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PROJECT A-2610

OUT-OF-BAND REFLECTOR ANTENNA MODEL

By
T. B. Wells and C. E. Ryan, Jr.

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MARCH 1980 through MAY 1981

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This final technical report presents the model and numerical simulations performed during the 12 month research project. During this program, a flexible, interactive program for Monte Carlo analysis of near-field and far-field fields of a prime focal fed out-of-band paraboloidal reflector antenna was developed and used for numerical simulation. The simulations are not sensitive to frequency only averaging. The distribution of the modal coefficient phases has the greatest effect on

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) the numerically simulated patterns. The numerical simulations also indicate the validity of near-field ensemble measurements in far-field pattern prediction and the role of near-field cross correlation terms in these patterns.

FINAL TECHNICAL REPORT

PROJECT A-2610

OUT-OF-BAND REFLECTOR ANTENNA MODEL

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Contract No. DAAG29-80-C-0083

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Engineering Experiment Station
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A

FOREWORD

The research on this program was performed by personnel of the Electromagnetic Effectiveness Division of the Electronics and Computer Systems Laboratory of the Engineering Experiment Station at Georgia Institute of Technology, Atlanta, Georgia 30332. Dr. C. E. Ryan, Jr. served as the Project Director. This program is sponsored by the Army Research Office, P.O. Box 12211, Research Triangle Park, North Carolina 27709, and is designated by Georgia Tech as Project A-2610. This Final Technical Report covers the period form March 15, 1980 through May 14, 1981. The report summarizes the key results and is provided for the purpose of disseminating technical information to interested parties.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

Approved:

Fred L. Cain
Director,
Electronics & Computer
Systems Laboratory

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INTRODUCTION

The characterization of the radiation properties of antennas at out-of-band frequencies has become increasingly important as the density of cosited antennas increases. For example, a high power system operating in X-band can cause interference to an S-band system by mainbeam-to-mainbeam, mainbeam-to-sidelobe, or sidelobe-to-sidelobe coupling. The typical waveguide feed and components of the S-band system are capable of supporting the higher frequency X-band radiation in the form of higher-order modes which propagate in the transmission waveguide of the feed system. It has been shown in the past that these modes are very sensitive to the particular feed system and to the component mix in the feed system. The purpose of this research project was to construct a computer algorithm which could be used to determine the statistical average patterns for an antenna operating at an out-of-band frequency. The particular antenna which was chosen for the model is a prime focus fed paraboloidal reflector which utilizes a conventional horn feed terminated in a coax-to-waveguide adapter. However, we should note that the program which was developed is quite general and if the statistics of the particular feed device are known or can be hypothesized, these particular statistics can be utilized in the model. Briefly, the model determines which higher-order modes can exist within the feed waveguide, and selects weighting coefficients both in amplitude and phase for these modes on the basis of a random draw from a specified statistical distribution. The particular mode set which has been drawn is utilized to determine the feed pattern for each mode, the resulting aperture distribution, and thus, via a Fourier transformation, the far-field pattern of the antenna for this specific mode. The far-field patterns corresponding to the individual modes are then superimposed to determine the pattern for that particular draw of weighting coefficients. These draws are repeated in a Monte Carlo technique to determine a complete statistical average far-field pattern. A feature of the present computer algorithm is that the analyst may choose to select sets of modes which correspond to the characteristics of known feed devices. For instance, since the coax-to-waveguide adapter is normally center fed, it is a generator of the odd order TE modes. That is, the TE_{10}, TE_{30}, TE_{50}, etc.

Thus, to model this particular feed component, one may choose to eliminate the even ordered TE modes TE_{20}, TE_{40}, TE_{60}, etc. However, we should note that even for the case of a coax-to-waveguide adapter, measured antenna patterns seem to indicate that some even TE modes may exist [1]. This can be due to minor variations in the manufacturing tolerances or to other discontinuities in the feed structure. It should be noted that extensive measured data is presently being obtained under another research contract on the out-of-band characteristics of a prime focus fed paraboloidal reflector [2] . These data will subsequently be statistically analyzed to obtain engineering data on the type of mode distributions which should be expected for a practical antenna. The present computer model is sufficiently adaptable so that when future information regarding the statistical mode distribution is available, it can be readily incorporated in the model. The following sections of this report will describe the methodology used to construct the model, the computer model architecture and subroutines which are employed for the computations, and present results of calculated statistical average and individual far-field radiation patterns. The present model performs a complete vector calculation of the far-field pattern but does not include effects such as edge diffraction from the paraboloidal reflector rim, blockage by the feed horn structure or diffraction by the feed horn. These features can be incorporated in the model at some future date.

SECTION II

MONTE CARLO ANALYSIS OF THE OUT-OF-BAND PARABOLOIDAL REFLECTOR ANTENNA

A. Introduction

The types of microwave antennas and their range of applications are constantly increasing. It is natural that problems which were previously neglected would become important. The interference or coupling between devices operating in different frequency bands is such a problem and is particularly important when many antennas must be operated on relatively small platforms. The analysis presented here addresses a limited portion of this problem, namely the out-of-band radiation characteristics of the class of paraboloidal reflector antennas.

The radiation pattern of such an antenna can be calculated by conventional deterministic analysis and a knowledge of all system variables. The feed network, however, can support multi-mode energy propagation and a calculation of the relative phases and amplitudes of the different modes requires a detailed knowledge of the feed network. This is generally a very difficult boundary value problem. Further, the coefficients of the modes will be quite sensitive to minor electrical and mechanical variations in the feed network so that nominally identical systems can produce distinctly different out-of-band patterns. This characteristic out-of-band pattern sensitivity is evident from experimental and theoretical studies [1,3,4,5]. In order to account for these random effects, the out-of-band mode excitation coefficients may be considered to be random variables. Treatment of these modal coefficients as random variables serves a double purpose. First, it allows the analysis to proceed independent of the feed structure (which may vary between otherwise identical antennas). Second, it leads to a statistical result that can account for variations in fabrication and excitation of the nominal antenna. In a similar manner, the out-of-band frequency may also be treated as a random variable. In this case the interference effects due to sources throughout a frequency band will not require separate analysis and also, interference from pulsed, and hence wide-band, sources can be assessed.

It does not seem appropriate to treat the physical parameters of the feed horn or reflector as random variables. These parameters impact in-band performance directly and so are controlled during fabrication. At the in-band frequency, higher-order modes are attenuated in the feed system and hence are not of interest to the design engineer. Therefore, random variation of the higher-order modal coefficients at out-of-band frequencies should be expected and should have a greater effect than typical variations of focal length, feed horn dimensions, etc. These geometrical variations will affect the reflector optics but will have a relatively minor effect on the aperture distribution and a correspondingly minor effect on the antenna pattern. However, the higher order mode coefficients directly affect the aperture distribution and hence have a major impact on the characteristics of the far-field pattern.

The following paragraphs describe the Monte Carlo analysis of prime focus fed paraboloidal reflector antennas wherein the operating frequency and modal coefficients are treated as random variables. Later it will be seen that the restriction to feeds at the focal point can be relaxed. The analysis determines Monte Carlo average fields and power patterns both in the near-field and in the far-field. The statistical planar near-fields can be used in the calculation of coupling between closely situated antennas. Since near-field measurements of ensembles of antennas operating at out-of-band frequencies have been performed [6], it is useful and convenient to determine how accurately the statistical far-field can be derived from the simple statistical near-field data. (Note that the ensemble of near-field measurements might involve only one antenna operated at different frequencies.) It should be apparent before any analysis, that the results are dependent on the distributions of modal coefficients and frequencies, and hence that the specialization of the model to a specific problem is equivalent to a specification of these statistical distribution functions.

Statistical analysis is generally accomplished by summations over the deterministic quantities in the problem. Thus, this analysis begins with the deterministic calculation of the fields of a paraboloidal reflector antenna. The calculation is a vector calculation as is essential due to the large cross polarized components of the higher-order modal fields.

B. Deterministic Calculation

The deterministic calculation is made using the conventional ray optics technique. The origin is chosen at the focus with the z-axis along the axis of symmetry and toward the paraboloid as shown in Figure (1). Paraboloids of revolution form a one-parameter family of surfaces. All of them are described in this coordinate system by

$$z = \frac{x^2 + y^2}{4f} + f \tag{1}$$

where f is the focal length of the paraboloid.

The field in the aperture plane of the feed horn is a summation of the TE_{mn} and TM_{mn} modal fields that exist in the waveguide but with a phase taper that arises from the flare of the feed horn. The transverse fields are (unnormalized)

$$\begin{aligned} E_x(x',y') &= \frac{n\pi}{b_F} \cos\left(\frac{m\pi x'}{a_F}\right) \sin\left(\frac{n\pi y'}{b_F}\right) e^{i\phi(x',y')} \\ E_y(x',y') &= \frac{m\pi}{a_F} \sin\left(\frac{m\pi x'}{a_F}\right) \cos\left(\frac{n\pi y'}{b_F}\right) e^{i\phi(x',y')} \end{aligned} \tag{2}$$

for the TE_{mn} modes and

$$\begin{aligned} E_x(x',y') &= \frac{m\pi}{a_F} \cos\left(\frac{m\pi x'}{a_F}\right) \sin\left(\frac{n\pi y'}{b_F}\right) e^{i\phi(x',y')} \\ E_y(x',y') &= \frac{n\pi}{b_F} \sin\left(\frac{m\pi x'}{a_F}\right) \cos\left(\frac{n\pi y'}{b_F}\right) e^{i\phi(x',y')} \end{aligned} \tag{3}$$

for the TM_{mn} modes where a_F and b_F are the x and y dimensions of the feed horn aperture and

$$\begin{aligned} x' &= x + a_F/2 \\ y' &= y + b_F/2 \end{aligned} \tag{4}$$

are distances measured from the corner of the feed horn, and $\phi(x',y')$ is the phase taper function. The field terms are expressed most simply in terms of distances from the edges of the feed horn since they arise from the imposition of boundary conditions at these edges. The phase taper function, which is not dependent on the mode, is more readily expressed as

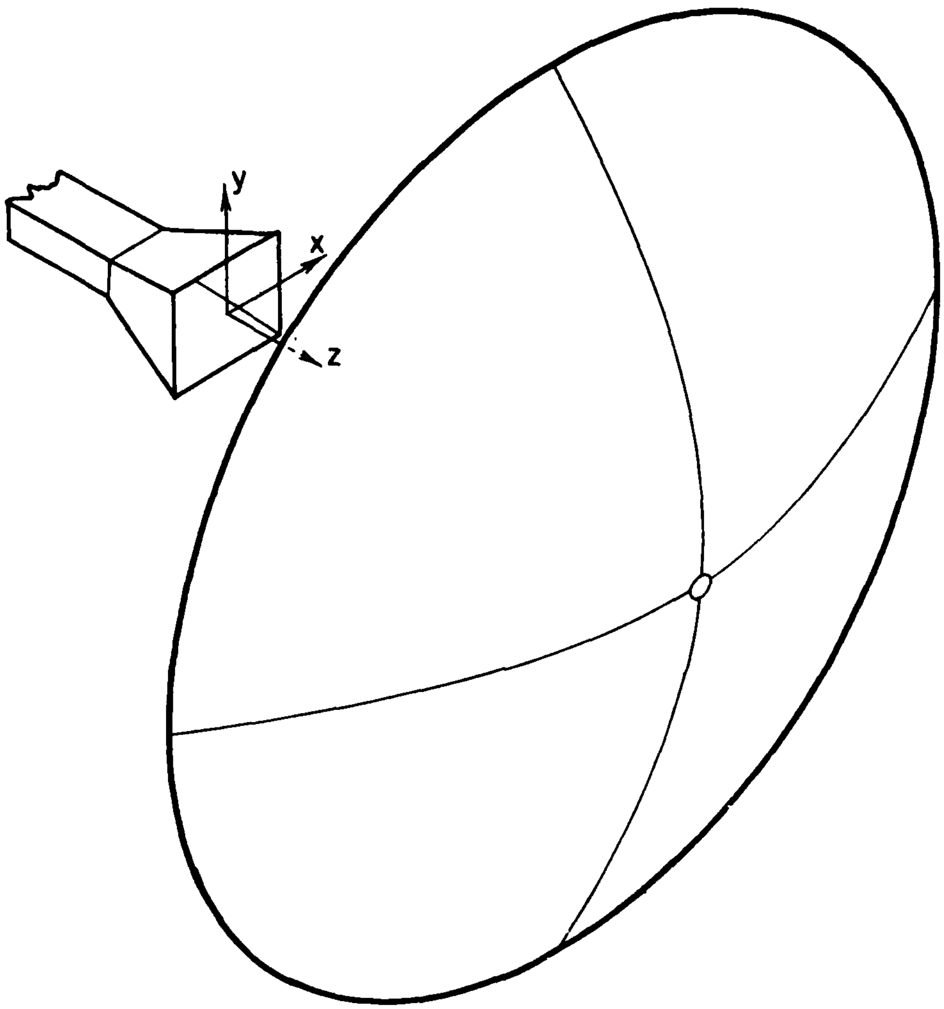

Figure 1. The origin of the coordinate system and the center of the feed horn are at the focus of the paraboloid. The z-axis is directed toward the paraboloidal surface along the axis of symmetry. The x-axis is parallel to the long side of the waveguide.

a function of x and y, the coordinates of Figure 1, originating at the center of the feed horn. The phase taper is

$$\phi\ (x,y) = \frac{\pi f}{c}\ x^2/h \tag{5}$$

for a horn with an H-plane flare and

$$\phi\ (x,y) = \frac{\pi f}{c}\ y^2/h \tag{6}$$

for a horn with an E-plane flare where h is the length of the horn. Note that the long side of the waveguide is parallel to the x-axis so that an H-plane flare is a variation of the x dimension of the horn. The phase taper terms are independent of mode because they represent only the differences in electrical path lengths to the face of the horn.

