2,'DEG. 4 ELEMENT='F7.
C 12.' ON 4 ELEMENT='F7.2.' ON')
C AFT=ABS(AFT)
C IF(ABS(AFT) .LT. 1.E-10) GO TO 10
C AF=20.*.434294*ALOG(AFT)
AF=DRAFT1+DRAFT2
RETURN
C 10 AF=-99.
C RETURN
END
FUNCTION FLE(THETA,PHI)
DIMENSION FF(9,3),APHI(10),ATHETA(3),I1(7,3),I2(7,6),I3(7,3)
DATA APHI/210.,50.,90.,110.,150.,180.,215.,270.,320.,370./,ATHETA/180
1.,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30.,32.5,35.,37.5
1.60.,42.5,65.,67.5,90.,92.5,95.,97.5,100.,102.5,105.,107.5,110.
1.,11.5,30.,32.5,35.,37.5,90.,7

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```

DATA T1/T1#1,83,3.76,3.72,3.73,3.74,3.85,3.80,3.80,3.67,3.54,3.65,
164,3.84,3.92,3.95,3.54,3.40,3.44,3.50,3.81,3.92,3.97000,3.38,3.19,
13.24,3.34,3.74,3.88,3.97,3.19,2.94,3.02,3.15,3.66,3.82,3.93,2.96,2
1.65,2.7600,2.93,3.54,3.72,3.88,2.68,2.32,2.46,2.88,3.40,3.6,3.74,2
1.36,1.94,2.12,2.39,3.23,3.44,3.68,1.44,1.52,1.74,2.07,3.03,3.24,3.
1530,1.57,1.05,1.31,1.70,2.81,3.01,3.36,1.09,1.52,1.82,1.29,2.56,2.75
1.3,15,1.55,-.06,1.28,1.83,2.24,2.46,2.91,-.06,-.71,-.32,1.48,2.13
1.2,64,-.74,-1.41,-.99,-.24,1.65,1.76,2.34,-1.51,-2.19,-1.73,-.87,1
1.3,1.36,2.-2.37,-3.03,-2.55,-1.56,0.93,0.93,1.62,-3.34,-3.95,-3.4
16,-2.33,1.55,1.46,1.21,-4.42,-4.93,-4.47,-3.18,0.15,-.04,1.77,-5.64,-
15.97,-5.59,-4.13,-.27,-.57,1.24,-7.0,-7.06,-6.82,-5.17,-.70,-1.1400
1,-.22,-8.53,-8.19,-8.19,-6.34,-1.14,-1.73,-.76,-10.22,-9.30,-9.700
1,-7.63,-1.59,-2.35,-1.34,-12.05,-10.36,-11.34,-9.07,-2.06,-2.29,-1
1.94,-13.40,-11.3,-13.10,-10.68,-2.56,-3.65,-2.57,-15.46,-12.08,-14
1.8700,-12.47,-3.1,-4.34,-3.22,-16.27,-12.65,-16.48,-14.40,-3.68,-5
1.04,-3.89,-16.14,-13.05,-17.62,-16.39,-4.32,-5.76,-4.59,-15.54,-13
1.32,-18.11,-18.16,-5.04,-6.5,-5.32,-14.78,-13.54,-18.06,-19.32,-5.
1860000,-7.26,-6.09,-14.15,-13.79,-17.8,-19.66,-6.81,-8.07,-6.91,-1
13.78,-14.15,-17.61,-19.5,-7.93,-8.94,-7.81,-13.76,-14.71,-17.7,-19
1.330,-9.30,-9.95,-8.87/
DATA T2/-14.23,-15.65,-18.25,-19.58,-11.05,-11.22,-10.21,-15.57,-1
17.35,-19.69,-20.72,-13.52,-13.13,-12.22,-19.12,-21.19,-23.37,-24.1
17,-18.01,-17.03,-16.23,7*0.0/
DATA T3/3.83,3.83,3.80,3.85,3.75,3.84,3.68,3.82,3.58,3.76,3.47,3.6
18,3.32000,3.57,3.16,3.44,2.97,3.27,2.76,3.07,2.52,2.83,2.25,2.5600
1.1.96,2.24,1.64,1.89,1.29,1.49,1.92,1.05,0.52,0.56,10,03,-.36,-.5
15,-.84,-1.18,-1.35,-1.85,-1.89,-2.56,-2.45,-3.30,-3.05,-4.06,-3.68
1,-4.84,-4.36,-5.61,-5.08,-6.37,-5.85,-7.04,-6.70,-7.76,-7.64,-8.40
1,-8.69,-9.01,-9.89,-9.66,-11.33,-10.43,-13.13,-11.49,-15.66,-13.74
1,-20.2200,-17.07,0.0.0./
I1=1
IF (PHI .LT. 10.) PH1=PHI+360.
DO 300 I=1,33
DO 400 J=1,4
EF(J,I)=T1(J,I)
400 CONTINUE
EF(5,I)=T3(1,I)
DO 450 J=5,7
EF(J+1,I)=T1(J,I)
450 CONTINUE
EF(9,I)=T3(2,I)
300 CONTINUE
DO 500 I=34,37
DO 600 J=1,4
IT=I-33
EF(J,I)=T2(J,IT)
600 CONTINUE
EF(5,I)=T3(1,I)
DO 650 J=5,7
EF(J+1,I)=T2(J,IT)
650 CONTINUE
EF(9,I)=T3(2,I)
500 CONTINUE
C WRITE(6,2000) ((I,(J,I),J=1,9),J=1,37)
C 2000 FORMAT(' ',37(' ',9(F7.2,3X),/))
I1=1
DO 100 I=2,10
IA=I
IT1=PHI(I) .GT. PHI) GO TO 1000
IT=IT1

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```

100 CONTINUE
1000 DO 200 J=2,36
      J3=J
      IF (ATHETA(J) .GT. THETA) GO TO 1100
      J1=J1+1
200 CONTINUE
      J3=36
      J1=J3-1
1100 FRACT=(THETA-ATHETA(J1))/(ATHETA(J3)-ATHETA(J1))
      IF (I3 .EQ. 13) WRITE(6,800) PHI
      FRACF=(PHI-APHI(I1))/(APHI(I3)-APHI(I1))
      IF (I3 .EQ. 10) I3=1
      EF1=FRACF*(FF(I3,J1)-FF(I1,J1))+FF(I1,J1)
      EF2=FRACF*(FF(I3,J3)-FF(I1,J3))+FF(I1,J3)
      FLF=FRACT*(FF2-EF1)+EF1
C     WRITE(6,700) FLF,ATHETA(J3),ATHETA(J1),APHI(I3),APHI(I1)
C     700 FORMAT(' ',ELEMENTAL FACTOR=' ,F6.2,' DB',4(3X,F6.2))
800 FORMAT(' ',F10.3,' PHI NOT IN RANGE 10 DEG TO 370 DEG')
      RETURN
      END
SUBROUTINE ANTPLOT(NUM,NUMD,XMIN,XMAX,YMIN,YMAX,NPNTS)
COMMON /BLOCK1/XVAL(181),YVAL(181),/HCD(4),/XCHDIR)
DIMENS(UN XVVV(36),YVVV(36))
INTEGER*4 YSCALE,XSCALE
C     NUM=# OF DIVISIONS ON X AXIS
C     NUMD = # OF DIVISIONS ON Y AXIS
C     XMIN = VALUE OF X AT ORIGIN
C     XMAX = VALUE OF X AT END OF AXIS
C     YMIN = VALUE OF Y AT ORIGIN
C     YMAX = VALUE OF Y AT TOP OF Y AXIS
C     NPNTS = # OF POINTS TO BE PLOTTED, MUST BE LESS THAN 81
      CALL PLTTYP(4662,6,37)
      CALL START
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,1.0,2)
      CALL PLOT(0.0,7.0,3)
      CALL PLOT(0.0,8.0,2)
      CALL PLOT(1.0,0.0,3)
      CALL PLOT(10.0,0.0,2)
      CALL PLOT(1.0,0.0,3)
      CALL PLOT(0.0,0.0,2)
      CALL NEWPEN(1)
C     DEFINE NEW ORIGIN FOR PLOT AXIS
      CALL PLOT(2.22,1.88,-3)
      CALL FACTOR(1.0)
C     DRAW AXIS
      ENTRY NXIPLI(NUM,NUMD,XMIN,XMAX,YMIN,YMAX,NPNTS)
      CALL RECT(0.0,0.0,7.0,8.0)
C     DRAW TIC MARKS ON AXIS, CSIZE=DIVISION SIZE IN INCHES X AXIS,
C     DSIZE=DIVISION SIZE IN INCHES Y AXIS
      CSIZE=.1,DSIZE=.05
      DSIZE=.05/FLI(181)
      DSIZE=.05/FLI(181)
      X1=0.0
      Y1=0.0
      Y2=Y1+.05
      X2=X1+.05
      DO 400 K=1,2
      DO 200 J=1,NUM
      XVAL=FLI(181)*(NUM-1)*CSIZE
      X=XVAL

```