The far-field of the feed horn is proportional to the Fourier Transform of the feed horn aperture field. It is assumed that the reflector is in the far-field of the feed horn and that ray optics describes the propagation of energy from the feed horn, via the reflection to the aperture plane. Also blockage due to the feed horn is neglected. These approximations and the use of the discrete Fourier Transform are the basis of the numerical code.

The expressions for the far-fields of the feed horn are given as [7]

$$\begin{aligned} E_\theta &= (A_x(k_x,k_y)\cos\phi + A_y(k_x,k_y)\sin\phi)/r, \\ E_\phi &= (-A_x(k_x,k_y)\sin\phi + A_y(k_x,k_y)\cos\phi)\cos\phi/r, \end{aligned} \tag{7}$$

where $A_x(k_x,k_y) = \int\int dxdy\ E_x(x,y)e^{-j(k_xX + k_yY)}$

and $A_y(k_x,k_y) = \int\int dxdy\ E_y(x,y)e^{-j(k_xX + k_yY)}$

are the Fourier Transforms of the feed horn fields E_x and E_y, and θ and ϕ are the normal elevation and azimuth angles defined for the coordinates of Figure 1. The radius r is the distance to the far-field point from the center of the feed horn aperture. The relation of the wave-numbers k_x,k_y to the far field angles is given by

$$k_x = k_o \sin \quad \cos \qquad (8)$$
$$k_y = k_o \sin \quad \sin$$

where $\quad k_o = 2\pi/\lambda.$

These components of the field are incident on the conducting parabaloidal surface and so are completely reflected along lines parallel to the z-axis (this follows from the definition of the paraboloid). The components of the reflected ray are still perpendicular to the direction of propagation after reflection and so lie in the xy-plane. It is convenient to define an aperture plane for the reflector antenna system parallel to the xy-plane and for definiteness, coinciding with the rim of the paraboloid. The reflected E_θ and E_ϕ components lie in the aperture plane, are perpendicular to each other, and are rotated to an angle ϕ relative to the xy axes. Therefore the x and y components of the aperture field E_x^A and E_y^A, are given by

$$E_x^A = C(E_\theta \quad \cos\phi \quad - E_\phi \quad \sin\phi \;) \qquad (9)$$
$$E_y^A = C(E_\theta \quad \sin\phi \quad + E_\phi \quad \cos\phi \;).$$

The proportionality constant C must account for space loss. There are no new phase difference terms because all ray paths from the focus to the paraboloid to the aperture plane are of equal length. The most direct determination of the space loss factor is by conservation of energy. As illustrated in Figure 2, rays from the focus diverge till they strike the reflector and then propagate parallel to one another to the aperture plane. Consider the bundle of rays that passes through an element S_F of the spherical surface a distance r from the focal point. These rays are reflected and pass through an area element S_a of the aperture plane. It is apparent physically that the energy of the ray bundle crossing S_F and S_a must be the same. This is clear formally by considering the closed surface consisting of S_F and S_a and the surfaces formed the rays that strike the edges of S_F and S_a and that part of the reflector S_p that the ray bundle intersects. This surface is denoted by S. Conservation of energy is imposed as

$$\int_S \vec{E} \times \vec{H}^* \cdot \hat{n} \, dS = 0 \tag{10}$$

where $\hat{n}$ is the unit outward normal to the surface. The surfaces parallel to the rays make no contribution to the integral. The surface S_P lies within the reflector and, since the reflector is a good conductor, the fields on S_P are zero. Thus Equation (10) reduces to

$$\int_{S_F} \vec{E} \times \vec{H} \cdot \hat{n} \, ds + \int_{S_A} \vec{E} \times \vec{H} \cdot \hat{n} \, ds = 0. \tag{11}$$

For differential area elements and the plane waves of ray optics this becomes

$$-\int_{\phi}^{\phi+\Delta\phi} \int_{\theta}^{\theta+\Delta\theta} E^2 \, r^2 \sin\theta d\theta d\phi + \int_{\rho}^{\rho+\Delta\rho} \int_{\phi}^{\phi+\Delta\phi} E^2 \rho \, d\rho \, d\phi = 0 \tag{12}$$

with notation as defined in Figure 2. The fact that the ray and the normal to the surface have opposite orientations on S_F and S_a is responsible for the minus sign in Equation (12). For differential area elements this becomes

$$E_F^2 S_F = E_A^2 S_A, \tag{13}$$

or

$$E_F^2 r^2 \Delta\phi \sin\theta\Delta\theta = E_A^2 \Delta\phi\rho\Delta\rho, \tag{14}$$

from which one determines that

$$E_F^2/E_A^2 = \frac{\rho}{r^2 \sin\theta} \frac{d\rho}{d\theta} \tag{15}$$

This is evaluated by rewriting Equation (1) for the paraboloidal surface as

$$\rho = r_p \sin\theta = 2f \sin\theta/(1 + \cos\theta) \tag{16}$$

where

$$\rho = x^2+y^2$$

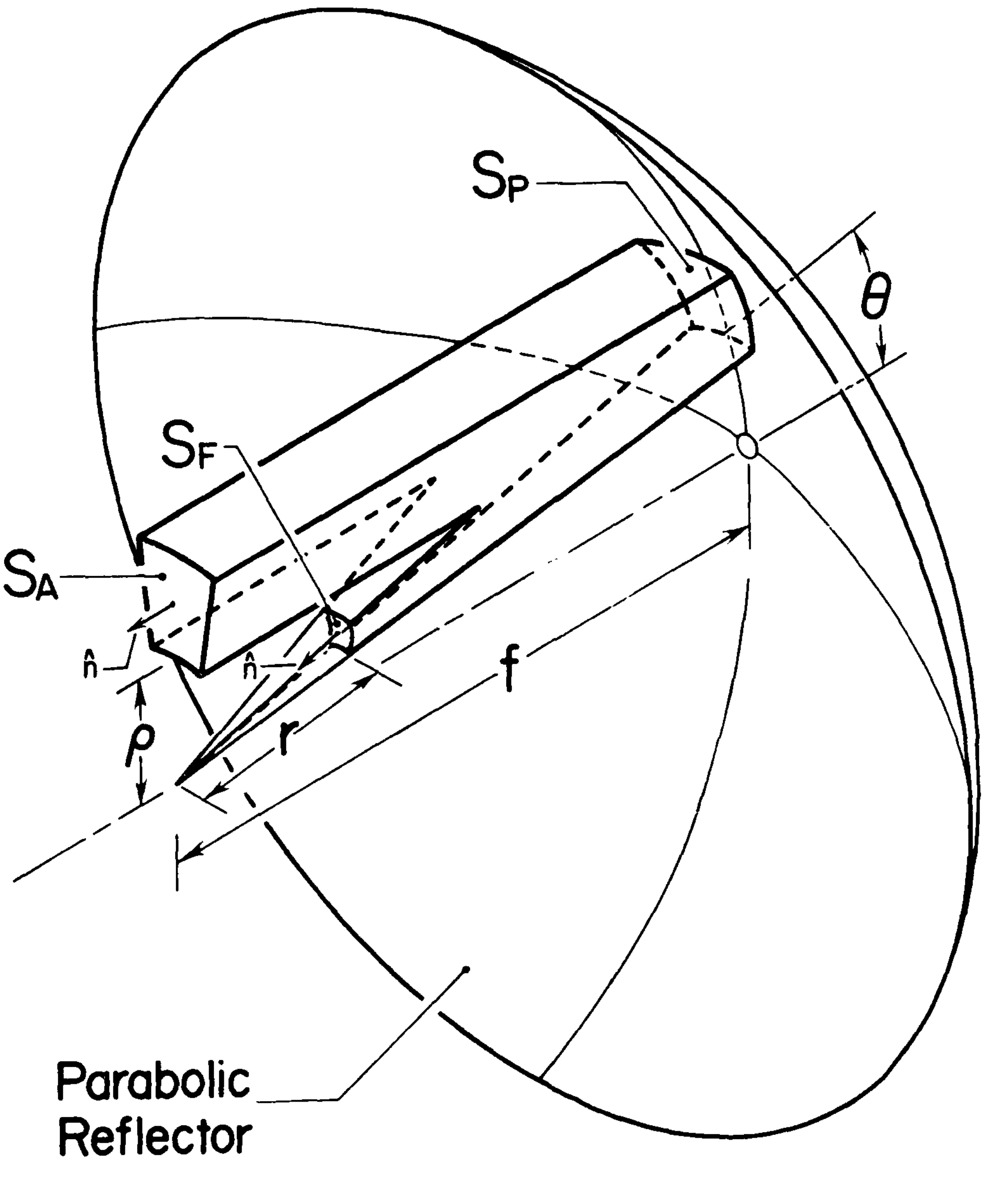

Figure 2. A ray bundle spreading from the focal point and subtending angles $\Delta\phi$ and $\Delta\theta$ of the sphere of radius r about the focal point is depicted. This ray bundle is incident on an area S_P of the paraboloid and is reflected through an area S_A of the aperture plane of extent $\Delta\phi$, $\Delta\rho$.

and r_p is the distance from the focal point to a point of the paraboloidal surface at an elevation angle θ . The result valid for each component of Equation (9) is

$$E_A = \frac{r}{r_p} E_F \qquad (17)$$

or $C = r/r_p$ and the r cancels the r in the feed horn far-field components of Equation (7). The x and y components of the aperture field can now be calculated via equations (7), (9), and (17). The field at a point x,y of the aperture plane is related to the Plane Wave Spectrum $\bar{A}(k_x,k_y)$ of the feed horn where k_x, k_y are given in terms of far-field angles about the focal point by Equation (8). With some algebra, it follows from Equation (16) that

$$k_x = 4k_o\ f\ x/(x + y + 4\ f^2) \qquad (18)$$

$$k_y = 4k_o\ f\ y/(x + y + 4\ f^2).$$

The calculation of the deterministic aperture field from the field in the feed horn aperture is now complete. The numerical evaluation of this field as implemented in the code PARAB requires the following observations. First note that any field in the feed horn aperture can be written as a sum of modal fields with specified modal coefficients. This principle of superposition follows from the linearity of Maxwell's Equations. Similarly, the far-field of the feed horn is proportional to the Fourier Transform (FT) of the feed horn aperture field and, by linearity of the FT, can be written as the sum of the FT of the modal fields times the modal coefficients. The mapping that represents the reflector is also linear and thus the fields in the reflector aperture and the antenna far-field are a sum over modal fields. One can therefore calculate the far-field pattern for each mode independently. The practical importance of treating the modal fields independently is that this allows the separability of the feed horn fields to be used.

Note also that the far-field pattern of the antenna is to be obtained as the FFT (Fast Fourier Transform) of the aperture field. The FFT algorithm assumes a regular rectangular grid of data points $n\Delta x$, $m \Delta y$. For $m \epsilon \{-N_y/2 - 1, \ldots N_y/2\}$ and $n \epsilon \{-N_x/2 - 1, \ldots N_y/2\}$ where N_x and

N_y are the dimensions of the data array. Equation (18) demonstrates that this regular array of points x,y does not correspond to regularly spaced points k_x,k_y. Values of the spectrum of the feed horn must be determined for this non-uniform array of points. These points could be calculated by a two-dimensional polynomial interpolation formula from data points on a uniform rectangular grid obtained by FFT of the feed horn fields. A more accurate method is direct calculation of the Fourier Transform. Such a direct calculation normally requires calculation of a two-dimensional integral for each point of the array and so is prohibitive. In this case, the modal fields are, by Equations (2) and (3), separable functions of x and y so that $A(k_x, k_y)$ for arbitrary k_x and k_y can be calculated by two one-dimensional integrals.

The approximations contained in the deterministic calculation are summarized as follows. The reflector is treated as being in the far-field of the feed horn. It is also assumed that the reflector is circular (that its rim is a circle) and that blockage effects due to the feed system are negligible; other shapes as well as geometrical blocking could readily be implemented (with an increase in the number of input parameters required). Ray optics without diffraction effects is used. The numerical evaluation is based on discrete Fourier Transforms without interpolation. The principal part of the deterministic calculation is implemented in Subroutine REFLEC.