```

CALL PLOT(X,Y1,3)
CALL PLOT(X,Y2,2)
200 CONTINUE
CALL PLOT(X1,Y1,3)
CALL PLOT(X2,Y1,2)
DO 300 J=1,NUMD
YHASF=FLOAT(NUMD-J)*DSIZE
CALL PLOT(X1,YHASF,3)
CALL PLOT(X2,YHASF,2)
300 CONTINUE
X1=7.0
Y1=5.0
X2=X1-.05
Y2=Y1-.05
400 CONTINUE
C PLOT SCALES ON Y AXIS
C UNITS = UNITS PER DIV ON Y AXIS
UNITS=(YMAX-YMIN)/FLOAT(NUMD)
YSCALE=AINT(ABS(YMIN)+.5)
IF(YMIN .LT. 0) YSCALE=YSCALE*(0-1)
IT2=NUMD+1
DO 900 I=1,IT2
HLOC=DSIZE*(I-1)+.04
X=-.46
IF(YSCALE .GE. 0) X=-.307
CALL INIMHR(X,HLOC,.15,YSCALE,0,0)
YSCALE=YSCALE+AINT(UNITS+.5)
900 CONTINUE
XT=-.5
YT=1.5
CALL LETTER(XT,YT,.15,LYCD,90,0,16)
C PLOT SCALES ON X AXIS
C PLOT SCALES ON X AXIS
C UNITX = UNITS PER DIV ON X AXIS
UNITX=(XMAX-XMIN)/FLOAT(NUM)
XSCALE=AINT(ABS(XMIN)+.5)
IF(XMIN .LT. 0) XSCALE=XSCALE*(0-1)
277.
C LABEL X AXIS SCALES
278.
750 IT1=NUM+1
279.
DO 700 I=1,IT1,3
280.
HLOC=DSIZE*(I-1)+.125
281.
IF(XSCALE .LT. 0) HLOC=HLOC-.15
282.
CALL INIMHR(HLOC,-.24,.15,XSCALE,0,0)
283.
XSCALE=XSCALE+AINT(UNITX+.5)*3
284.
700 CONTINUE
285.
XT=1.0
286.
YT=-.46
287.
CALL LETTER(XT,YT,.15,LYCD,0,0,12)
288.
C UNITS = UNITS PER DIV ON Y AXIS
289.
C PLOT DATA
290.
ENTRY PLINE(PPNTS)
291.
DO 600 I=1,PPNTS
292.
IF(XVAL(I) .GT. XMIN) XVAL(I)=XMIN
293.
IF(XVAL(I) .GT. XMAX) XVAL(I)=XMAX
294.
IF(YVAL(I) .LT. YMIN) YVAL(I)=YMIN
295.
IF(YVAL(I) .GT. YMAX) YVAL(I)=YMAX
296.
600 CONTINUE
297.
WRITE(6,1001) XVAL(I),YVAL(I),I,1,PPNTS
298.
1001 FORMATT(1,2,3,4,5,6,7,8,9,10,11)
299.
X=(XVAL(I)-XMIN)/UNITX*DSIZE
300.
301.

```

Y=(YVAL(1)-YMIN)/(UNITS/HSIZE)	302.
CALL PLOT(X,Y,3)	303.
C NPPTS = # OF POINTS TO BE PLOTTED	304.
DO 500 I=2, NPPTS	305.
X=(XVAL(1)-XMIN)/(UNITS/CSIZE)	306.
Y=(YVAL(1)-YMIN)/(UNITS/HSIZE)	307.
CALL PLOT(X,Y,2)	308.
500 CONTINUE	309.
C PLOT RICE PAPER DATA	310.
C DATA XVVV/-48.9,-52.8,-56.2,-42.3,-40.2,-38.0,-36.0,-28.6,-25.8,-2	311.
C 10.,-16.2,-15.3,-13.8,-10.3,-6.8,-4.16,5.20,0.,6.8,4.8,11.3,14.3,15	312.
C 1.8,17.2,23.6,25.8,28.6,31.4,34.,36.1,38.0,40.5,42.3,44.4,53.47	313.
C DATA YVVV/7.11,-3.39,-23.89,15.61,15.61,11.61,-1.39,-1.89,2.11,0.0,	314.
C 1-29.39,-15.69,-7.89,-8.79,-29.89,0.11,19.51,23.11,24.11,8.11,-7.39	315.
C 1,-3.89,7.11,6.61,4.61,-12.89,2.31,4.61,-.89,-17.89,-1.39,7.11,13.1	316.
C 11,13.61,14.11,11.61,1.61/	317.
C DO 1002 I=1,36	318.
C X=(XVVV(I)-XMIN)/(UNITS/CSIZE)	319.
C Y=(YVVV(I)-YMIN)/(UNITS/HSIZE)	320.
C CALL SYMBOL(X,Y,.05,4,0.0,-1)	321.
C 1002 CONTINUE	322.
C WRITE(6,1001)(XVVV(I),YVVV(I),I=1,36)	323.
RETURN	324.
END	325.
BLICK DATA	326.
CLIMMIN /BLOCK1/XVAL(1R1),YVAL(1R1),IYRCD(4),IXRCD(N)	327.
DATA IYRCD/'HEAT', 'FR G', 'AIN', '(DH)'	328.
DATA IXRCD/'', ' ', 'INF', 'A', ' ', '(DFG', 'WEPS', ')', ' ', ' '	329.
1/	330.
END	331.
//DATA,FT37F001 DD VOL=REF=MFN,HR4490,KJC;LIB,DISP=(NEW,KEEP),	332.
// DSN=MFN,HR4490,KJC,PLNT,INPTIT,SPACE=(CYL,(1,1),RLSF),	333.
// DCB=(RECFM=FR,LKFL=80,RLKSIZ=3120)	334.
//DATA,INPT DD *	335.

Program VI

*Program to compute relative HF power above isotropic on a 70km altitude plane. Frequency=3.17 MHz

*note: Function subprograms AF (Theta, Phi) and ELF (Theta, Phi) are not shown. They are the same as in program IV.

Program VII

*Program to compute relative HF power above isotropic on a 70km altitude plane. Frequency=5.1MHz.

*note: Function subprograms AF (Theta,Phi) and ELF (Theta, Phi) are not shown. They are the same as those in program V.

04/04/82 1 1 1
 C C C 1 1 1
 9 8 7 6 5 4 3 2 1

```

1 //*****
2 //SCF ERIC GEN=ICFRP14
3 //SCF ERIC DIS=HOLD,DELTEI,VOL=REF=VCL001,
4 // IS=HEG,IR=450,KJC,PLCT,CPUINPUT
5 // ERIC ERIC
6 //JIS SP=VICCENOFFR
7 //JIS ENLSNIPS
8 //SYSTL D0 *
9 C 405 J=1,245,?
10 J=J-123
11 V=V+V*(J)
12 C-107 I=1,245,2
13 L=I-123
14 E=I0A(I111)
15 V=SQRT(V*V+Y*Y)
16 TETA=ATAN(X/Y)-PI/180./3.14159
17 I=ASIN(X)-LT. 0) PHI=90.
18 I=ASIN(X)-GT. 0) PHI=ATAN(Y/X)*180./3.14159
19 I=X-LT. -1) PHI=PHI+180.
20 I=PHI-LT. 0) PHI=PHI+360.
21 P=I+PHI*90.
22 I=PHI-LT. 360) PHI=PHI-360.
23 TETAP=(TETA/180.-.33-14159
24 PRORP=2)+SIN(COS(TETAP))
25 C TETA=CHECK(I)
26 C FINE TOTAL FIELD. GPR IS FACTOR TO NORMALIZE TO GAIN OVER ISOTHERMIC
27 Q=AF(THTA,PHI)+FL(THTA,PI)+RPRORP-9.*82
28 Z=90
29 I=I03-LT. 0) Z=0.
30 I=TIE(17,200) X,Y,Z
31 CONTINUE
32 FORMATE 1,F9.3,2X,F9.3,2X,F9.3)
33 CONTINUE
34 STOP
35 E*0
36 //*****
37 // DIS=PHI,IR=450,KJC,PLCT,CPUOUTPUT,SPACE=(CYL,11,11),RLSEI),
38 // DCR=(SECTW=PP,LRFL=90,RLKSIZE=3120)
39 //DATA,INPUT DD *

```

Program VIII

Program to compute relative magnetic field strength at
observation point for ionospheric ELF/VLF current element array.

3.17 HF pattern.

09/04/42 PAGE 1

TOP VOL-VOL001

1 2 3 4 5 6 7 8 9 0

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0

```

1 //*****
2 //SCE REC *****
3 //SCE REC *****
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41 //SCE REC *****
42 //SCE REC *****
43 //SCE REC *****
44 //SCE REC *****
45 //SCE REC *****
46 //SCE REC *****
47 //SCE REC *****

```


Program IX

Program to compute relative magnetic field strength of an
observation point for an ionospheric ELF/VLF current element array.

5.1 MHz HF pattern.

01/04/02 09/28/02 00/24/02 1 1 1 1
 01/04/02 09/28/02 00/24/02 2 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 3 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 4 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 5 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 6 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 7 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 8 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 9 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 10 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 11 0 0 1 1 1 1 1
 01/04/02 09/28/02 00/24/02 12 0 0 1 1 1 1 1

```

1. /C/0000000000
2. /C/0000000000
3. /C/0000000000
4. /C/0000000000
5. /C/0000000000
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7. /C/0000000000
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42. /C/0000000000
43. /C/0000000000
44. /C/0000000000
45. /C/0000000000

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APPENDIX II

USE OF CHEBYSHEV'S POLYNOMIALS TO SIMPLIFY ANTENNA FACTORS

The Chebyshev's polynomials are the solution to the Chebyshev differential equation (A-1). The solution has the form of equation (A-2)

$$(1 - x^2) \frac{d^2y}{dx^2} - x \frac{dy}{dx} + n^2y = 0 \quad (\text{A-1})$$

With a recursive formula given in equation (A-3)(13)

$$T_m(x) = \cos(m \cos^{-1}x) \quad m \geq 0, |x| \leq 1 \quad (\text{A-2})$$

$$T_{m+1}(x) = 2x T_m(x) - T_{m-1}(x) \quad (\text{A-3})$$

Equation (A-4) and (A-5) follow from substitution of 0 and 1 for m in (A-2)

$$T_0 = 1 \quad (\text{A-4})$$

$$T_1 = x \quad (\text{A-5})$$

By using the recursion relationship (A-3), the following polynomials are obtained:

$$\begin{aligned} T_2(x) &= 2x^2 - 1 \\ T_3(x) &= 4x^3 - 3x \\ T_4(x) &= 8x^4 - 8x^2 + 1 \\ T_5(x) &= 16x^5 - 20x^3 + 5x \\ T_6(x) &= 32x^6 - 48x^4 + 18x^2 - 1 \\ T_7(x) &= 64x^7 - 112x^5 + 56x^3 - 7x \\ T_8(x) &= 128x^8 - 256x^6 + 160x^4 - 32x^2 + 1 \end{aligned}$$

Let "w" equal " $\cos^{-1}x$ " then "x" is equal to " $\cos w$."

Substitution for "x" in equation (A-2) gives (A-6).

$$T_m(\cos w) = \cos(m w) \quad (\text{A-6})$$

By using equation (A-6) with the polynomials, trigonometric identities can be found for expressing "cos (m w)" or "sin (m w)" in terms of "sin w" and "cos w." For example, using "T₂(x)" and letting "x" equal "cos w", equation (A-7) is obtained.

$$T_2(\cos w) = \cos (2w) = 2 (\cos^2 w) - 1 \quad (A-7)$$

Expressions for sin(m w) can be obtained by taking the derivative of the "cos (m w)" identity. Equation (A-8) was obtained by taking the derivative of (A-7).

$$\sin (2w) = 2 (\cos w) \sin w \quad (A-8)$$

To obtain the antenna factors in the form of equation (1-13) and (1-14), equation (1-7) must be expanded. Equation (A-9) is the expansion for the 8-element case. Let $w = \beta (d/2) \sin \theta$.

$$AF = \sum_{m=1,3,5,\dots}^{8-1} \cos (m \beta d/2 \sin \theta) = \cos(w) + \cos (3w) + \cos (5w) + \cos (7w) \quad (A-9)$$

Use the Chebyshev's polynomials to find trigonometric identities to reduce (A-9) into an equation in terms of powers of cos w. These identities are given in equation (A-10).

$$\begin{aligned} T_1 &= \cos w = \cos w \\ T_3 &= \cos 3w = 4\cos^3 w - 3 \cos w \\ T_5 &= \cos 5w = 16\cos^5 w - 20\cos^3 w + 5\cos w \\ T_7 &= \cos 7w = 64\cos^7 w - 112\cos^5 w + 56\cos^3 w - 7\cos w \end{aligned} \quad (A-10)$$

Substituting (A-10) into (A-9), the expression for the antenna factor becomes (A-11).

$$AF = 64\cos^7 w - 96\cos^5 w + 40\cos^3 w - 4\cos w \quad (A-11)$$

An identity for " $\cos(8w)$ " can be found from polynomial " T_8 ." By taking the derivative of " $\cos(8w)$ ", an identity for " $\sin(8w)$ " can be found, (A-12).

$$\begin{aligned} \sin 8w &= 1024 \cos^7 w \sin w - 1536 \cos^5 w \sin w + 640 \cos^3 w \sin w - \\ &64 \cos w \sin w = 16 \sin w (64 \cos^7 w - 96 \cos^5 w + 40 \cos^3 w - 4 \cos w) \end{aligned}$$

(A-12)

Equation (A-12) can be rearranged into (A-13).

$$\frac{1}{16} \frac{\sin 8w}{\sin w} = 64 \cos^7 w - 96 \cos^5 w + 40 \cos^3 w - 4 \cos w$$

(A-13)

Equation (A-14) can be obtained by substituting equation (A-13) into (A-11).

$$AF = \frac{1}{16} \frac{\sin 8w}{\sin w}$$

(A-14)

This is identical with equation (1-14) for the 8-element array antenna factor with the exception of the $1/16$ constant in (A-14). The constant can be neglected at this point, due to the fact that when the directive gain is calculated, the AF will be normalized.

A similar calculation can be performed to obtain the 4-element array factor, (1-13).

APPENDIX III

REVISED ARECIBO HF ANTENNA ARRAY GEOMETRY

After completion of the work described in the main body of this report, a preliminary copy was reviewed by the Arecibo Observatory. At this time the Arecibo Observatory made available additional information about the HF array. The following differences were reported between the model used in the main text and the actual A.O. array:

1. The τ for the antenna is .774.
2. The pyramid structure is elevated five feet above ground.
3. The feed point of each face is capacitively loaded.

This appendix presents the information provided by the A.O. and discusses its possible effects on the work presented in the main body of this report.

The τ of the NPLA is .774. It is obtained by taking the ratio of the lengths of two consecutive elements of a face on the same side of the feed line. Table III-1 provides a list of the element lengths and the length of the feed line to that element. The even numbered elements represent the dimensions for the scaled faces of the pyramid structure.

Figure (III-1) provides a view of the structure at the vertex of the pyramid. It was concluded from this figure that height of the vertex of the pyramid was 1.524 m (60 inches).

<u>Element Number</u>	<u>Element Length (m)</u>	<u>Feed Line Length (m)</u>
1	25.000	35.704
2	23.454	33.49
3	22.001	31.42
4	20.638	29.47
5	19.361	27.65
6	18.163	25.94
7	17.035	24.33
8	15.984	22.82
9	14.993	21.41
10	14.064	20.01
11	13.195	18.84
12	12.378	17.68
13	11.610	16.58
14	10.891	15.55
15	10.217	14.59
16	9.586	13.69
17	8.992	12.84
18	8.434	12.05
19	7.913	11.30
20	7.422	10.60
21	6.902	9.94
22	6.532	9.33
23	6.126	8.75
24	5.749	8.21
25	5.392	7.70
26	5.060	7.22
27	4.746	6.78
28	4.450	6.36
29	4.176	5.96
30	3.917	5.59

Table III-1. NPLA Element and Feed Line Lengths Provided by A.O.
Even element numbers are for the scaled faces.
 $\tau = .774$.

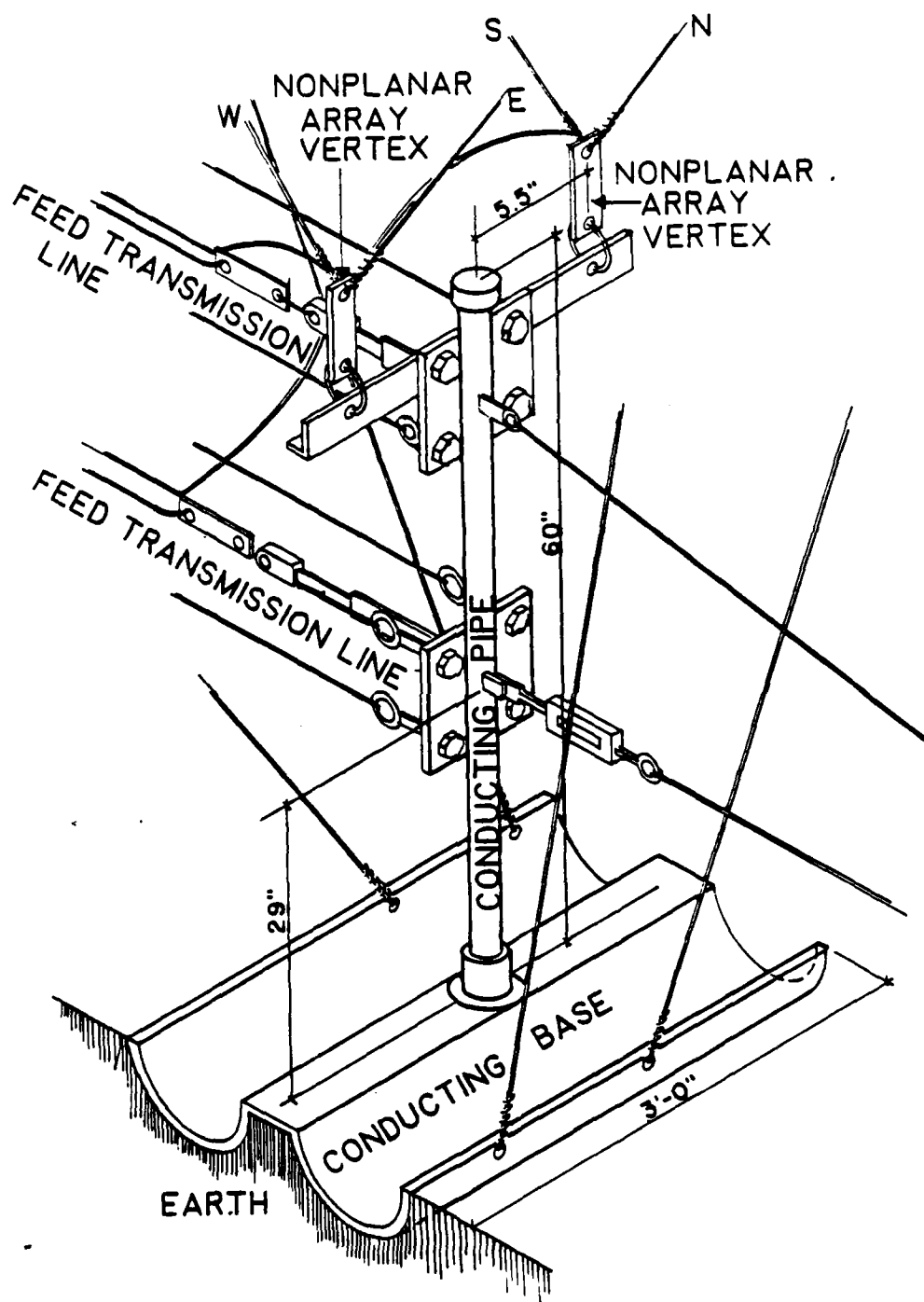


Figure III-1 Vertex of pyramid for Arecibo Observatory HF non-planar log-periodic array

Figure (III-2) shows a sketch of a feed point of one of the faces of the pyramid. The wires detailed by "A" are in addition to previously used geometry. All of the conducting elements of the antenna consist of three #12 twisted steel wires with 10% aluminum coating.

The additional information on the array elements was combined into a new geometry description for AMP. Discrepancies exist within the new information provided. Figure (III-1) depicts the height of the vertex at five feet, while figure (III-2) shows a six-foot height. Table III-1 and figure (III-2) give different distances between the feed point and the bottom element. It is unclear whether figure (III-2) represents a scaled face or unscaled face of the pyramid and whether the dimensions of the additional wires are also scaled between the two sets of faces. For the new geometry description to be used with AMP the following geometry was decided upon:

1. The height of the vertex is 1.524 m.
2. The lengths of all the feed lines to the elements are all taken from table III-1 (including the length to the bottom element).
3. Figure (III-2) was taken to be an unscaled face of a pyramid. The 144" dimension was taken to be correct and the other dimensions were adjusted to correspond to table III-1.
4. All wires and dimensions from the unscaled face were scaled by the fourth root of τ ($\tau = .774$) for the scaled face. This includes the additional wires shown in figure (III-2).

The final AMP geometry deck incorporating these changes is given in figure (III-3). The computer results of the power gain

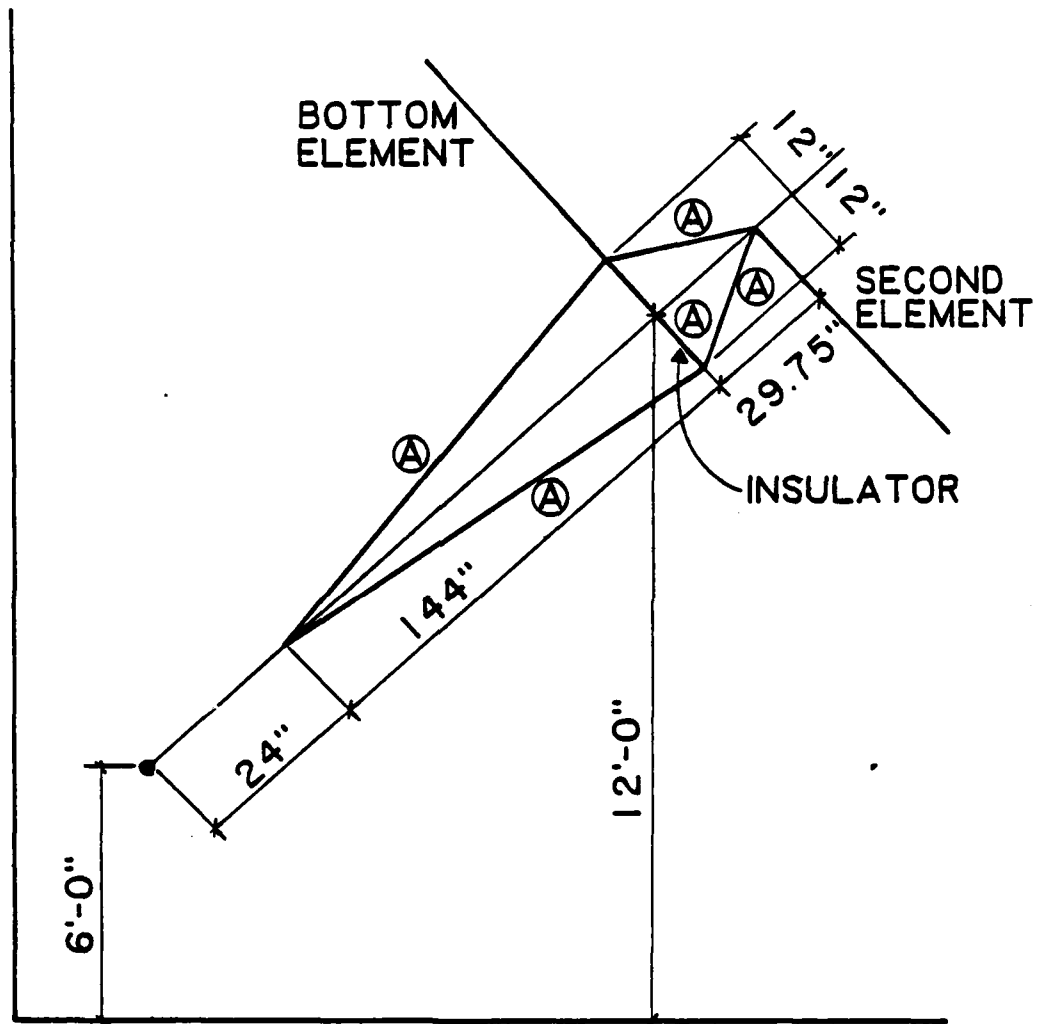


Figure III-2 Capacitively loaded feed region for one face of pyramid element in Arcibo Observatory HF heating non-planar log-periodic array