C. Statistical Analysis

As described previously, the statistical problem consists of the treatment of the modal coefficients and the operating frequency as random variables in the calculation of the fields and power of the antenna. The treatment that is implemented is a Monte Carlo calculation wherein sampled values of an assumed distribution of the random variable are used in a deterministic calculation to determine statistical values of the field and its moments. Such a calculation evidently reproduces the results obtained by measurement of an ensemble of antennas if (1) the assumed and actual distribution of the random variables are the same, (2) the deterministic calculation is accurate, and (3) the size of the statistical sample is sufficiently large.

The size of sample required is determined by the precision with which the various statistical moments are to be calculated. In practice, the size of the sample is varied and the effect on the various computed moments of the field are noted. The limitations of the deterministic calculation have already been discussed. The determination of the distribution functions for the frequency and modal coefficients is a separate problem requiring a complete specification of the feed system and sources of higher-order mode generation, including the modal distribution functions. Such specifications are not currently available, although a measurement program [2] is being undertaken to determine the statistics for the case of a coax-to-waveguide fed paraboloidal antenna. Thus the specific calculations to be described in this report are geared to determining the qualitative effects of varying the distribution functions.

A realizable aperture field for the out-of-band antenna can be written as

$$\bar{E}_A(x,y,f) = \sum_{m,n,k} C(m,n,k)\ \bar{E}_{A,m,n,k}\ (x,y;f) \qquad (19)$$

where the summation is over all allowable propagating waveguide modes TE_{mn} and TM_{mn}. The value k=1 is associated with TE modes and k=2 with TM modes. The deterministic modal fields in the aperture plane $\bar{E}_{A,m,n,k}$ are as described in the previous section. Their dependence on frequency is through the phase tapers of Equation (5) and (6) and through the k_x and k_y values at which the feed horn spectrum is to be calculated as given by Equation (18), specifically the k_o factor. The specification of a set of modal coefficients is then sufficient to determine the aperture field $\bar{E}_A(x,y;f)$.

It is clear that the deterministic aperture field can be calculated for any frequency and any set of modal coefficients. Similarly, the deterministic far-field or spectrum can be calculated. Specifically, the spectrum is given by:

$$\begin{aligned}\bar{A}(k_x,k_y;f) &= \text{F.T.}\ [\ \vec{E}_A(x,y;f)\ ] \\ &= \sum_{m,n,k} C(m,n,k)\ \text{F.T.}\ [\ \vec{E}_{A,m,n,k}(x,y;f)\ ] \\ &= \sum_{m,n,k} C(m,n,k)\ \vec{A}_{m,n,k}\ (k_x,k_y;f) \qquad (20)\end{aligned}$$

where linearity of the Fourier Transform has been used and spectra $\bar{A}_{m,n,k}$ of the aperture modal fields have been defined. The near-field or aperture power is proportional to

$$P^x_{n.f.} = |E_{Ax}|^2 \qquad (21)$$
$$P^y_{f.f} = |E_{Ay}|^2$$

The spectral power pattern, proportional to the far-field pattern of the antenna, is defined by

$$P^x_{f.f} = |A_x|^2 \qquad (22)$$
$$P^y_{f.f} = |A_y|^2$$

Ensemble averages of these quantities can now be written for arbitrary ensembles of frequencies and coefficient sets. These averages are the statistical quantities that will be calculated. Higher moments of the field will be important in future calculations.

The average of the near-field over an ensemble of coefficient sets is given by

$$\langle E_A \rangle_C = \frac{1}{N_c} \sum_i \bar{E}_A{}^i \qquad (23)$$

where N_c is the number of coefficient sets in the ensemble and $\bar{E}_A$ is the determinstic aperture or near field that occurs for the set of coefficients $C^i(m,n,k)$. Writing the average in terms of these coefficients as in Equation (19):

$$\langle E_A \rangle_c = \frac{1}{N_c} \sum_i \sum_{m,n,k} C^i(m,n,k)\, \bar{E}_{A\ m,n,k}(x,y;f)$$

$$= \sum_{m,n,k} \langle C(m,n,k) \rangle_c\, \bar{E}_{A\ m,n,k}(k,y;f) \qquad (24)$$

where

$$\langle C(m,n,k) \rangle_c = \frac{1}{N_c} \sum_i C^i(m,n,k).$$

This has the form of Equation (19) and demonstrates that the statistical coefficient average of the near-field is identically the deterministic near-field that occurs when each mode is present with its average coefficient. The situation is the same for the average of the far-field over an ensemble of coefficient sets as can be seen by replacing E_A by A in Equations (23) and (24) and using Equation (20). The situation is not as simple for averages over frequencies or for averages of the near-field or the spectral powers.

Writing the ensemble average over frequencies of the near-field

$$< \bar{E}_A >_f = \frac{1}{N_f} \sum_i \sum_{m,n,k} C^i(m,n,k)\ \bar{E}_{A,m,n,k}(x,y;f^i) \qquad (25)$$

where N_f is the number of frequencies in the ensemble, it is apparent that the sum cannot be rearranged as in Equation (24) because of the dependence of the modal aperture fields on the frequency. Neither the frequency average of the near-field nor of the spectrum is equivalent to a similar deterministic quantity.

In discussing the deterministic calculation, the dependence of the fields on frequency through the direction cosines $\hat{k}_x = k_x/k_o$ and $\hat{k}_y = k_y/k_o$ where $k_o = 2\pi\ c/f$ has been noted. This requires careful treatment in forming the frequency average and leads to a distinction between the calculations of near-field and spectral frequency averages. Specifically, the near-field average requires that the modal fields of different frequency be calculated on a regular grid of points x,y in the aperture. By Equation (18), this means that the points k_x,k_y at which the feed horn spectrum must be calculated will be different for different frequencies. On the other hand, the calculation of frequency averages of spectral or far-field quantities, requires that the direction cosines $\hat{k}_x^A$ and $\hat{k}_y^A$ with respect to the aperture plane be the same for the different frequencies. This means that the different frequency fields are calculated on aperture grids with different spacings. If, for a nominal center frequency f_o, an aperture grid with an x_o spacing is used, then an aperture grid with spacing

$$\Delta x_i = \Delta x_o f_o/f_i \qquad (26)$$

is used for the frequency f_i. Again, the points at which the feed horn spectrum must be evaluated are given by Equation (18) but with points x,y that are frequency dependent.

With the above background, calculation of the near-field or spectral power averages is straightforward. The averages over frequency ensembles and/or ensembles of coefficient sets are given by

$$\langle P^x_{n.f} \rangle_{f,c} = \frac{1}{N_{f,c}} \sum_i |E_{Ax}|^2 \qquad (27)$$

$$\langle P^y_{n.f} \rangle_{f,c} = \frac{1}{N_{f,c}} \sum_i |E_{Ay}|^2$$

for the near-field power and

$$\langle P^x_{f.f} \rangle_{f,c} = \frac{1}{N_{f,c}} \sum_i |A_x|^2 \qquad (28)$$

$$\langle P^y_{f.f} \rangle_{f,c} = \frac{1}{N_{f,c}} \sum_i |A_y|^2$$

for the spectral power. It should be noted that the sums cannot be expanded and rearranged and that the results are not equivalent to deterministic patterns.

D. An Approximate Statistical Far-Field Pattern

The statistical moments of the near field are directly of use in the calculation of near-field coupling. They also provide an approximate means of evaluating the spectral power average as follows. The average spectral power is given in terms of aperture fields by

$$\langle \overset{i}{P}(k_x,k_y) \rangle = \langle A_i^*(k_x,k_y)\, A_i(k_x,k_y) \rangle$$

$$= \iint dx\,dy\,dx'\,dy' \, \langle E^*_{A_i}(x',y')\, E_{A_i}(x,y) \rangle e^{j[k_x(x'-x)+k_y(y'-y)]} \qquad (29)$$

for i=x,y. Similarly the average spectral field is given by

$$\langle \overline{A}(k_x,k_y) \rangle = \iint dx\,dy \; \langle \overline{E}_A(x,y) \rangle \; e^{-j(k_x x + k_y y)} \qquad (30)$$

The covariance of the spectral power is defined by

$$C^{i}_{A^*A} = < A^*_i(k_x,k_y \quad A_i(k_x,k_y)> \; -< A^*_i(k_x,k_y)> <A_i(k_x,k_y) \; >. \quad (31)$$

with i=x,y. Assuming as usual that the integrals of Equations (27) and (30) are evaluated by quadrature, and after some rearrangement this can be written as:

$$C^{i}_{A^*A} = \sum_{p,q} (\sigma^{i}_{p,q})^2 + \sum_{\substack{p\neq q' \\ q\neq q'}} C^{i}_{pp'qq'} e^{j[k_x(x_{p'}-z_{p'})+k_y(y_{q'}=y_q)]} \quad (32)$$

where

$$C^{i}_{pp'qq'} = < E^*_{Ai}(x_{p'}y_{q'}) \; E_{Ai}(x_q y_q)> \; - <E^*_{Ai}(x_{p'},y_{q'})> <E_{Ai}(x_p,y_q)> \quad (33)$$

and

$$(\sigma^{i}_{p,q})^2 = <E^*_{Ai}(x_p,x_q)E_{Ai}(x_p y_q)> - <E^*_{Ai}(x_p,y_q)> <E_{Ai}(x_p,y_q)> \quad (34)$$

for components i=x,y. Neglect of the cross correlation coefficients $C_{pp'qq'}$ then leads to an expression for the spectral power pattern in terms of near-field quantities that can be measured with a single probe:

$$\overset{i}{<P(k_x,k_y)>} \; =< A^*_i(k_x,k_y)> \; < A_i(k_x,k_y)> \; + \sum_{p,q} (\rho^{i}_{p,q})^2 \quad (35)$$

For discussion of the validity of this approximation see [6] . It might be expected that $C^{i}_{pp',qq'}$ is small when $(\sigma^{i}_{p,q})$ is small and thus calculation of a small standard deviation suggests that Equation (35) is a valid approximation. As noted previously, the average $< A_i(k_x,k_y)>$ is a deterministic spectrum and hence the app[illegible]mate average power given in Equation (35) is a deterministic pattern plus an isotropic standard deviation term. Note also that for frequency averages, the Fourier Transform of the near-field average in Equation (30) suffers from formal problems described in association with Equation (26) and becomes less reliable as wider frequency intervals are considered. This statistical analysis is implemented in subroutine MCSUM.

The fact that the statistical average far-field is related not only to the statistical average near-field but also to the cross correlation coefficients means that a valid statistical average must be performed mode-by-mode in the far-field. That is, it is not sufficient to obtain an average near-field distribution and then, via Fourier transformation, obtain the far-field. However, it is instructive to compare the results obtained by both far-field and near-field averaging to determine the effects of the correlation coefficients.

SECTION III
DESCRIPTION OF SUBROUTINES

A. Introduction

Brief descriptions of the subroutines that comprise the statistical modal computer code "PARAB" are presented here. These paragraphs reference the analytical equations implemented and are intended to show the method and technique employed without the detail of a line-by-line description. One objective is to make clear how extensions and program modifications are to be made by describing the extent to which the subroutines are interrelated. The dependence of subroutines on one another has been minimized by avoiding redefinition of common block variables and auxiliary formal parameters. The code is written in standard Fortran IV with the exception of bit-shifting in the Subroutine FFT and random number generation in FRANDOM and CRANDOM. The complete program source listing is given in Appendix I.

B. Discussion of Subroutines

1. Routine CALLER

Subroutine CALLER has two fundamental functions. The first function *is the acquisition of run parameters.* The second function is to establish the architecture of the program that provides for computational efficiency for differing user supplied parameters. In this role, CALLER establishes the memory allotments for the computed arrays and these variable dimension arrays are then used in the various subroutines. The arrays can then be written and read efficiently in an unformatted (binary) format allowing array space to be re-used repeatedly. The variable dimension technique is important because of core memory costs and limitations, and because it allows the varying number of modal fields in the out-of-band problem to be handled simply. The number of intervals used in evaluating the feed (FEED) and aperture (APER) Fourier integrals is given by the array size parameters (IFEED, JFEED, IAPER, JAPER). These array size parameters are the crucial determinants of the convergence of the numerical integrations and the cost (number of computations) for the specific antenna and Monte Carlo average employed.

Presently the arrays to be called with variable dimensions are all dimensioned (32) or (32,32). Thus the maximum permissible values of IFEED, JFEED, IAPER, and JAPER is 32. It is expected generally that IFEED and

JFEED can be smaller than IAPER and JAPER since the feed horn is smaller than the aperture plane (the aperture plane must be at least as large as the paraboloidal reflector). While this reduces computation considerably, no similar reduction of core requirements is available. Only the sizes of one-dimensional arrays EXOFX, EXOFY, EYOFX, EYOFY are determined everywhere by IFEED and JFEED. (Details are given in comment cards, lines 30 to 41.) Thus it is convenient to let the expected value (32) of IAPER and JAPER determine all array sizes in CALLER. If larger or smaller values of IAPER, JAPER are found desirable, the dimension statements in CALLER (lines 99 to 103) should be changed accordingly.