1.	//DATA.INPLT DD *								
2.	CM	THE DECK MUST BEGIN WITH CM,CE CARDS							
3.	CM	HEATER ARRAY ELEMENT AT ARECIBC P.R. FREQ=3.170 MHZ.							
3.5	CM	MODIFIED GEOMETRY TAU=.774 ELEMENT ELEVATION 60 INCHES							
4.	CE	EE 438 FALL TERM 1981							
5.	GW001	2	0.000	0.000	0.000	0.000	2.305	0.000	0.0020
6.	GW002	3	0.000	2.305	0.000	0.304	5.963	0.000	0.0020
7.	GW003	3	0.000	2.305	0.000	0.000	5.963	0.000	0.0020
8.	GW004	3	0.000	2.305	0.000	-0.304	5.963	0.000	0.0020
9.	GW005	1	0.000	5.963	0.000	-0.304	5.963	0.000	0.0020
10.	GW006	4	-0.304	5.963	0.000	-4.176	5.963	0.000	0.0020
11.	GW007	1	0.000	5.963	0.000	0.000	5.776	0.000	0.0020
12.	GW008	1	0.304	5.963	0.000	0.000	6.776	0.000	0.0020
13.	GW009	1	-0.304	5.963	0.000	0.000	6.776	0.000	0.0020
16.	GW010	4	0.000	6.776	0.000	4.746	6.776	0.000	0.0020
17.	GW011	1	0.000	6.776	0.000	0.000	7.700	0.000	0.0020
18.	GW012	4	0.000	7.700	0.000	-5.392	7.700	0.000	0.0020
19.	GW013	1	0.000	7.700	0.000	0.000	6.750	0.000	0.0020
20.	GW014	5	0.000	8.750	0.000	6.126	8.750	0.000	0.0020
21.	GW015	1	0.000	8.750	0.000	0.000	9.944	0.000	0.0020
22.	GW016	5	0.000	9.944	0.000	-6.962	9.944	0.000	0.0020
23.	GW017	1	0.000	9.944	0.000	0.000	11.299	0.000	0.0020
24.	GW018	5	0.000	11.299	0.000	7.913	11.299	0.000	0.0020
25.	GW019	1	0.000	11.299	0.000	0.000	12.840	0.000	0.0020
26.	GW020	5	0.000	12.840	0.000	-8.992	12.840	0.000	0.0020
27.	GW021	1	0.000	12.840	0.000	0.000	14.591	0.000	0.0020
28.	GW022	5	0.000	14.591	0.000	10.217	14.591	0.000	0.0020
29.	GW023	1	0.000	14.591	0.000	0.000	16.581	0.000	0.0020
30.	GW024	5	0.000	16.581	0.000	-11.610	16.581	0.000	0.0020
31.	GW025	1	0.000	16.581	0.000	0.000	18.642	0.000	0.0020
32.	GW026	5	0.000	18.642	0.000	13.195	18.642	0.000	0.0020
33.	GW027	1	0.000	18.642	0.000	0.000	21.412	0.000	0.0020
34.	GW028	6	0.000	21.412	0.000	-14.993	21.412	0.000	0.0020
35.	GW029	1	0.000	21.412	0.000	0.000	24.331	0.000	0.0020
36.	GW030	7	0.000	24.331	0.000	17.035	24.331	0.000	0.0020
37.	GW031	2	0.000	24.331	0.000	0.000	27.649	0.000	0.0020
38.	GW032	6	0.000	27.649	0.000	-19.361	27.649	0.000	0.0020
39.	GW033	2	0.000	27.649	0.000	0.000	31.420	0.000	0.0020
40.	GW034	9	0.000	31.420	0.000	22.001	31.420	0.000	0.0020
41.	GW035	2	0.000	31.420	0.000	0.000	35.704	0.000	0.0020
42.	GW036	10	0.000	35.704	0.000	-25.000	35.704	0.000	0.0020
43.	GM000	3	45.000	0.000	0.000	0.000	0.000	0.000	0.000
44.	GM036	1	90.000	0.000	0.000	0.000	0.000	0.000	0.000
45.	GW073	2	0.000	0.000	0.000	2.162	0.000	0.000	0.0020
45.02	GW074	3	2.162	0.000	0.000	5.594	0.000	0.000	0.0020
45.04	GW075	3	2.162	0.000	0.000	5.594	0.296	0.000	0.0020
45.06	GW076	3	2.162	0.000	0.000	5.594	-0.296	0.000	0.0020
45.08	GW077	1	5.594	0.000	0.000	5.594	-0.296	0.000	0.0020
45.1	GW078	4	5.594	-0.286	0.000	5.594	-3.917	0.000	0.0020
45.12	GW079	1	5.594	0.000	0.000	6.356	0.000	0.000	0.0020
45.14	GW080	1	5.594	-0.286	0.000	6.356	0.000	0.000	0.0020
45.16	GW081	1	5.594	0.286	0.000	6.356	0.000	0.000	0.0020
48.	GW0A2	4	6.356	0.000	0.000	5.356	4.450	0.000	0.0020
49.	GW0A3	1	6.356	0.000	0.000	7.223	0.000	0.000	0.0020
50.	GW084	4	7.223	0.000	0.000	7.223	-5.060	0.000	0.0020

Figure III-3 AMP geometry deck containing structure modifications: $\tau=.774$, capacitively loaded feed, and elevation of 1.524 m

51.	GW085	1	7.223	0.000	0.000	8.209	0.000	0.000	0.0020
52.	GW086	5	8.209	0.000	0.000	9.209	5.749	0.000	0.0020
53.	GW087	1	8.208	0.000	0.000	9.329	0.000	0.000	0.0020
54.	GW088	5	9.328	0.000	0.000	9.328	-6.532	0.000	0.0020
55.	GW089	1	9.328	0.000	0.000	10.599	0.000	0.000	0.0020
56.	GW090	5	10.599	0.000	0.000	10.599	7.422	0.000	0.0020
57.	GW091	1	10.599	0.000	0.000	12.045	0.000	0.000	0.0020
58.	GW092	5	12.045	0.000	0.000	12.045	-8.434	0.000	0.0020
59.	GW093	1	12.045	0.000	0.000	13.688	0.000	0.000	0.0020
60.	GW094	5	13.688	0.000	0.000	13.688	9.596	0.000	0.0020
61.	GW095	1	13.688	0.000	0.000	15.554	0.000	0.000	0.0020
62.	GW096	5	15.554	0.000	0.000	15.554	-10.891	0.000	0.0020
63.	GW097	1	15.554	0.000	0.000	17.675	0.000	0.000	0.0020
64.	GW098	5	17.675	0.000	0.000	17.675	12.378	0.000	0.0020
65.	GW099	1	17.675	0.000	0.000	20.086	0.000	0.000	0.0020
66.	GW100	6	20.086	0.000	0.000	20.086	-14.064	0.000	0.0020
67.	GW101	1	20.086	0.000	0.000	22.825	0.000	0.000	0.0020
68.	GW102	7	22.825	0.000	0.000	22.825	15.994	0.000	0.0020
69.	GW103	2	22.825	0.000	0.000	25.937	0.000	0.000	0.0020
70.	GW104	8	25.937	0.000	0.000	25.937	-18.183	0.000	0.0020
71.	GW105	2	25.937	0.000	0.000	29.475	0.000	0.000	0.0020
72.	GW106	9	29.475	0.000	0.000	29.475	20.638	0.000	0.0020
73.	GW107	2	29.475	0.000	0.000	33.493	0.000	0.000	0.0020
74.	GW108	10	33.493	0.000	0.000	33.493	-23.454	0.000	0.0020
75.	GM000	0	0.000	-45.000	0.000	0.000	0.000	0.000	73.0
76.	GM036	1	0.000	-90.000	0.000	0.000	0.000	0.000	73.0
77.	GM000	0	0.000	0.000	0.000	0.000	0.000	1.524	
78.	GW145	2	0.000	0.000	0.000	0.000	0.000	1.524	0.0020
79.	GE001								
80.	GN000	0		20.0	0.000				
81.	FR000	1		3.176	0.000				
82.	EX000	001 001 00		1.000	0.000				
83.	EX000	037 001 00		1.000	0.000				
84.	EX000	073 001 00		1.000	0.000				
85.	EX000	109 001 00		1.000	0.000				
86.	RP000	45 72 1000		0.0	0.0	2.5	5.0	7.5E 04	
87.	EN000								

Figure III-3 (con.) AMP geometry deck containing structure modifications: $\tau = .774$, capacitively loaded feed, and elevation of 1.524 m

for the two cases of 3.17 MHz and 5.1 MHz are shown in figures (III-4) and (III-5). In these figures the "x" denotes the results of the new modified geometry given in this appendix, and the "." denotes the results of the "old" geometry used in the main body of this report. Figure (III-4) shows the power gain as a function of "phi" for selected constant values of "theta." These are the same values of "theta" used in figure (1-6). Figure (III-5) is a plot of power gain as a function of "theta" for selected values of "phi." The selected values of "phi" are the same values of "phi" used in figure (1-7) plus additional values corresponding to the "x" and "y" axis (i.e., $\phi = 0^\circ, 90^\circ, 180^\circ, 270^\circ$).

Examination of figures (III-4) and (III-5) leads to the conclusion that the changes in geometries between the two cases result in only a small difference in power gain for small values of "theta" and large differences for large values of "theta."

It is necessary to determine what effect the new geometry will have on the results of the main body of this report. The elemental power gain for $\theta < 50^\circ$ is approximately equal for the two geometries. Since a large portion of the radiated power is contained in this region, it is expected that the directivity of the total array would remain approximately the same. The results shown in figures (1-10) and (1-11) should be approximately the same for $\theta < 50^\circ$ but significant differences could occur for $\theta > 50^\circ$.

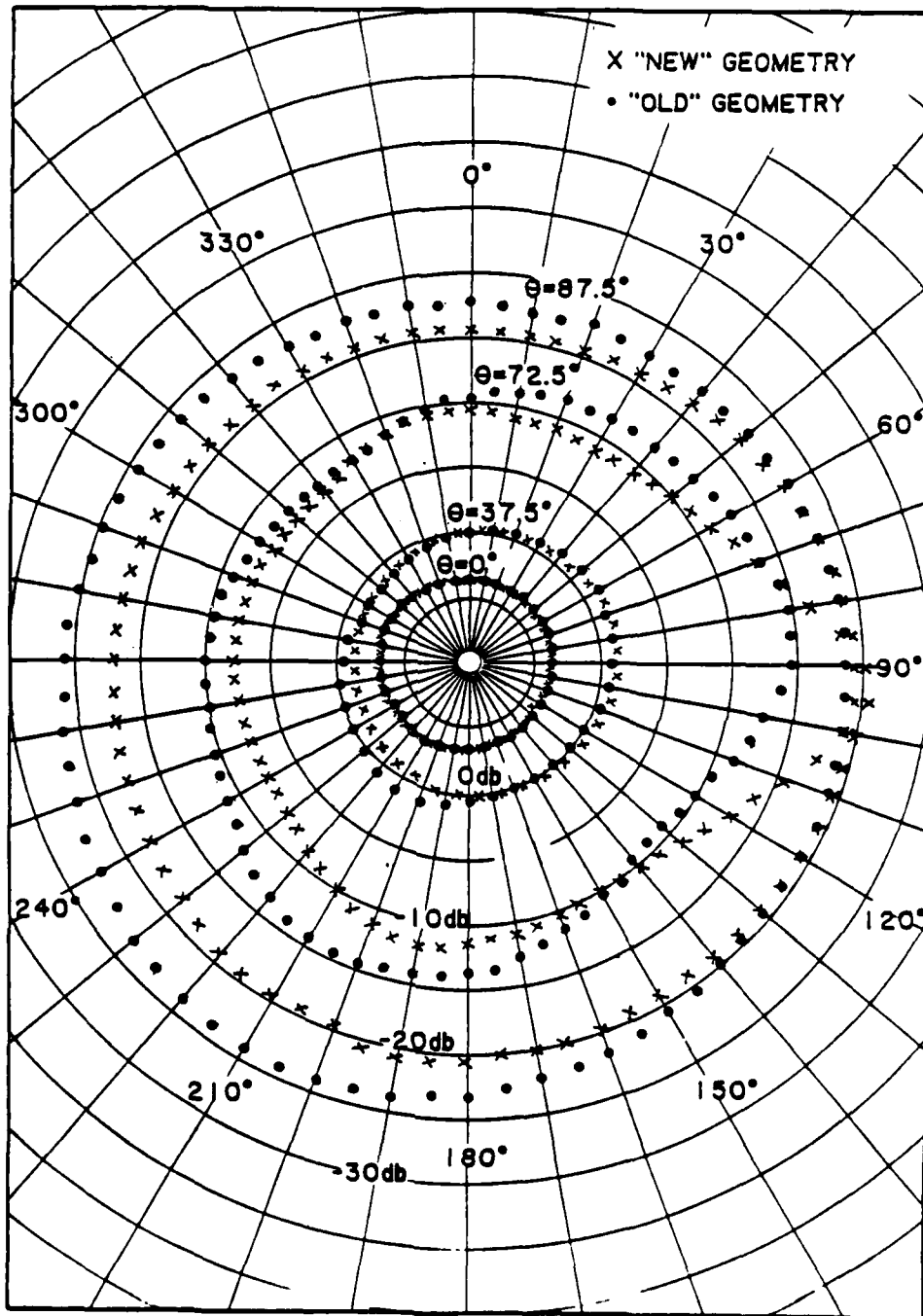


Figure III-4a Power gain vs. phi for constant theta. Comparison of "new" and "old" heating array element geometry. Frequency= 3.17 MHz

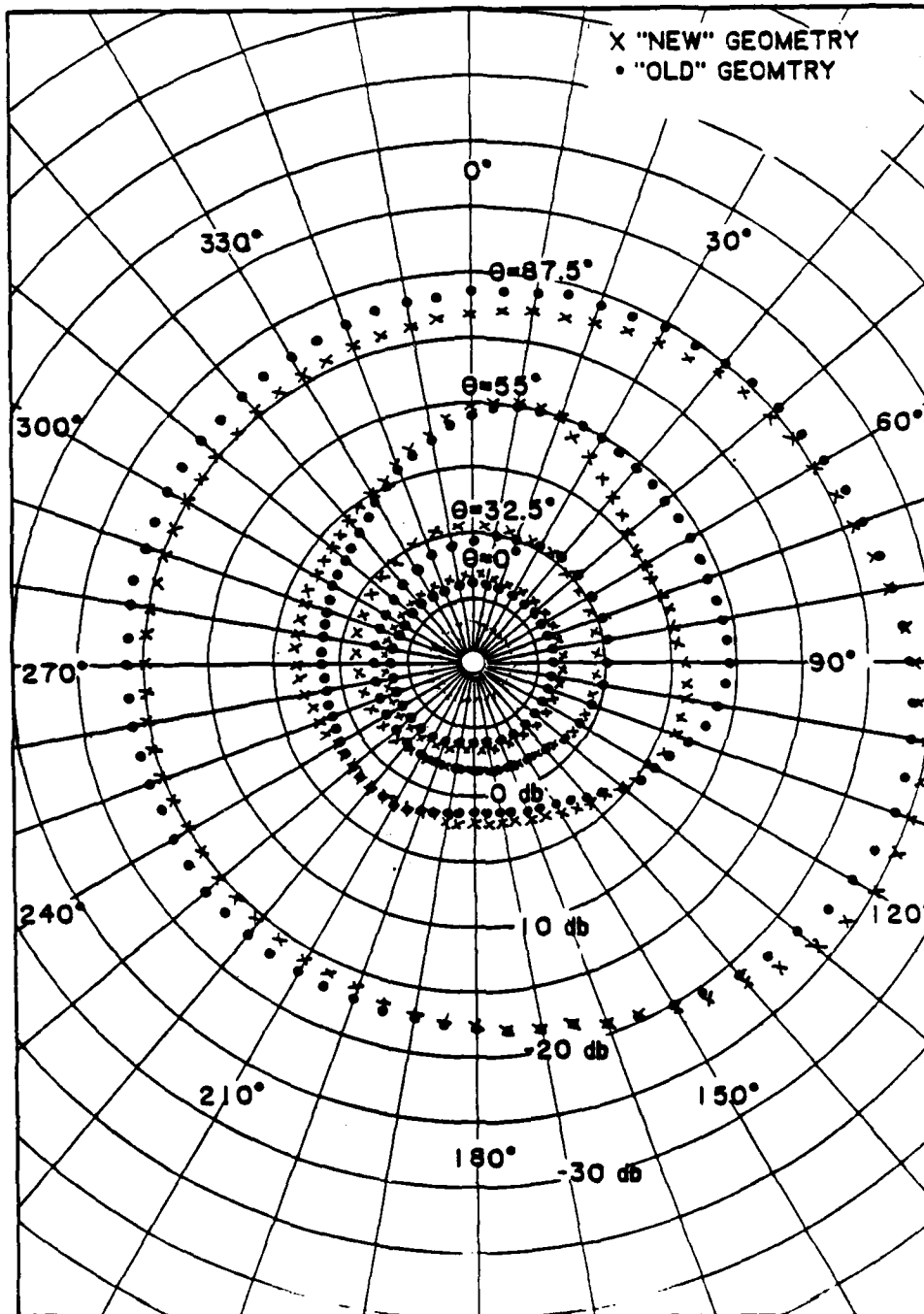


Figure III-4b Power gain vs. ϕ for constant θ . Comparison of "new" and "old" heating array element geometry. Frequency = 5.1 MHz

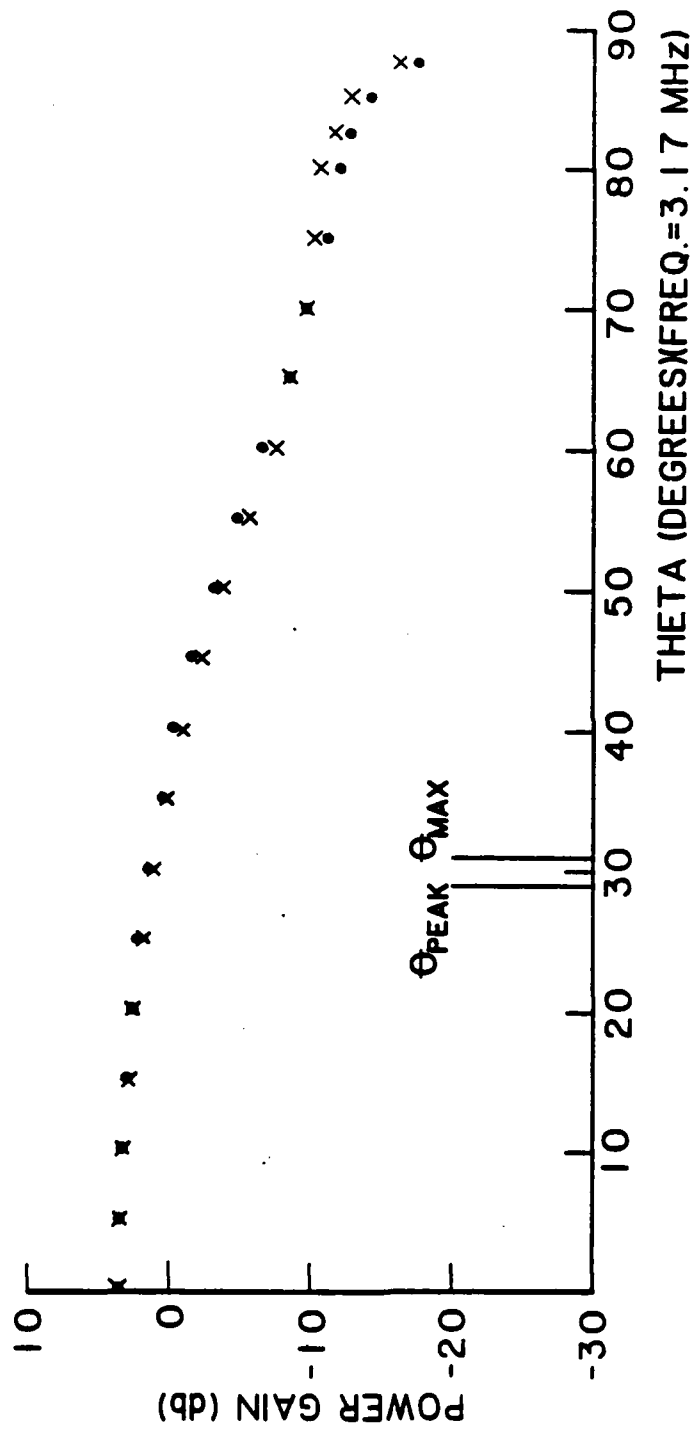


Figure III-5a.1 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 0°
Frequency = 3.17 MHz

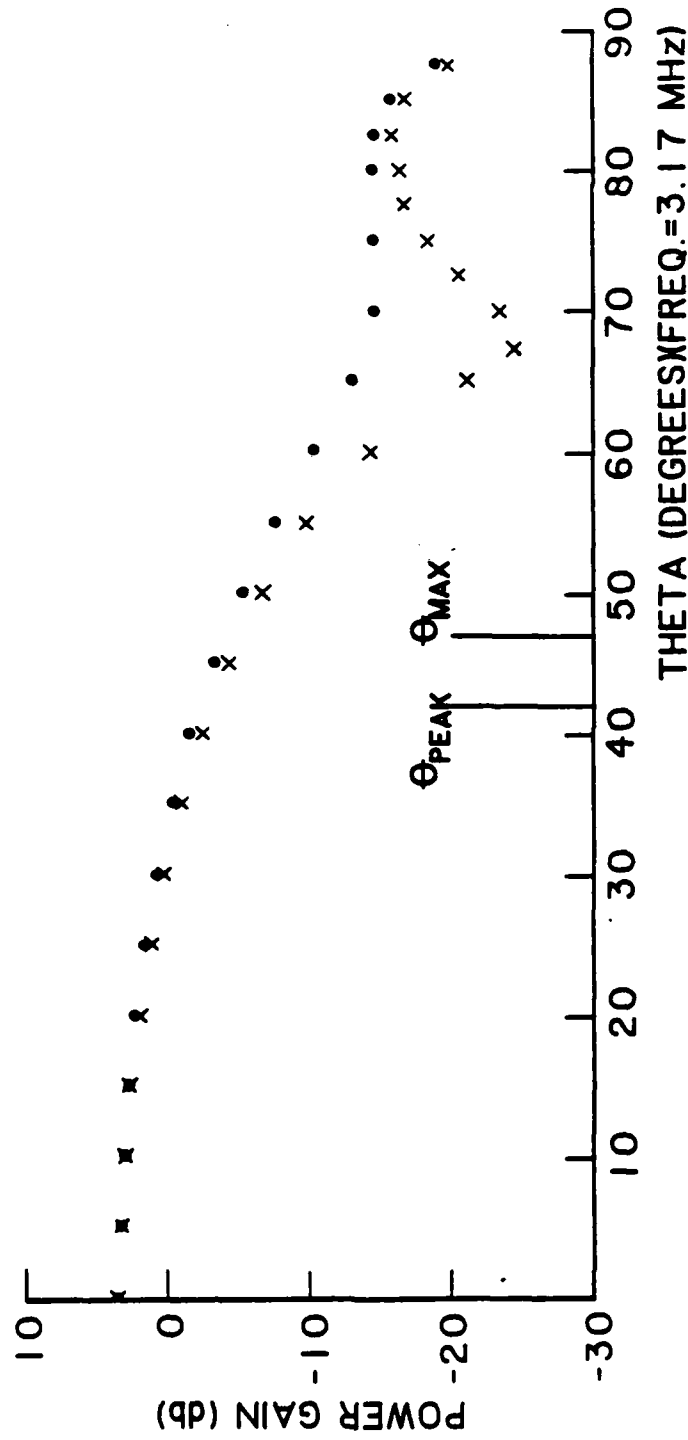


Figure III-5a.2 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. $\Phi = 90^\circ$
Frequency = 3.17 MHz

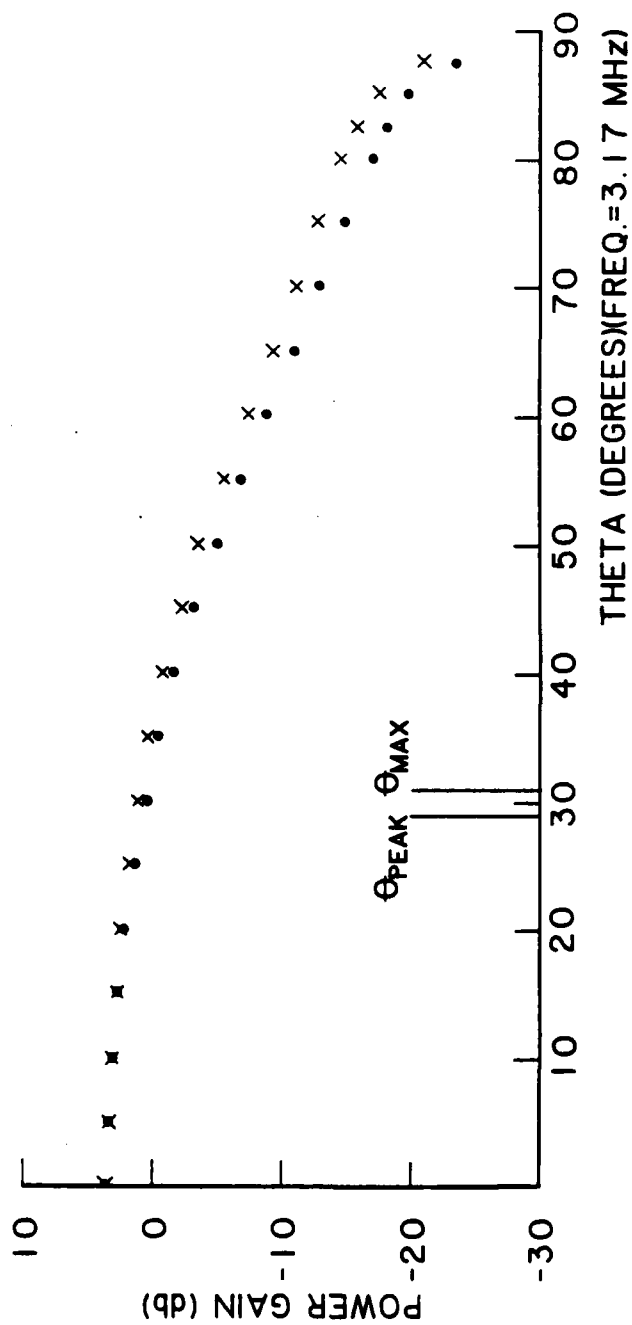


Figure III-5a.3 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. $\Phi = 180^\circ$
Frequency = 3.17 MHz