At card 300 of CALLER, the common blocks and array dimensions have been defined and all the run parameters have been defined and read in. Lines 300 to 311 assign values to the real array COMDAT. This array is written as a header at the top of the output files containing the Monte Carlo average field or power arrays. As noted in lines 313 to 325, the elements of this array define the x,y grid and the k_x,k_y grid obtained from it by subroutine FFT. This information is sufficient to allow a plotting program to draw scaled plots of the data. The element COMDAT (12) is intended to indicate whether x,y arrays are in the file (COMDAT (12) = 0) or k_x,k_y arrays (COMDAT (12) = 1). When file PFFDER is written, this element is reset at the write statement.

The remainder of CALLER determines the number of modes to be used in the calculation for the minimum and maximum frequencies considered and then transfers control to subroutine MCSUM.

2. SUBROUTINE COUNT

Subroutine COUNT determines what modes, within a restricted set of modes, can propagate in the waveguide of the feed system at a given frequency f. The number of such modes is then counted. The calculation of whether a mode may propagate requires only the frequency and waveguide dimensions. Specifically a mode TE_{mn} or TM_{mn} will propagate if

$$(f/c)^2 - (m/a_G)^2 - (n/b_G)^2 > 0 \qquad (36)$$

where a_G AGUIDE = width of waveguide

b_G BGUIDE = height of wavegude.

c = speed of light.

After determining the modes that can propagate, subroutine COUNT then imposes an external restraint limiting the modes to be used. The mode is not allowed and not counted if the externally supplied array RCOEFF read from file STANCO has a complex zero in the element of the array corresponding to that mode. Modes TE_{mn} and TM_{mn} correspond to array elements RCOEFF (m + 1, n + 1, 1) and RCOEFF (m + 1, n + 1, 2). Allowable modes are indicated by elements of the array AMODE being +1. The arrays are dimensioned (8,8,2). Modes of higher orders than 7 can be handled by relatively minor program modifications, involving only dimension statements and limits on DO loops. This provision to exclude modes is included so that specified types of waveguide/feed devices which may generate only even or odd order modes can be modelled. For example, a coax-to-waveguide adapter which feeds the waveguide on the centerline might be expected to generate only odd-order TE_{mo} modes. Also, future measurements of components at out-of-band frequencies may disclose characteristic mode structures.

3. SUBROUTINE MCSUM

Subroutine MCSUM determines the values taken by the random variables, either by calling subroutines which perform draws on specified distributions or by reading values produced by these subroutines, calls subroutine REFLEC to produce the deterministic near or far field for each mode, and performs the sums over modes and over the Monte Carlo ensemble to determine the near or far field and power.

The body of MCSUM consists of three physically distinct parts. The first two ts consisting of lines 43-157 and lines 164-298 perform parallel calculations and differ only in whether values of random variables are to generated (IGEN=1 branch) in the current run of the program as in lines 168-298, or read from a file presumably created by an earlier run of the program (IGEN=0 branch). This synopsis will be in terms of the IGEN=1 branch. (The IGEN=0 branch is obtained by reading from file RCOEFF at every point that the IGEN=1 branch writes on this file.)

The loops that begin at line 170 sum over the number of frequencies in the Monte Carlo ensemble. If there is no frequency averaging (IFMC=1) then the central frequency is used. The loop ends with calculation of the near-field or spectral powers as given in Equations (27) and (28). As an intermediate step the detrministic fields are calculated by the sum over allowable modes ending at line 234. (This is the inner sum in Equation (25)). For the case of averages over coefficients, only the average near-field or spectra is calculated at line 289 as in Equation (24) with the average coefficient calculated at line 262. The more general calculation of the average field quantities given by Equation (25) is postponed to the third section of MCSUM.

The remainder of MCSUM, the third distinct part of the subroutine consisting of lines 279 to 422, completes the calculation of averages over frequency and/or modal coefficients (lines 299 to 350) and, for the case that near-field averages have been calculated (IAVGFF=0), derives the approximate far-field pattern (lines 352 to 422). Note that the frequency average in Equation (25) can be performed either with one set of coefficients $C^i(m,n,k)$ which is denoted as frequency only average in the program or with different sets of coefficients at each frequency, which is an average over frequency and coefficients.

The standard deviation of Equation (34) is calculated at lines 358 to 361 and the uncorrelated spectral power needed in Equation (35) is calculated at line 391. The various arrays are also written on files in this section after being normalized. Since the normalization of fields and powers are different, the arrays must be unnormalized for the calculation of standard deviations. Therefore the normalization factors are removed in lines 326 to 330 and 341 to 346.

4. SUBROUTINE CUTMODE

For the allowable modes, as cataloged by the array AMODE calculated in COUNT, the field on principle plane cuts in the feed horn aperture is calculated for each polarization. The values of the fields are stored in the one-dimensional arrays EXOFX, EXOFY, EYOFX, EYOFY corresponding to $E_x(x)$, $E_x(y)$, $E_y(x)$, $E_y(y)$. Specifically these fields are given by:

$$
\begin{array}{llll}
 & \text{for } TE_{mn} & \text{for } TM_{mn} & \\
E_x(x') = & \cos\dfrac{m\pi x'}{a_F}\,, & \dfrac{m\pi}{a_F}\cos\dfrac{m\pi x'}{a_F} & \\
E_x(y') = & \dfrac{n\pi}{b_F}\sin\dfrac{n\pi y'}{b_F}\,, & \sin\dfrac{n\pi y'}{b_F} & (37) \\
E_y(x') = & \dfrac{m\pi}{a_F}\sin\dfrac{m\pi x'}{a_F}\,, & \sin\dfrac{m\pi x'}{a_F} & \\
E_y(y') = & \cos\dfrac{n\pi y'}{b_F} & \dfrac{n\pi}{b_F}\cos\dfrac{n\pi y'}{b_F} &
\end{array}
$$

where a_F (AFEED) and b_F (BFEED) are the x and y dimensions of the feed horn aperture. The variables $x' = x + a_F/2$ and $y' = y + b_F/2$ are the distances from a corner of the feed horn. The x, y origin is at the center of the feed horn.

Since the modal fields are separable, the x-component of the field at any point x,y in the feed horn aperture is the product $E_x(x)\ E_x(y)$ and similarly for the y-components. This is true even with the inclusion of H-plane and E-plane phase tapers given by $\phi_x = \frac{\pi f}{c} x^2/h$ when the horn flares in the H-plane, and $\phi_y = \frac{\pi f}{c} y^2/h$ when the horn flares in the E-plane. The variable h(HORLEN) is the length of the horn and is supplied by the user. A special branch allows zero phase taper to be implemented by entering HORLEN = 0.0. The phase taper is proportional to the frequency and so becomes larger the further out-of-band the frequency is. The effect of the phase taper therefore is larger than in the in-band problem.

The fields on the principle plane cuts are calculated at IFEED equally spaced points for functions of x and at JFEED points for functions of y. The array sizes IFEED and JFEED are supplied by the user and are arbitrarily less than 32. The first point of each array is at the edge of the feed horn and value stored in this element is the average of the field at that wall and at the far wall. This is appropriate since these arrays will be used for numerical integration and the half-interval nearest each wall is to be accounted for.

5. SUBROUTINE FRANDOM

Subroutine FRANDOM returns a random value of the frequency selected from the user specified frequency distribution. The selected frequency is restricted to the interval $f_o \pm \Delta f$ where f_o(FREQ) and Δf(DELFREQ) are the user selected nominal out-of-band frequency and the frequency spread. Uniform and Gaussian frequency distributions have been implemented and are specified by IFDIST = 1 and IFDIST = 2, respectively. The Gaussian distribution is characterized by a mean f_o and standard deviation of $\Delta f/2$. The Gaussian distribution is modified in that elements that are more than two standard deviations from the mean are rejected and recomputed. This affects less than four percent of the sample.

Additional distributions can be implemented by the user.

6. SUBROUTINE CRANDOM

Each call of CRANDOM generates a complex modal coefficient for each allowable mode with the amplitude and phase of the coefficient selected from user specified distributions. The statistical amplitude distributions implemented are: uniform (ICDIST = 1), Gaussian (ICDIST = 2), and a $1/(m + 1)(n + 1)$ distribution where m and n are the orders of the TE or TM modes (ICDIST = 3). The Gaussian distribution is specified by a mean of one and standard deviation of one half, but with negative amplitudes rejected and recomputed. While the absolute amplitude is arbitrary, different standard deviations do lead to different physical results and represent a degree of freedom not implemented in the program. The mode dependent amplitude distribution of ICDIST = 3 is similar to the modal distribution excited by a coax-to-waveguide adapter and is an example of a distribution reflecting mode dependent device characteristics.

Uniform and Gaussian phase distributions are provided and correspond to IPHIRV values of 1 and 2. Since the absolute phase is irrelevant, both phase distributions are given zero phase mean. The uniform phase distribution produces an ensemble of phases distributed uniformly over the interval ±PHIDEV (degrees). The standard deviation of the Gaussian distribution is PHIDEV. Other phase or amplitude distributions are easily added.

7. SUBROUTINE UNIFOR

Subroutine UNIFOR calls an external random number generator that returns a random value in the interval zero to one and redistributes this variable on the interval CENTER ± SPREAD uniformly.

8. SUBROUTINE GAUSR

Subroutine GAUSR calls an external random number generator that returns a random value in the interval zero to one and redistributes this variable according to a Gaussian distribution with mean zero and standard deviation one.

9. SUBROUTINE REFLEC

Subroutine REFLEC performs the principal deterministic portions of the calculation. Specifically, the values of the direction cosines about the feed horn such that rays in these directions will be reflected by the paraboloid onto a rectangular grid in the aperture are calculated. The modification of this for far-field calculation discussed in connection with Equation (26) is implemented in lines 40 to 50. The far-field of the feed horn for these values of KXAPER and KYAPER is calculated by 1-D Fourier integrals over the separable modal feed horn fields. Note that the calculation is a vector calculation. Provisions for feeds not at the focus can be made as suggested in lines 133 to 152.

10. SUBROUTINE FFTDOUB

Subroutine FFTDOUB is a specialized algorithm designed to transform N_x x N_y arrays of x-y data with spacings Δx, Δy into arrays in k_x, k_y space with spacings

$$\Delta k_x^d = 1/2\pi/(N_x \cdot x) = 1/2\,\Delta k_x$$
$$\Delta k_y^d = 1/2\pi/(N_x \cdot y) = 1/2\,\Delta k_y \qquad (38)$$

while preserving the fundamental speed of the FFT and minimizing additional storage requirements. These spacings are half what the simple FFT would yield. Since the x-y array and the k_x-k_y array are the same size, the maximum k_x and k_y are half those normally obtained by the FFT. This subroutine is of use for high gain antennas where the major spectral components are near the boresight direction. It provides better resolution in the forward direction and drops the less important wide-angle components. An alternative means of calculating points more densely is a linear or polynominal interpolation. The FFTDOUB algorithm is a Fourier interpolation and determines all points with an accuracy consistent with that of the FFT.

The basic operation implemented in the algorithm is as follows

$$A(n\Delta k_x, m\Delta k_y) = \text{FFT}[\,E\,] \qquad (39)$$

$$= \iint dxdy\; E(x,y)e^{j(n\Delta k_x x + m\Delta k_y y)}\Big|_{\text{discrete}}$$

so that

$$A(n\Delta k_x + \tfrac{1}{2}\Delta k_x, m\Delta k_y) = \iint dxdy\; E(x,y)e^{j1/2\Delta k_x x}e^{i(n\Delta k_x x + m\Delta k_y y)}\Big|_{\text{discrete}}$$

$$= \text{FFT}\,[E(x,y)e^{j1/2\Delta k_x x}] \qquad (40)$$

Thus by multiplying the E-field array by appropriate factors and performing the FFT, the spectral components at positions offset from those produced by the direct FFT are found. By identical arguments $A(n\Delta k_x + \frac{1}{2}\Delta k_x, m\Delta k_y + \frac{1}{2}\Delta k_y)$ and $A(n\Delta k_y, m\Delta k_y + \frac{1}{2}\Delta k_y)$ are determined. By merging all of these with $A(n\Delta k_x, m\Delta k_y)$ found directly from FFT[E] , the array of spectral components with spacings Δk_x^d, Δk_y^d is determined. Only the middle N_x x N_y subset of these points is retained. The same array spacings and numerical values of the spectral components can be obtained by the FFT of a $2N_x$ x $2N_y$ array consisting of zeroes and the original N_x x N_y array at its center. This requires more computation and storage.

11. SUBROUTINE FFT

Subroutine FFT is a realization of the well-known Fast Fourier Transform algorithm for complex two-dimensional arrays. In this specific implememtation, the origin of the coordinate system and of the transformed coordinate system is at the $N_x/2 + 1$, $N_y/2 + 1$ point of the array (the array is dimensioned (N_x, N_y) with $N_x + N_y$ being integer powers of two). Also the symmetric normalization of the Fourier Transform pair is used so that the sums that form the transform and inverse transform are multiplied by $1/\sqrt{N_x \ N_y}$.