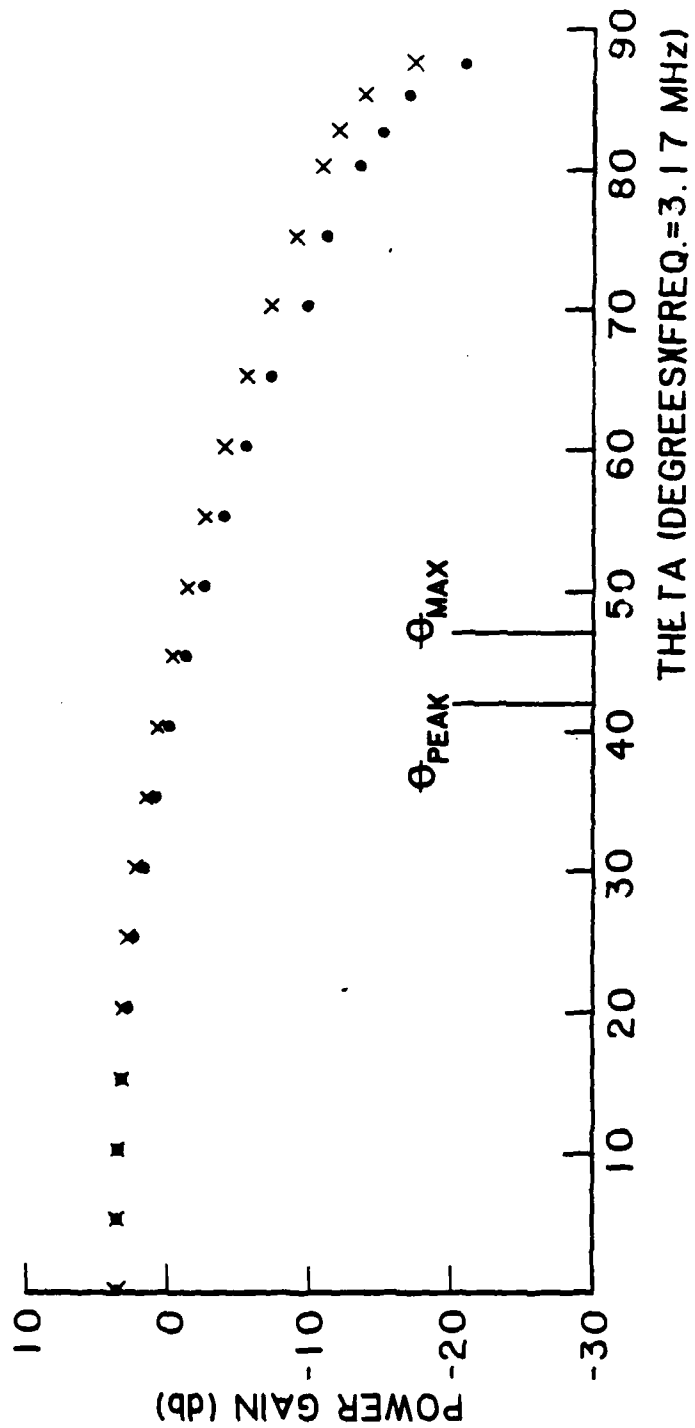


Figure III-5a.4 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 270°
Frequency = 3.17 MHz

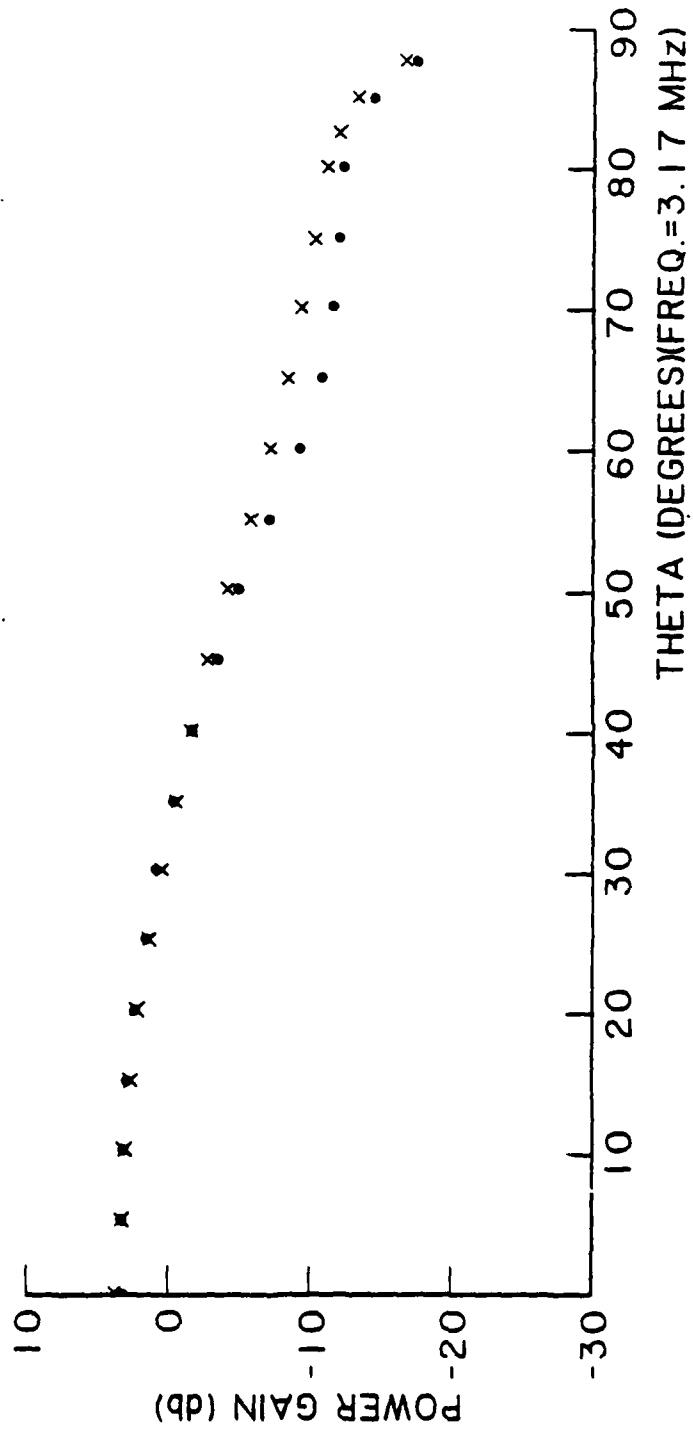


Figure III-5a.5 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 40°
Frequency = 3.17 MHz

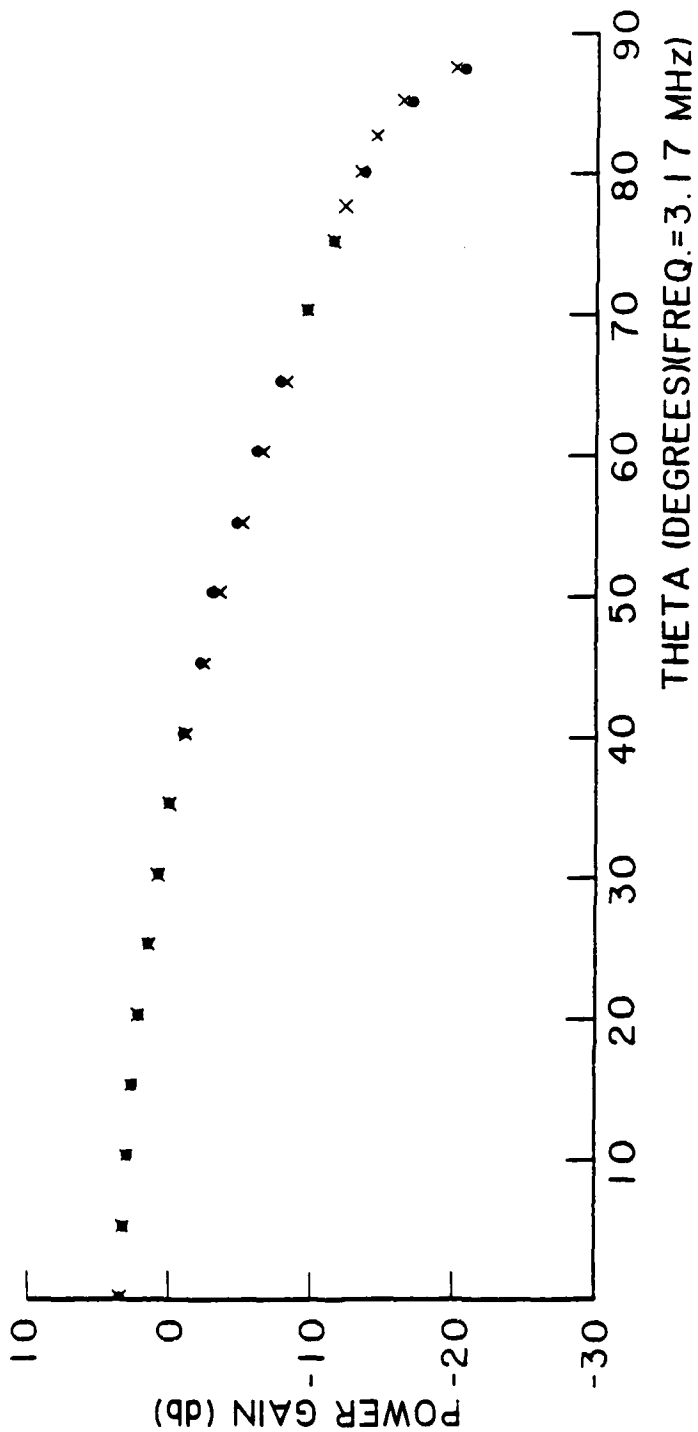


Figure III-5a.6 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 150°
Frequency = 3.17 MHz