The FFT is organized so that an array that is regularly spaced is transformed into another regularly spaced arrays. The spacings of the points of the array in x,y and in k_x, k_y are related by

$$\Delta k_x = \pi/(N_x \cdot \Delta X)$$
$$\Delta k_y = \pi/(N_y \cdot \Delta Y) \quad (41)$$

12. SUBROUTINE NORMIM

Subroutine NORMIM takes two variably dimensioned complex two-dimensional arrays denoted by "ARRAYX(ISPEC, JSPEC)" and "ARRAYY(ISPEC, JSPEC)" and finds the element with the largest magnitude. The array that this element occurs in is noted and the location of the element in this array is recorded. Both arrays are then divided by this complex element.

The intended use of this subroutine is normalization of parallel and cross polarized field components with the preservation of relative normalization.

13. SUBROUTINE NORMXY

Subroutine NORMXY takes two variably dimensioned real two-dimensional arrays denoted by "ARRAYX(ISPEC, JSPEC)" and "ARRAYY(ISPEC, JSPEC)" and finds the element with the largest magnitude. The array that this element occurs in is noted and the location of the element in this array is recorded. Both arrays are then divided by this element.

The intended use of this subroutine is normalization of parallel and cross polarized components of the power with the preservation of relative normalization.

SECTION IV

NUMERICAL SIMULATIONS

A. Introduction

The numerical algorithm described in the previous sections has been tested and results obtained for two representative antennas with a variety of frequency and modal coefficient distributions. The physical parameters of these antennas are listed in Table I. The results for these initial trials are presented as 3-D patterns of the near-field or spectral power. Parameters such as main beam pointing direction, 3 dB beam width, and average sidelobe level can be determined from these patterns. The importance of these global parameters will depend on the geometry of the problem being addressed. Thus, in different coupling problems, statistical averages of the sidelobe level over different solid angles might be crucial. More directly, the out-of-band pattern may not exhibit a distinctive main beam, thus making impractical a description in terms of beam widths and pointing directions. Thus ,it is prudent initially to examine the out-of-band pattern in detail to ascertain clearly the effects of differing distributions of the random variables and changes in the modal content. The discussion of numerical results will also emphasize use of the program and control of numerical convergence and computational cost.

B. Single Mode Patterns

The numerical code is, of course, applicable to the in-band problem. In fact, the tailoring of the code to the out-of-band problem consists principally in the choice of modal coefficients as random variables with the implication that these coefficients vary significantly for antenna ensembles of interest. It is therefore convenient to examine the numerical aspects of the deterministic calculation at the in-band frequency. For antenna 1 (see Table I) deterministic patterns are calculated at the in-band frequency of 3 GHz by selecting IRV=1 and ICSETS=1 as input parameters. A complete input list is given in Table II as the Run A column. This run uses 32 by 32 arrays to describe both the feed horn fields and the aperture fields. When the program is run with IFEED=JFEED=16 and all other parameters the same, the answer varies by less than 1%. This indicates that the integrals over the feed horn have converged for this array size. Since the feed horn is electrically small

TABLE I

PHYSICAL DESCRIPTION OF THE TWO ANTENNAS FOR WHICH RESULTS ARE PRESENTED

Physical Parameter	Input Variable	Antenna 1	Antenna 2
Waveguide Width	AGUIDE	2.84 (in.)	1.87 (in.)
Waveguide Height	BGUIDE	1.34 (in.)	0.87 (in.)
Feed Horn Width	AFEED	2.84 (in.)	1.87 (in.)
Feed Horn Height	BFEED	1.94 (in.)	1.25 (in.)
Horn Length	HORLEN	4.0 (in.)	2.25 (in.)
Focal Length	FOCUS	15.44 (in.)	14.63 (in.)
Paraboloid Radius	RMAX	24.00 (in.)	24.00 (in.)
Aperture Plane Width	AAPER	48.00 (in.)	48.00 (in.)
Aperture Plane Height	BAPER	48.00 (in.)	48.00 (in.)
Cut-off Frequency	-	2.1 (GHz)	3.1 (GHz)
Nominal In-Band Frequency	-	3.0 (GHz)	4.5 (GHz)

TABLE II

Examples of input parameter sets. The interactive portion of the program determines the number of Monte Carlo sets and distributions for the particular random variable selected (value of IRV). The distributions and numbers of sets of variables not relevant to the run take the Default Values listed in the Table. Run A is for antenna 1 at the in-band frequency with only 1 Monte Carlo frequency set and hence is a deterministic calculation.

Input Parameters	Default Values	Run A	Run B	Run C
LOUT	-	1	1	1
IRV	-	1	1	2
ICDIST	0	-	-	3
ICSETS	1	-	-	25
IPHIRV	0	-	-	1
PHIDEV	0	-	-	20.0
IFDIST	0	1	2	-
IFSETS	1	1	10	-
IAVGFF	-	1	1	1
FREQ	-	3.0	6.0	9.6
DELFREQ	-	0.0	0.5	0.0
AGUIDE	-	2.84	2.84	1.87
BGUIDE	-	1.34	1.34	0.87
AFEED	-	2.84	2.84	1.87
BFEED	-	1.94	1.94	1.25
HORLEN	-	4.0	4.0	2.25
IFEED	-	32	32	32
JFEED	-	32	32	32
FOCUS	-	15.44	15.44	14.63
RMAX	-	24.0	24.0	24.0
AAPER	-	48.0	48.0	48.0
BAPER	-	48.0	48.0	48.0
IAPER	-	32	32	32
JAPER	-	32	32	32
IGEN	-	1	1	1

at this frequency, this degree of convergence is not surprising. Reducing the aperture arrays also to 16 by 16 produces variations of roughly 3%. Note that the aperture plane is several wavelengths in extent. It is thus advisable to use IAPER=JAPER=32 particularly at higher frequencies. The array sizes, of course, govern the number and hence cost of computations. The run times (which vary between successive identical runs) are consistent with the total number of calculations being proportional to IFEED + JFEED and to JAPER • JAPER. This indicates that essentially all the computation is related to the arrays. The roughly linear dependence on the feed horn array dimensions is a result of the one-dimensional Fourier integrals used to construct the aperture plane fields. Similarly the number of computations is proportional to the number of points in the aperture plane as given by the product of aperture array dimensions. The far-field patterns for this in-band case are given in Figure 3 for the parallel poalrization and Figure 4 for the cross polarization. The cross polarized component arises wholly from the rotation of polarization by the reflector and is zero on the principal planes. Note that the above procedure, varying the feed and aperture array sizes in the calculation of the pattern for a single mode, is the recommended way to validate the degree of numerical convergence and to minimize computation time.

Calculations of antenna 1 at the out-of-band frequency of 6 GHz are presented next. Again it is instructive to examine single modes. This is accomplished by using the external file STANCO to restrict the modes used in the calculation as described in the comments of routine CALLER. Specifically, the file STANCO, a specimen of which is included at the end of the program listing in Appendix I, contains a value of the modal coefficient for each mode. If this supplied value is zero, then the mode is not used in the calcuation, see subroutine COUNT. The deterministic patterns of the TE_{20} mode for antenna 1 are given in Figures 5 and 6 for the parallel and cross polarized spectral power components. Figures 7 and 8 are the similar TE_{20} patterns obtained by a Monte Carlo frequency average over 10 frequencies selected from a Gaussian distribution on the interval 5.5 GHz to 6.5 GHz. The effects of the frequency averaging, evident by comparison of Figures 5 and 6 and Figures 7 and 8 are not dramatic. The principal effect of the frequency average is to reduce the average level of the lobes away from the forward direction, presumably this is accomplished

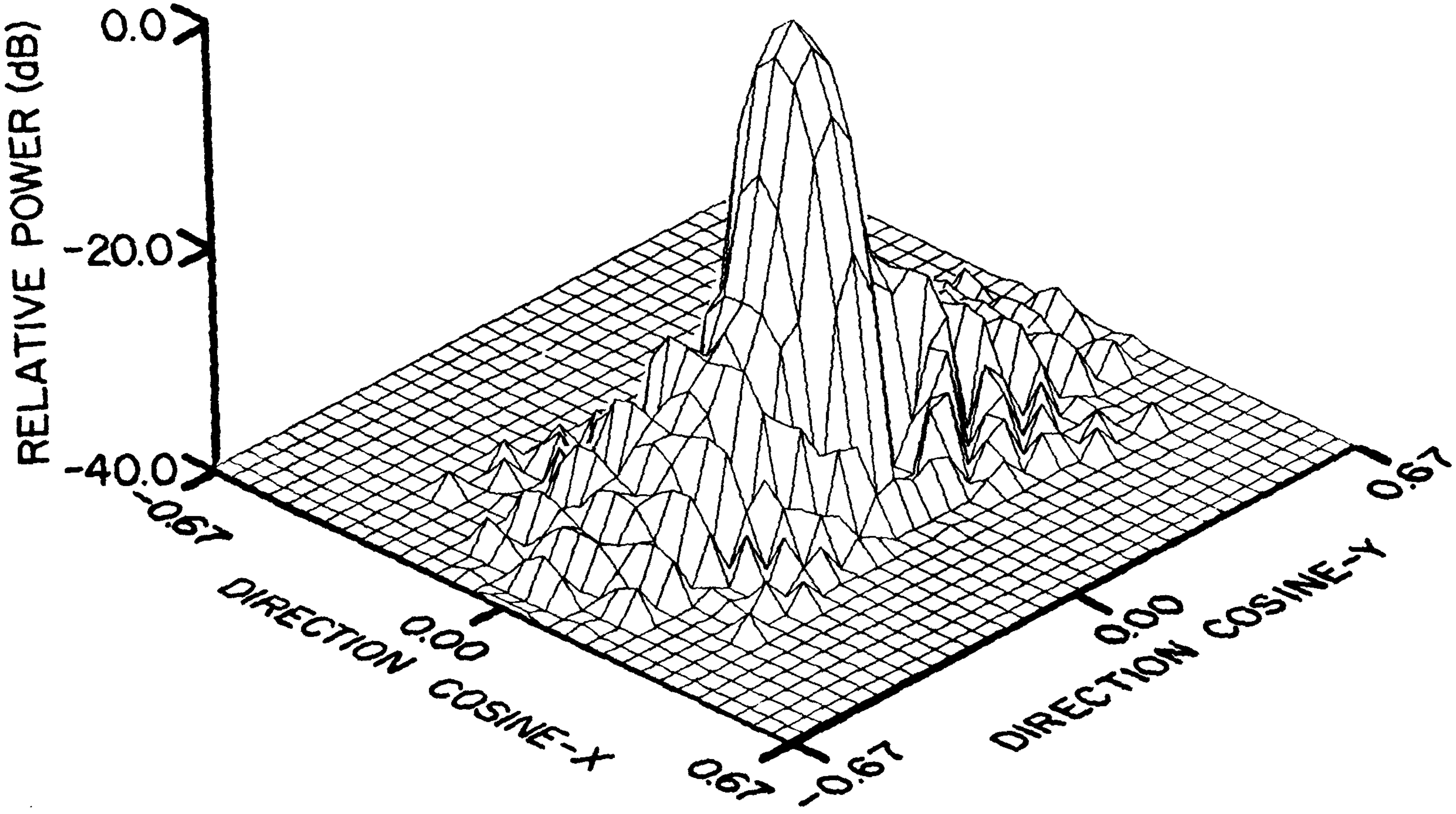

Figure 3. The deterministic spectral power pattern for the parallel polarized component for the TE_{10} mode calculated for antenna 1 operating at a frequency of 3 GHz.

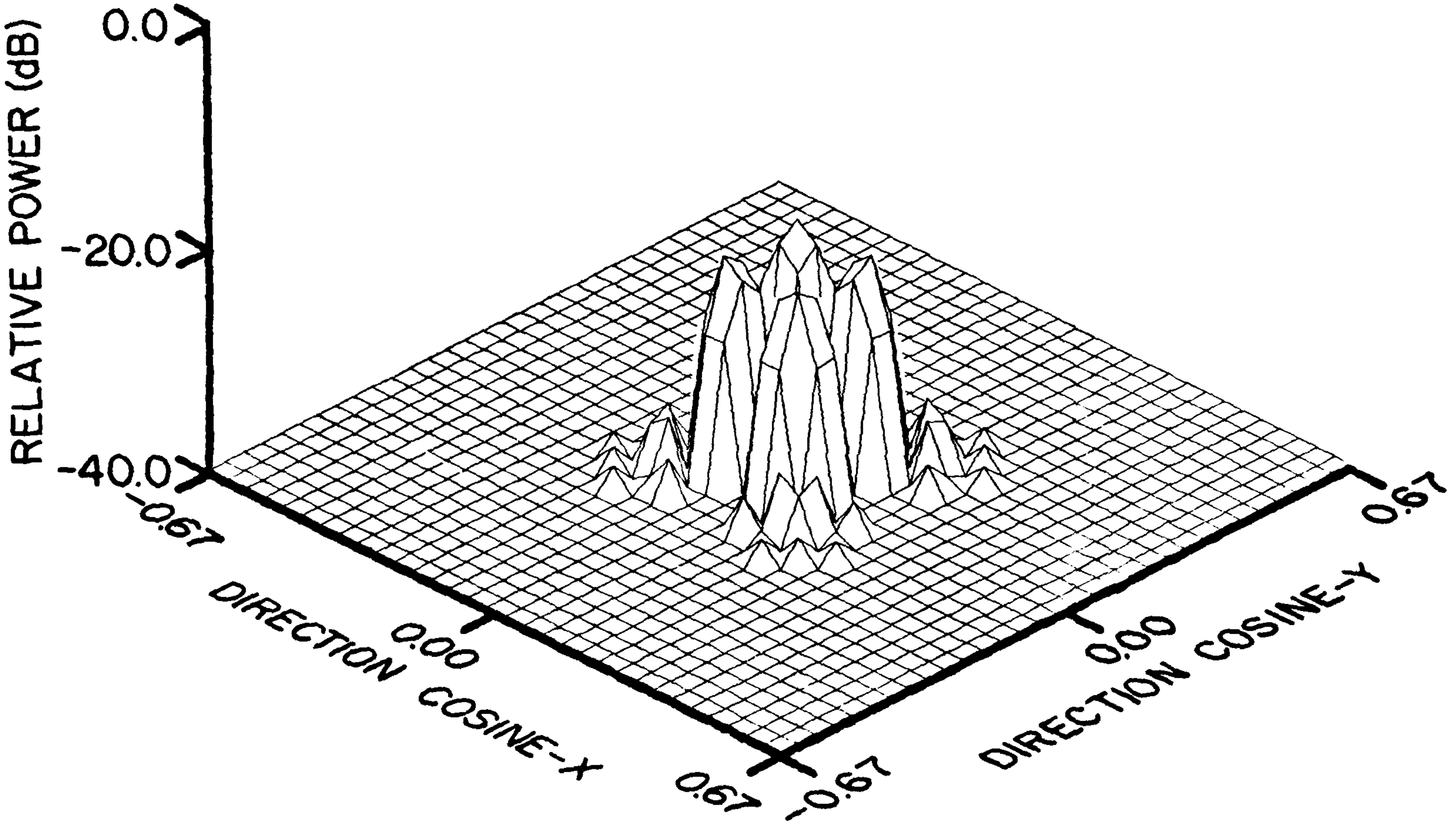

Figure 4. The deterministic spectral power pattern for the cross polarized component for the TE_{10} mode calculated for antenna 1 operating at a frequency of 3 GHz.

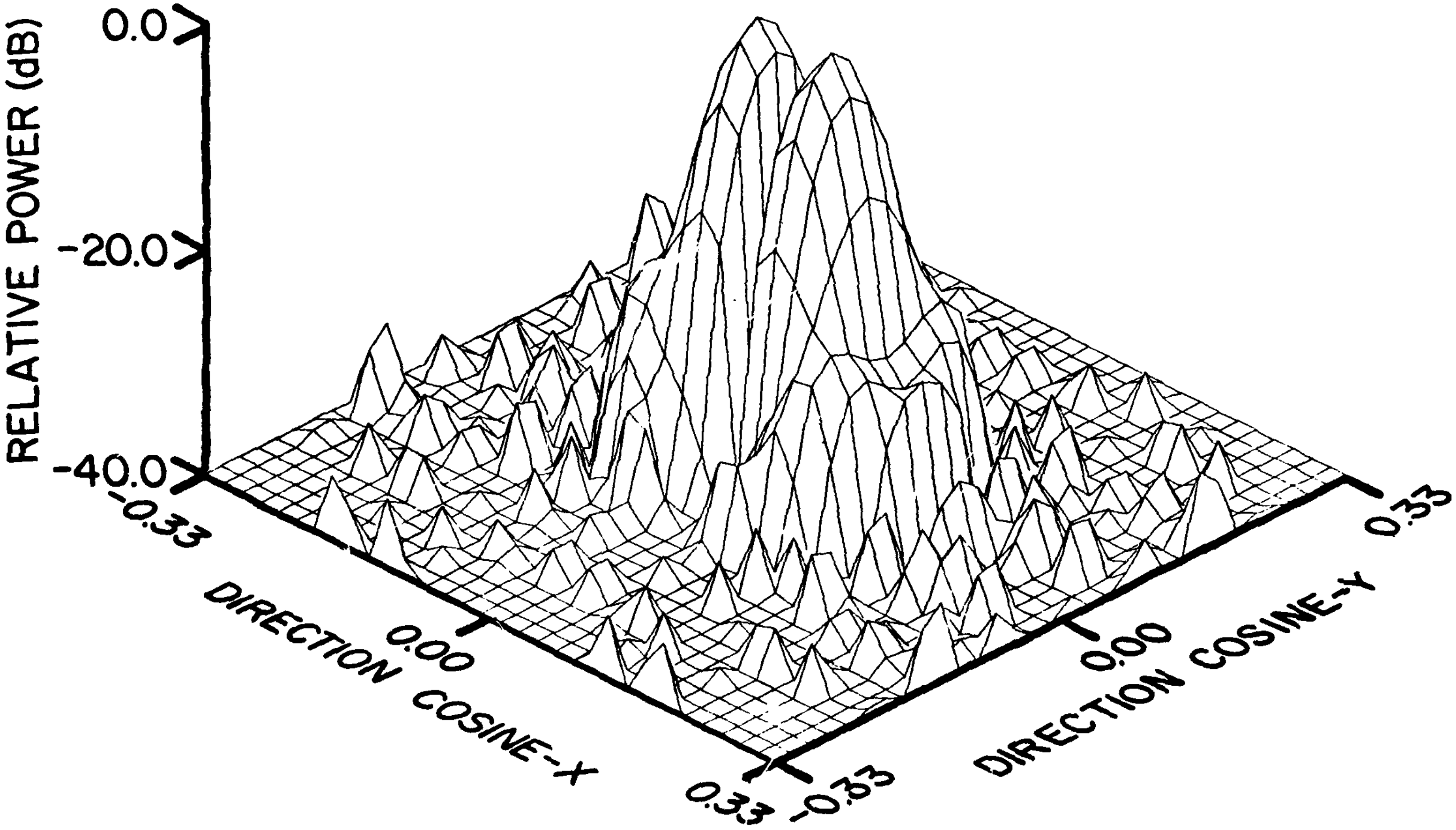

Figure 5. The deterministic spectral power pattern for the parallel polarized component for the TE_{20} mode calculated for antenna 1 operating at a frequency of 6 GHz.

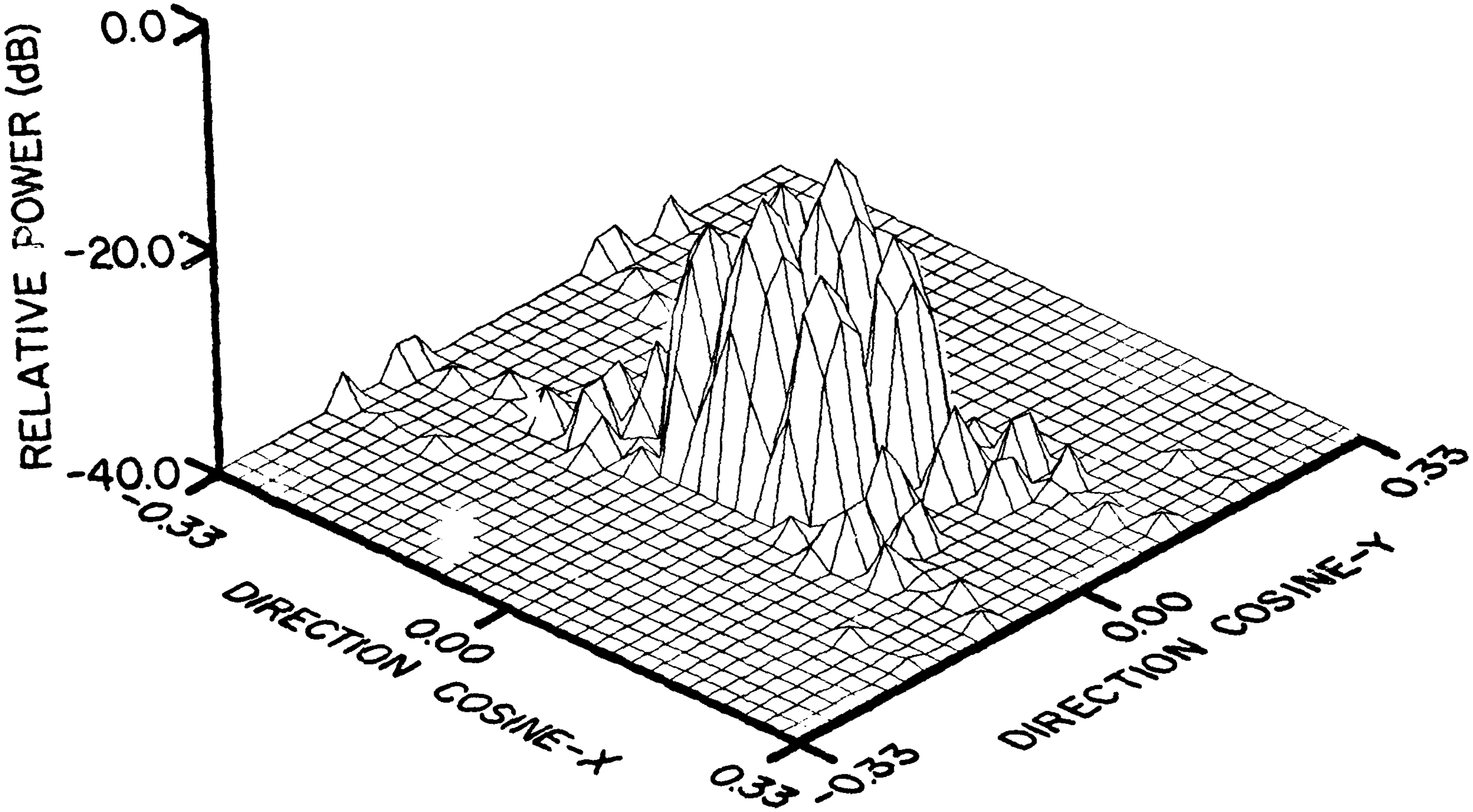

Figure 6. The deterministic spectral power pattern for the cross polarized component for the TE_{20} mode calculated for antenna 1 operating at a frequency of 6 GHz.

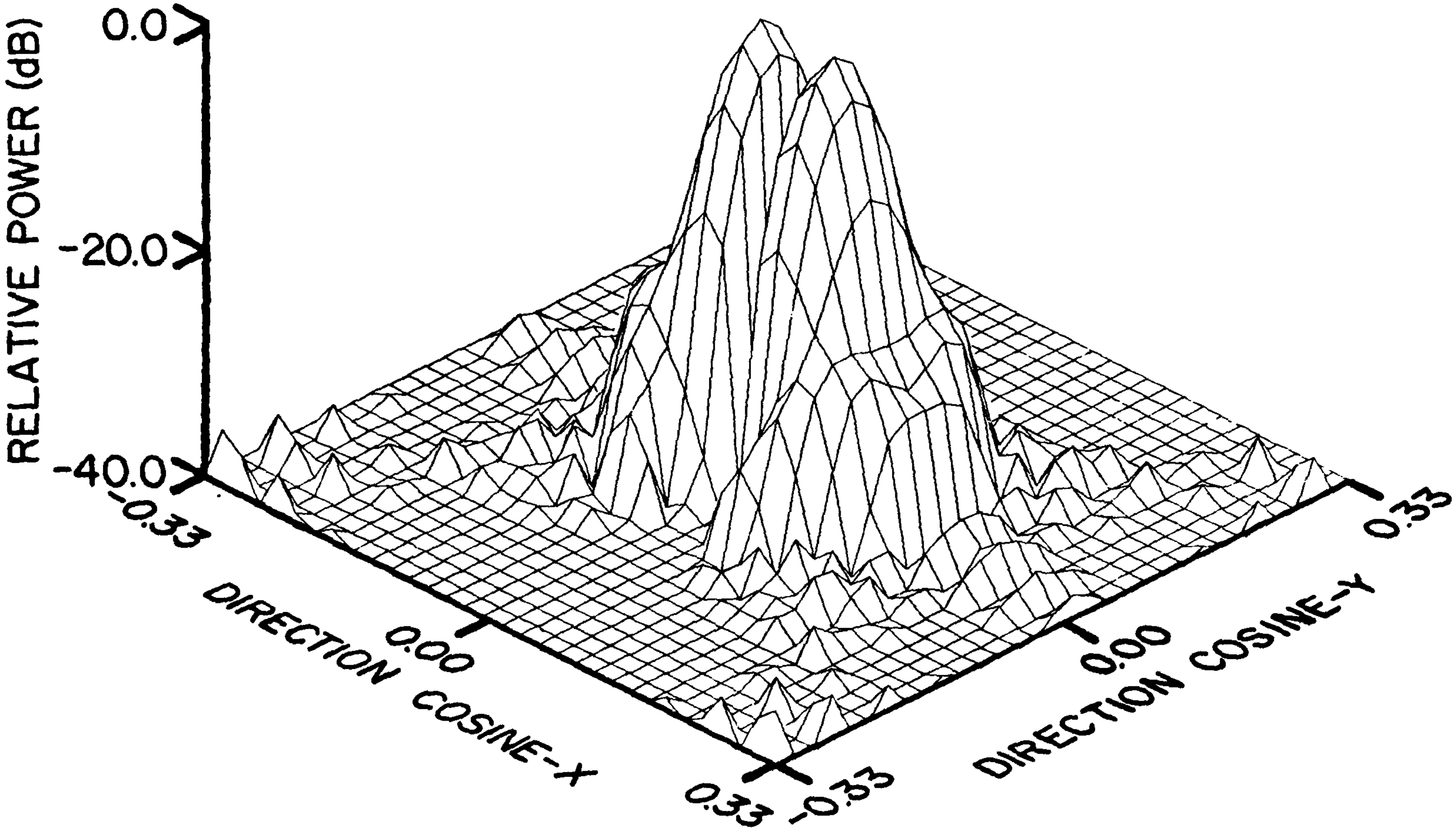

Figure 7. The spectral power pattern of the parallel polarized component for the TE_{20} mode of antenna 1 calculated by Monte Carlo frequency average over 10 frequencies Gaussian distributed between 5.5 and 6.5 GHz.