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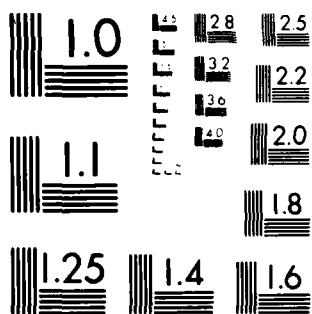
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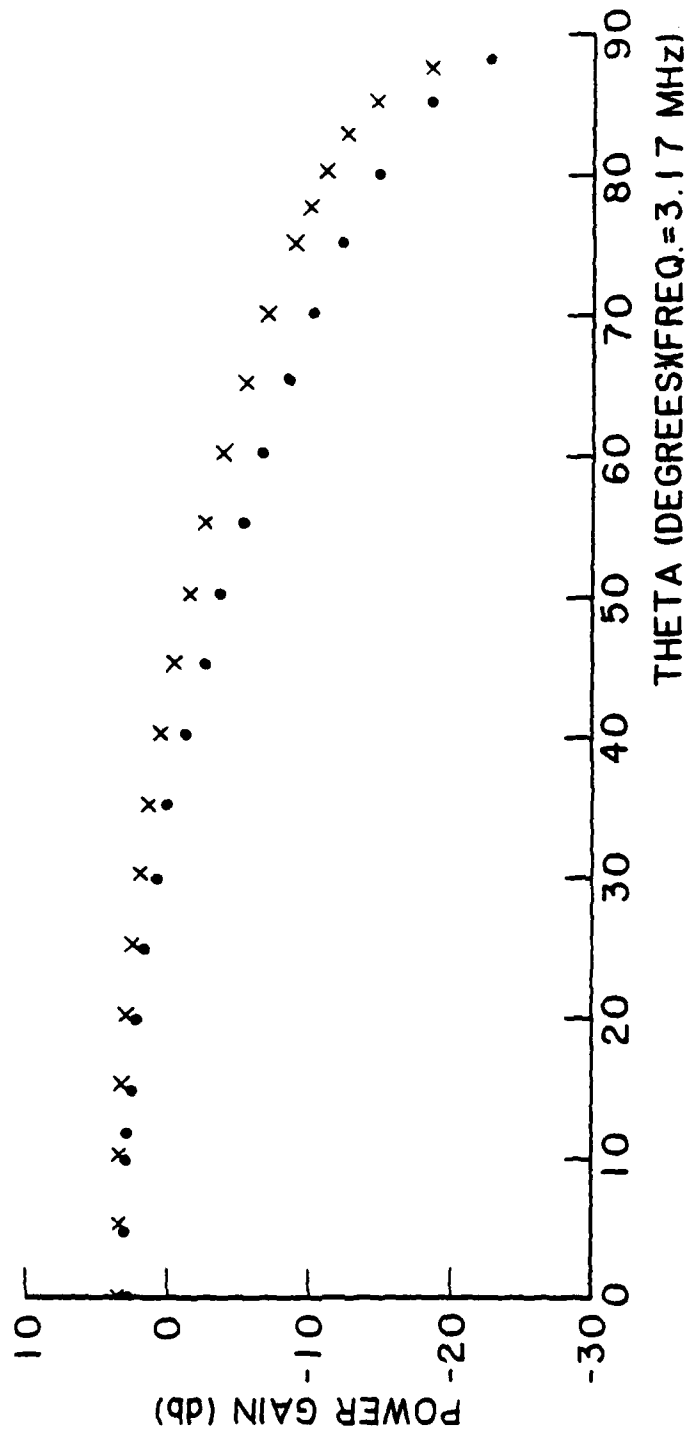


Figure III-5a.7 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 24.00
Frequency = 3.17 MHz

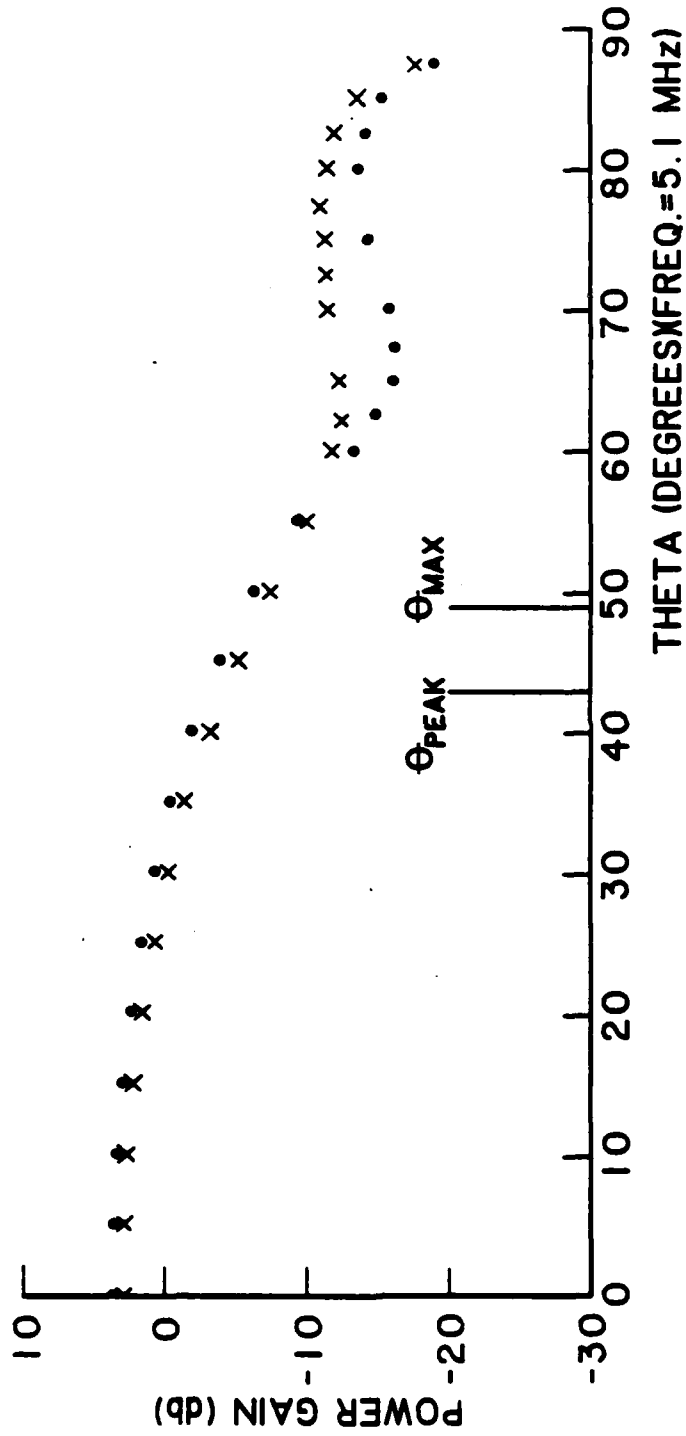


Figure III-5b.1 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 0
Frequency = 5.1 MHz

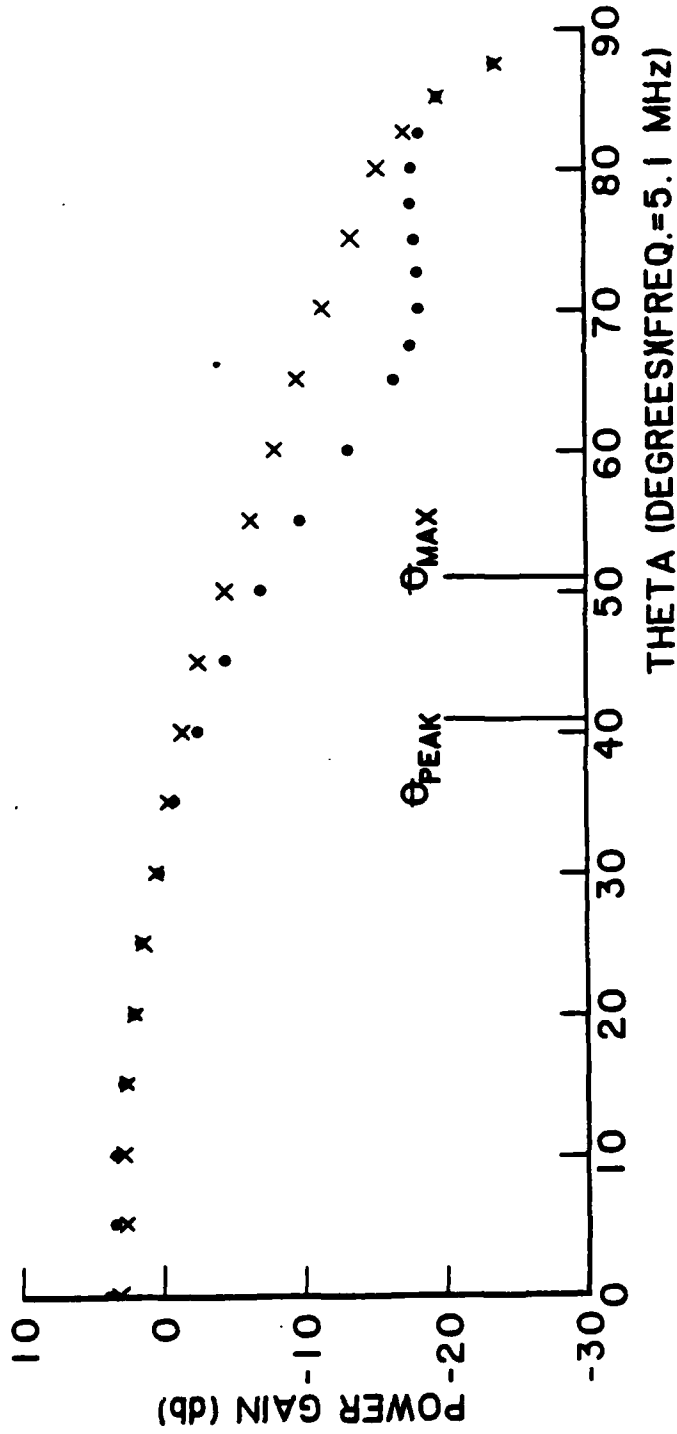


Figure III-5b.2 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. $\phi = 90^\circ$
Frequency = 5.1 MHz

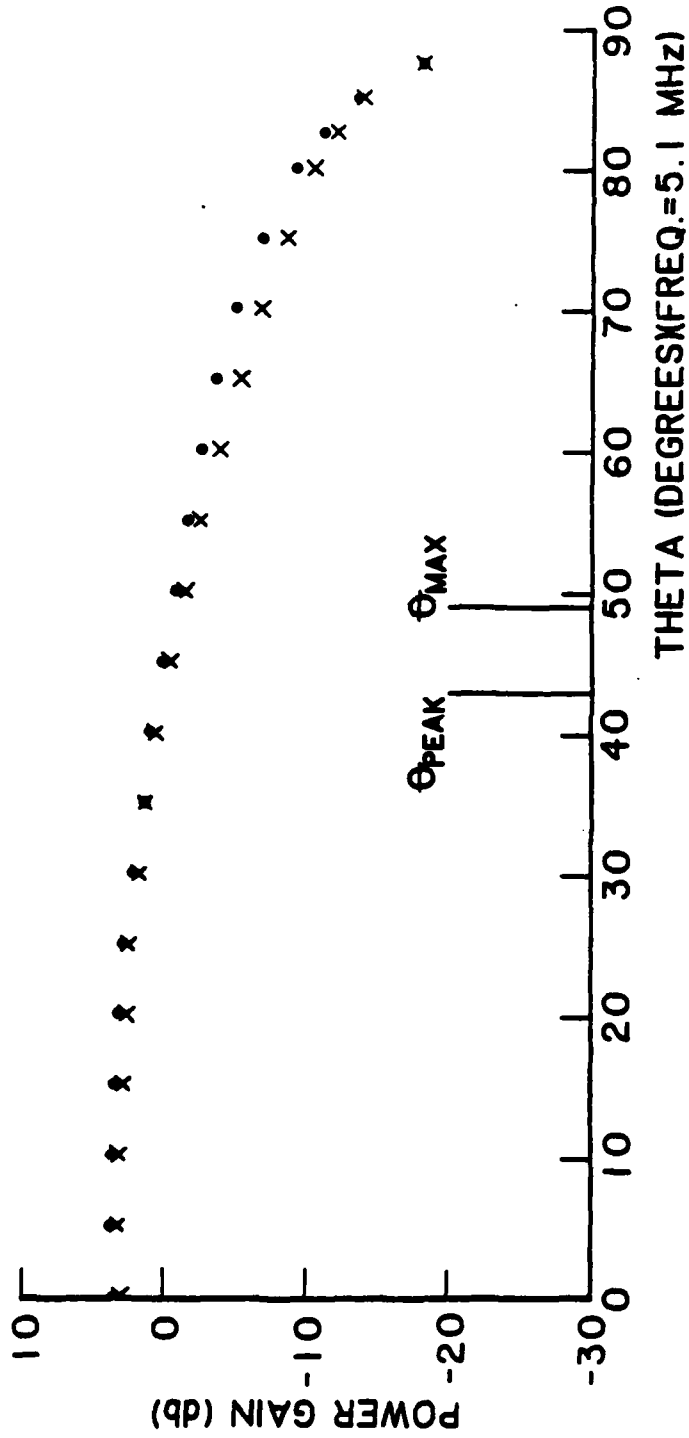


Figure III-5b.3 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 180 degrees. Frequency = 5.1 MHz