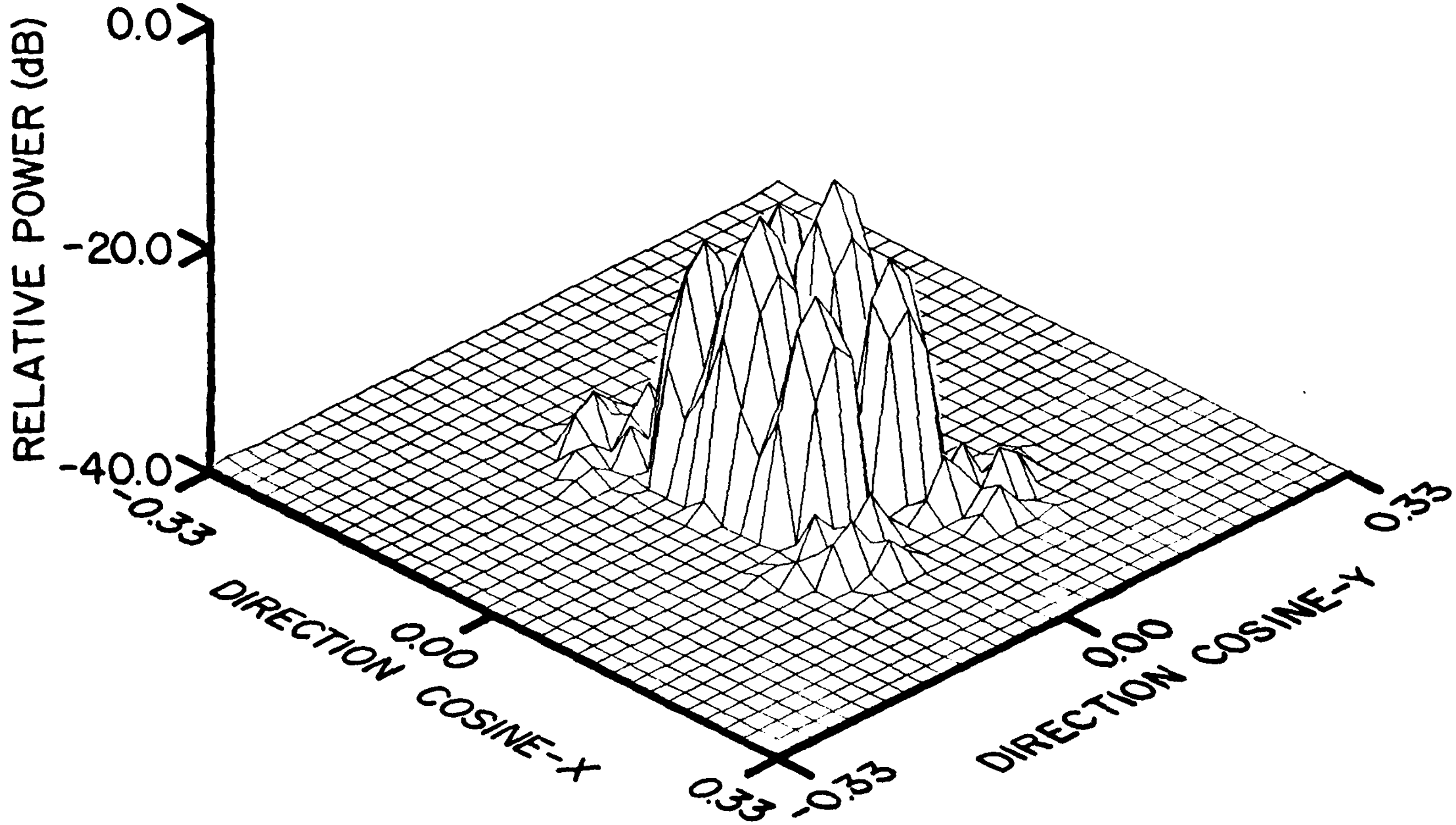

Figure 8. The spectral power pattern of the cross polarized component for the TE_{20} mode of antenna 1 calculated by Monte Carlo frequency average over 10 frequencies Gaussian distributed between 5.5 and 6.5 GHz.

by changing the positions of the low sidelobes and then reducing them by the averaging. The effects of the frequency average in the forward direction are negligible. Using the same ensemble of frequencies, the averaging can be performed in the near-field and an approximate far-field pattern derived as in Section II.D. The results of this computation are shown in Figures 9 and 10. Note that the standard deviations associated with Figures 9 and 10, referenced to the peak of the parallel component, are -47 and -57 dB, respectively. The result given in Figures 9 and 10 more nearly resembles the deterministic patterns of Figures 5 and 6 than the frequency averaged patterns of Figures 7 and 8. This principally reflects the arbitrariness in the pattern derivation from near-field averages that exists for frequency averages due to the different criteria used in selecting aperture points for near-field and far-field averages described in Section II.C. For coefficient averages, the near-field derived result does not suffer this ambiguity. Thus a coefficient average produces the parallel components given in Figures 11 and 12 for a far-field average and for pattern derived from a near-field average, respectively. The standard deviation associated with Figure 12 is -37 dB. Comparison of Figures 11 and 12 indicates that the standard deviation and neglected cross correlation terms are comparable since the patterns are very similar over the 40 dB range plotted.

The computational cost of the average over 10 frequencies is roughly 10 times the cost of the deterministic calculation. This is because the calculation must start from the feed horn fields at each new frequency. The total cost of an average over 200 sets of coefficients is between three and four times that of the deterministic calcuation. The coefficient average is accomplished by reading and re-reading the modal aperture fields.

It was determined, by varying the size of the ensemble in the coefficient average, that the use of 25 Monte Carlo sets is sufficient for most purposes. For instance, the standard deviations calculated by Equation (34) change by 3 dB between sets of 25 and sets of 200 modal coefficients. For sets of 7 modal coefficients, the standard deviations differ by roughly 10 dB from the numbers obtained from larger ensembles and from other trial with 7 sets. In the multi-mode calculations, the additional sum over modes reduces the sensitivity to the number of Monte Carlo sets.

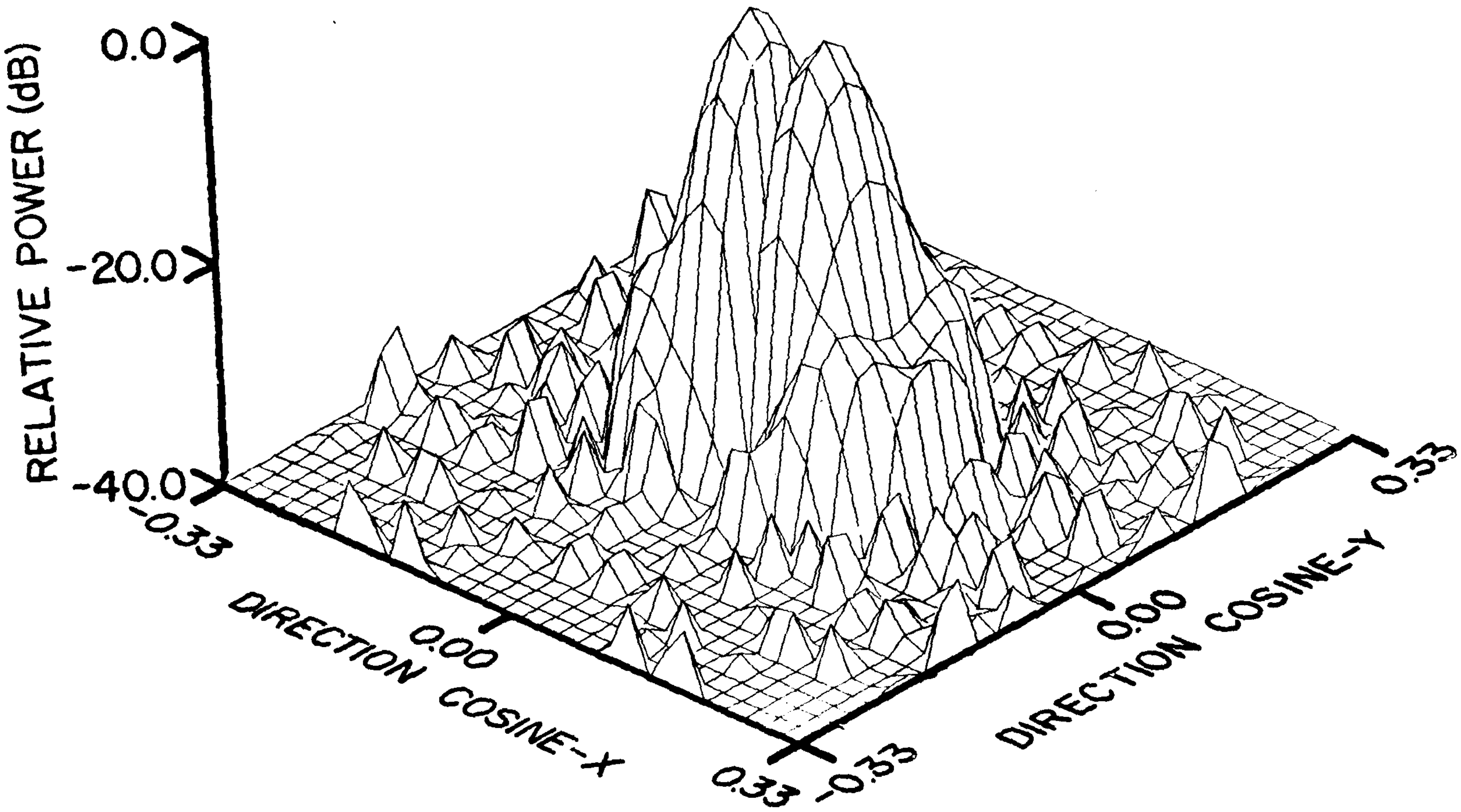

Figure 9. The near-field derived spectral power pattern of the parallel component for the TE_{20} mode of antenna 1 calculated by Monte Carlo frequency average over 10 frequencies Gaussian distributed between 5.5 and 6.5 GHz.