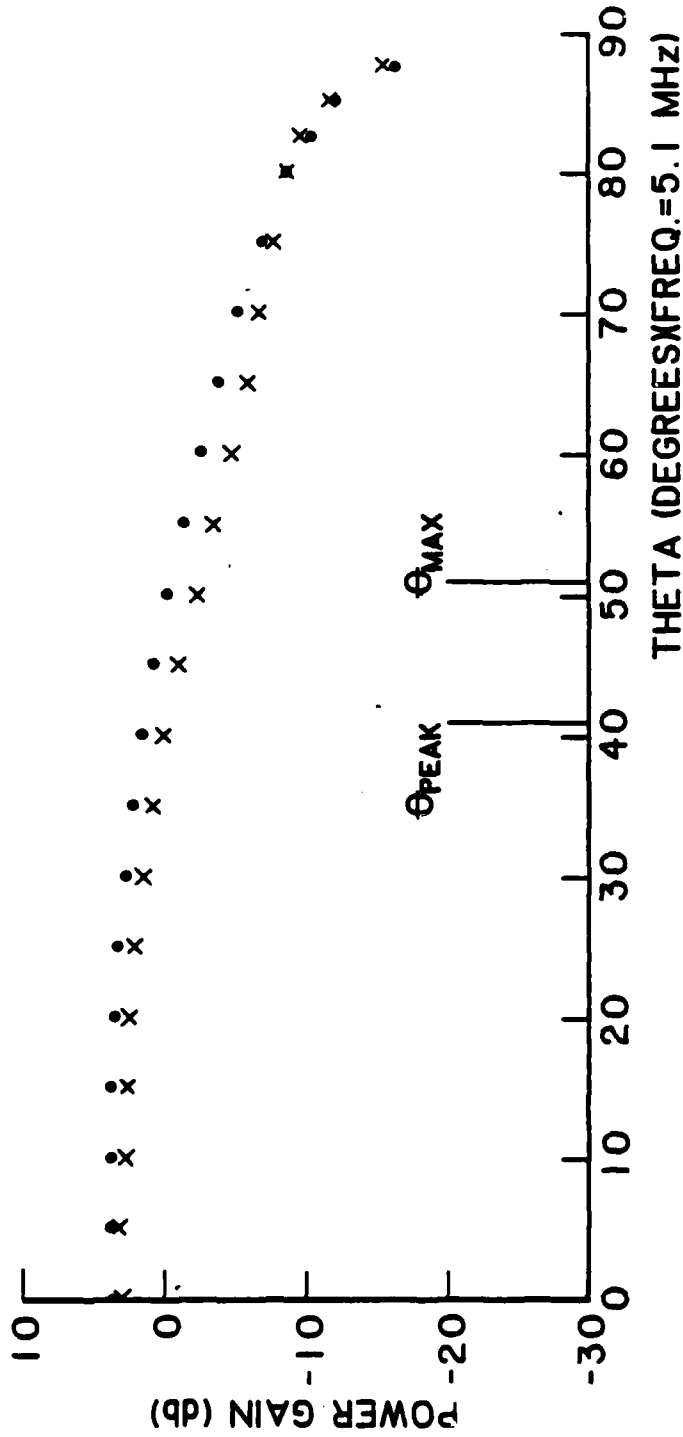


Figure III-5b.4 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. $\Phi = 270^\circ$
 Frequency = 5.1 MHz

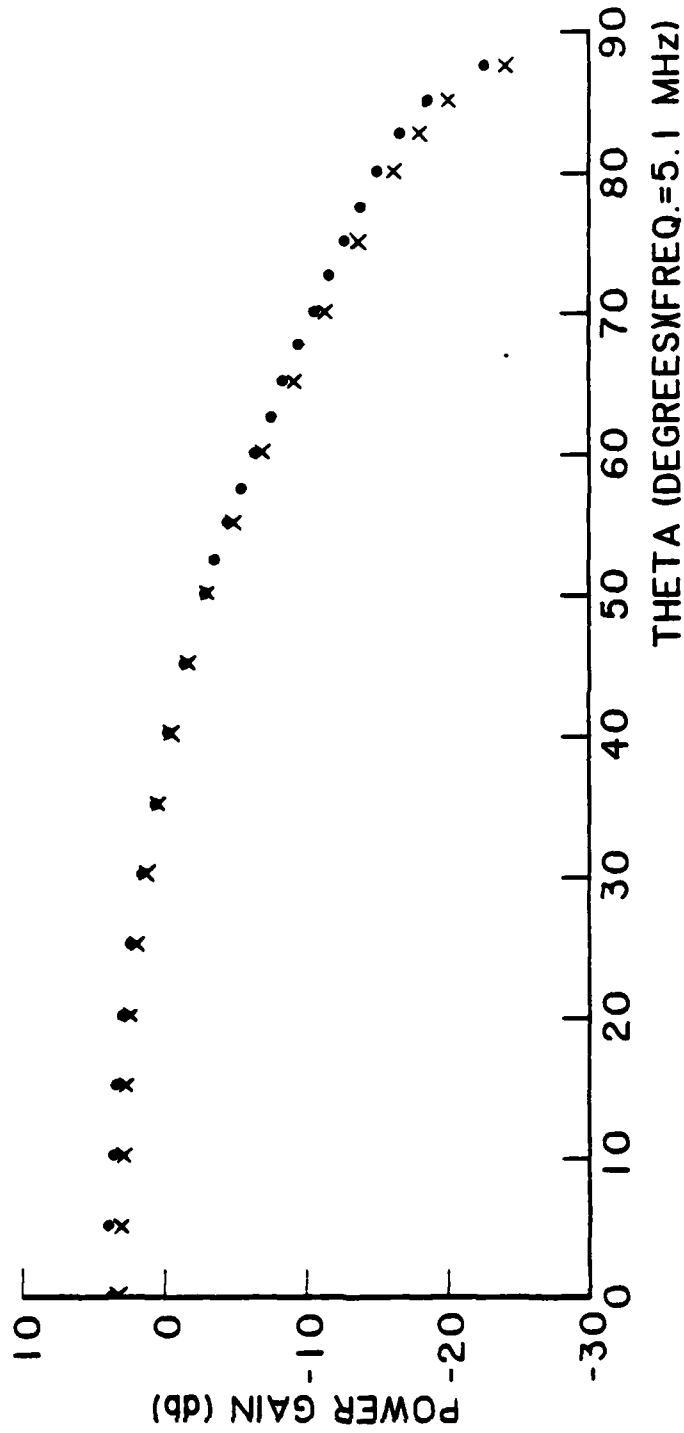


Figure III-5b.5 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. $\Phi = 130^\circ$
Frequency = 5.1 MHz

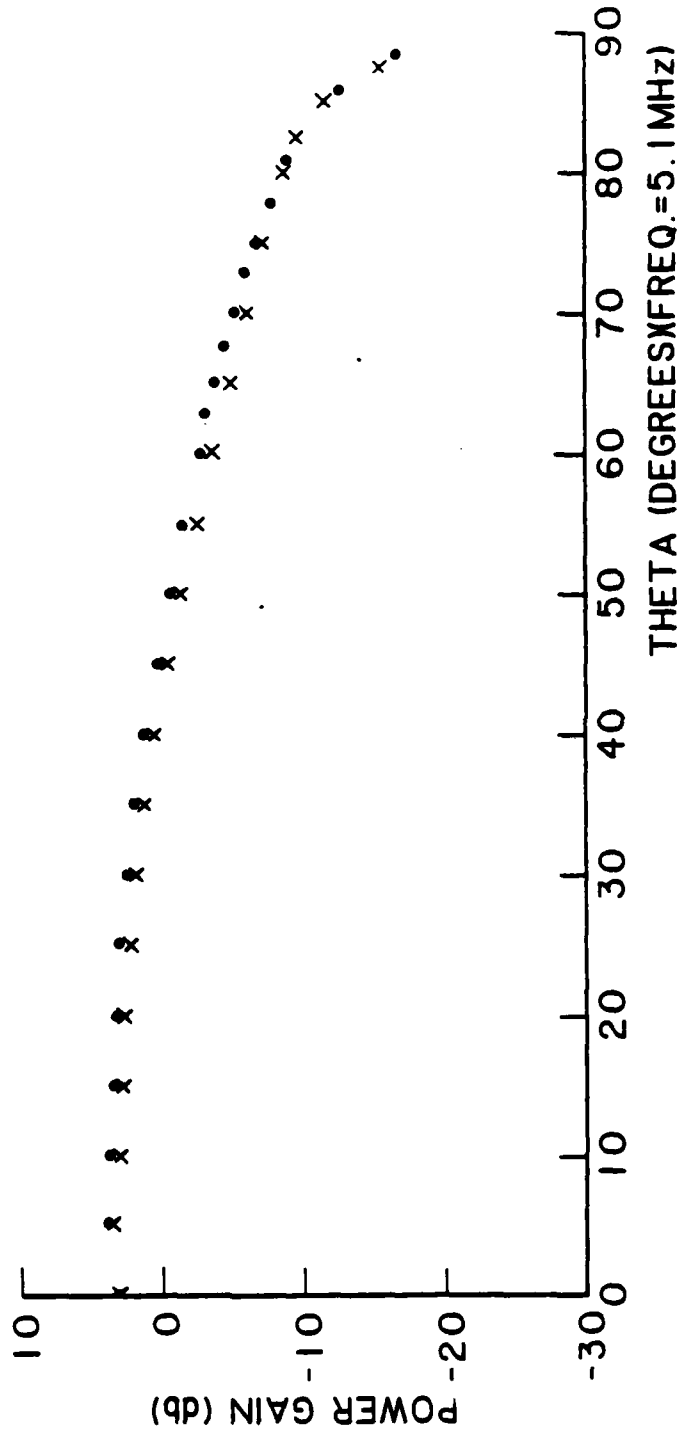


Figure III-5b.6 Power gain vs. 'theta' for constant 'phi'. Comparison of 'new' and 'old' heating array element geometry. Phi = 250°
Frequency = 5.1 MHz

Of particular interest is the differences in directive gain along the "x" and "y" axis. The ELF/VLF source array originates from the HF antenna response along these lines. Table III-2 shows the value of "theta" to the center and furthest edge of the ELF/VLF source region (shown in figures (1-15) and (1-16)) which is furthest from the origin.

Frequency	Source Location		Length	Width	Center	Edge
	x	y				
3.17 MHz	63 km	0	24 km	-----	42°	47°
3.17 MHz	0	38 km	----	7 km	29°	31°
5.1 Mhz	60 km	0	54 km	---	41°	51°
5.1 MHz	0	65 km	---	28 km	43°	49°

Table III-2. Value for θ to the Source Regions Furthest from Origin.

Since all the ELF/VLF sources are located in a region where "theta" is less than 50°, it is concluded that the new geometry will not significantly affect the zero approximation ELF/VLF array model. The plots of relative field intensity versus ELF/VLF frequency should remain essentially the same. The fundamental conclusion of the main body of the report that the ELF/VLF frequency response is affected by the geometry of the HF heating antenna pattern remains intact.

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- 1.5.4 Numerical Techniques and Measurements
- 1.7 Instrumentation and Facilities for Ionospheric Measurements

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