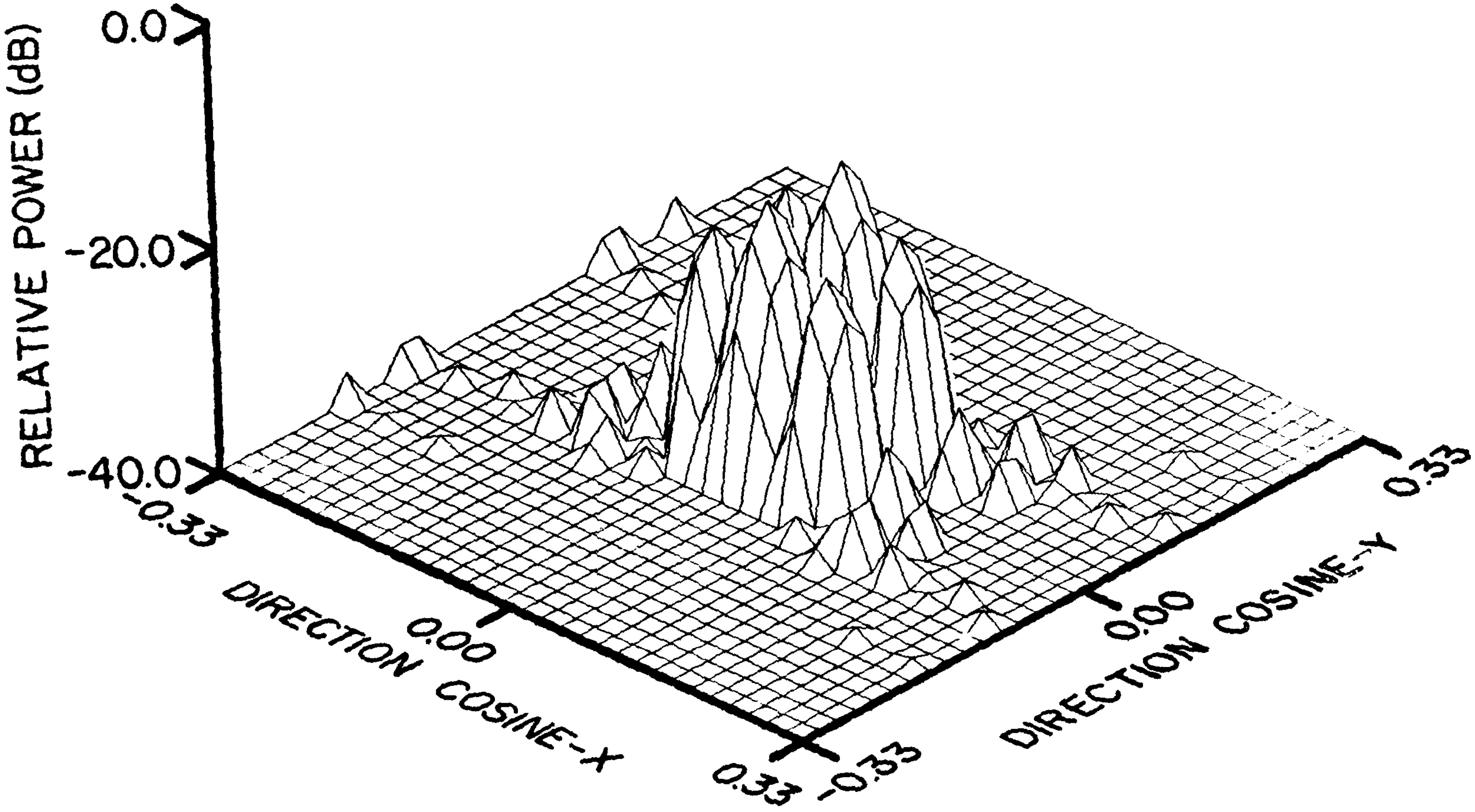

Figure 10. The near-field derived spectral power pattern of the cross polarized component for the TE_{20} mode of antenna 1 calculated by Monte Carlo frequency average over 10 frequencies Gaussian distributed between 5.5 and 6.5 GHz.

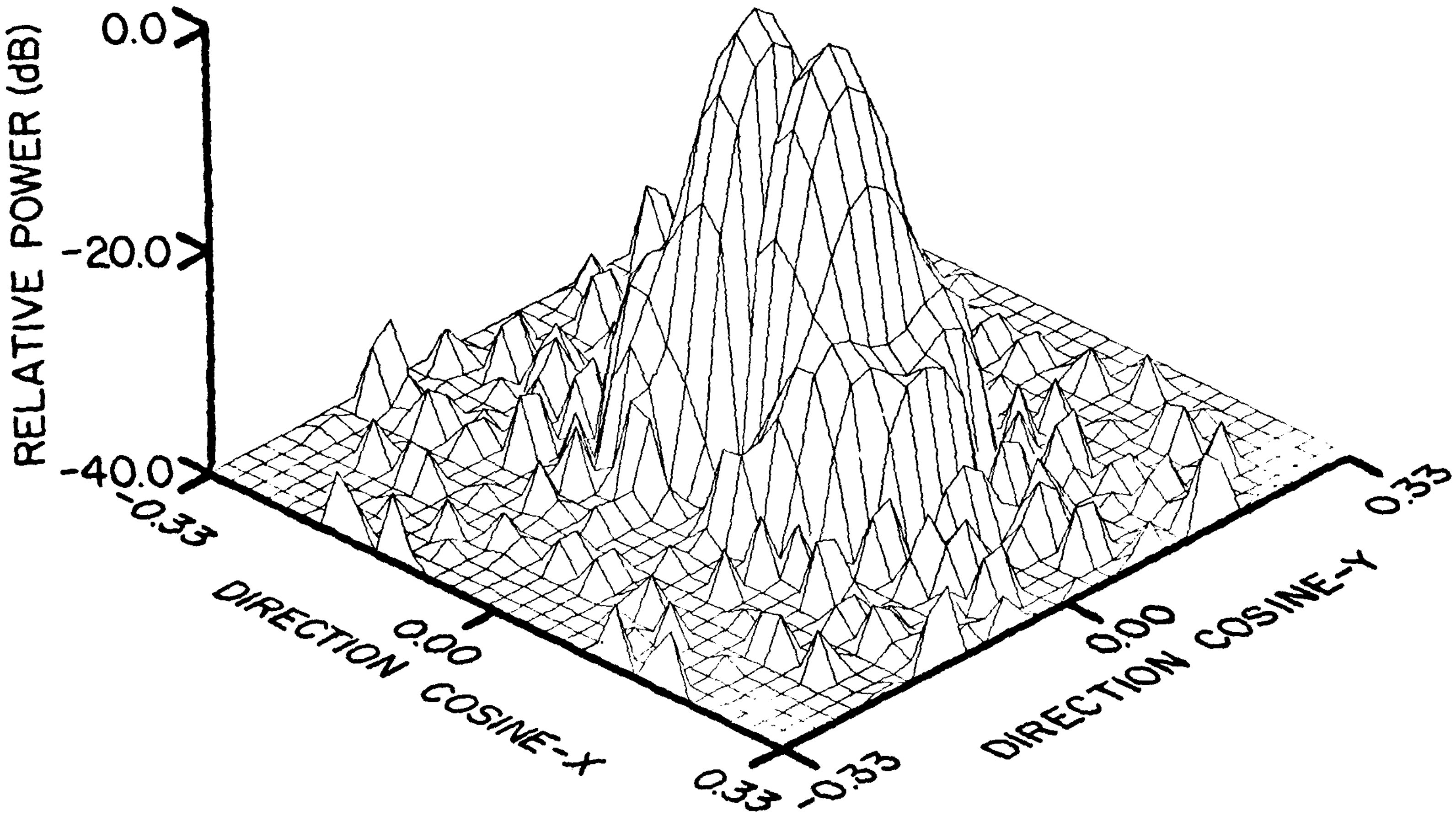

Figure 11. The spectral power pattern of the parallel polarized component for the TE_{20} mode of antenna 1 operating at 6 GHz calculated by Monte Carlo average over 25 coefficients distributed as $1/(m+1)(n+1)$ in amplitude and Gaussian in phase with a standard deviation of 20°.

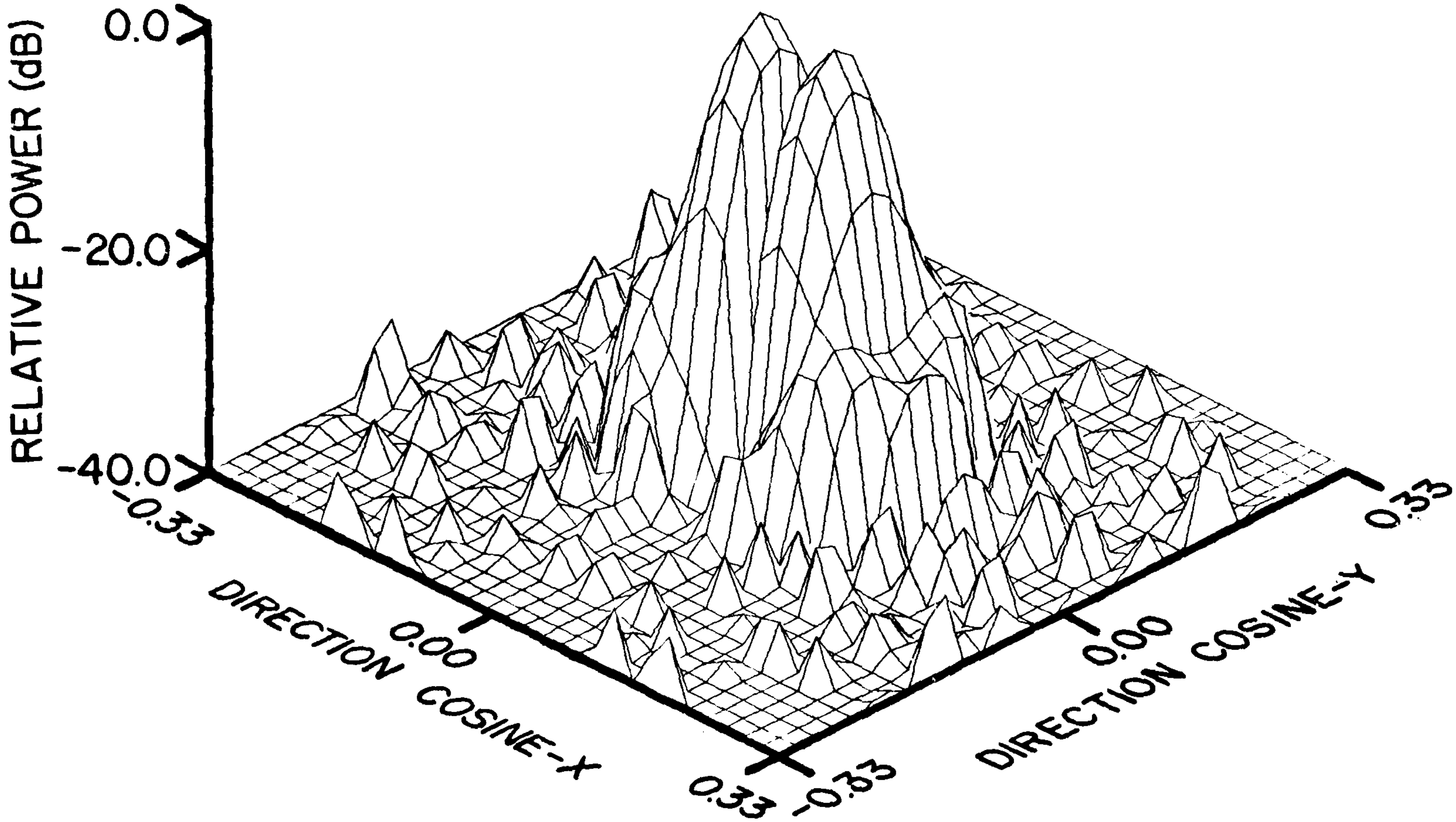

Figure 12. The near-field derived spectral power pattern of the parallel polarized component for the TE_{20} mode of antenna 1 operating at 6 GHz calculated by Monte Carlo average over 25 coefficients distributed as $1/(m+1)(n+1)$ in amplitude and Gaussian in phase with a standard deviation of 20°.

C. Multi-Mode Patterns

The frequency average of 10 Gaussian distributed frequencies in the interval 5.5 GHz to 6.5 GHz with allowable modes TE_{10}, TE_{11}, TE_{21}, TM_{11} produces the far-field averaged patterns of Figures 13 and 14. The modal coefficients determined from file STANCO are set to one for each mode and frequency. Note that the nominal cross polarized component is larger than the nominal parallel component.

The patterns derived from near-field averages have standard deviations of -44 dB and -41 dB and are not visibly different from Figures 13 and 14 and so are not reproduced. (The single mode calculation was more useful in indicating the effects of the frequency average and the faults of the result derived from near-field frequency averages.) The run parameters of the far-field frequency average represented by Figures 13 and 14 are given in Table II as Run B. The frequency average is expensive and does not produce dramatic results. The remaining results will be for coefficient averages only.

Monte Carlo averages over 25 sets of coefficients for all propagating modes of antenna 2 in Table I at a frequency of 9.6 GHz were performed. The propagating modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}. Results are presented for a coefficient amplitude distribution proportional to $1/(m+1)(n+1)$ where m and n are the orders of the mode and with coefficient phases distributed uniformly over $\pm 20^{\circ}$ and $\pm 180^{\circ}$. The far-field averages for the nominal parallel and cross polarized components for these cases are given by Figures 15 and 16 and Figures 17 and 18. Note that a more detailed structure occurs in the case of the smaller phase deviation. Specifically, the peaks are narrower, the nulls deeper, and sidelobes sharper for the small phase deviation as a result of greater coherence between the elements of the Monte Carlo ensemble. Since the phase of the coefficients in Figures 17 and 18 is completely random and uniformly distributed over the entire 360° cycle, it is apparent that considerable cancellation can occur. Specifically, the near-field average field of Equation (24) will approach zero for large enough samples. This tendency to cancellation in the random phase case is also evidenced by a greater than two to one ratio of the unnormalized maxima of Figures (15) and (17). For the random phase calculation, the patterns derived from near-field averages are associated with standard deviations of -1 dB and -2

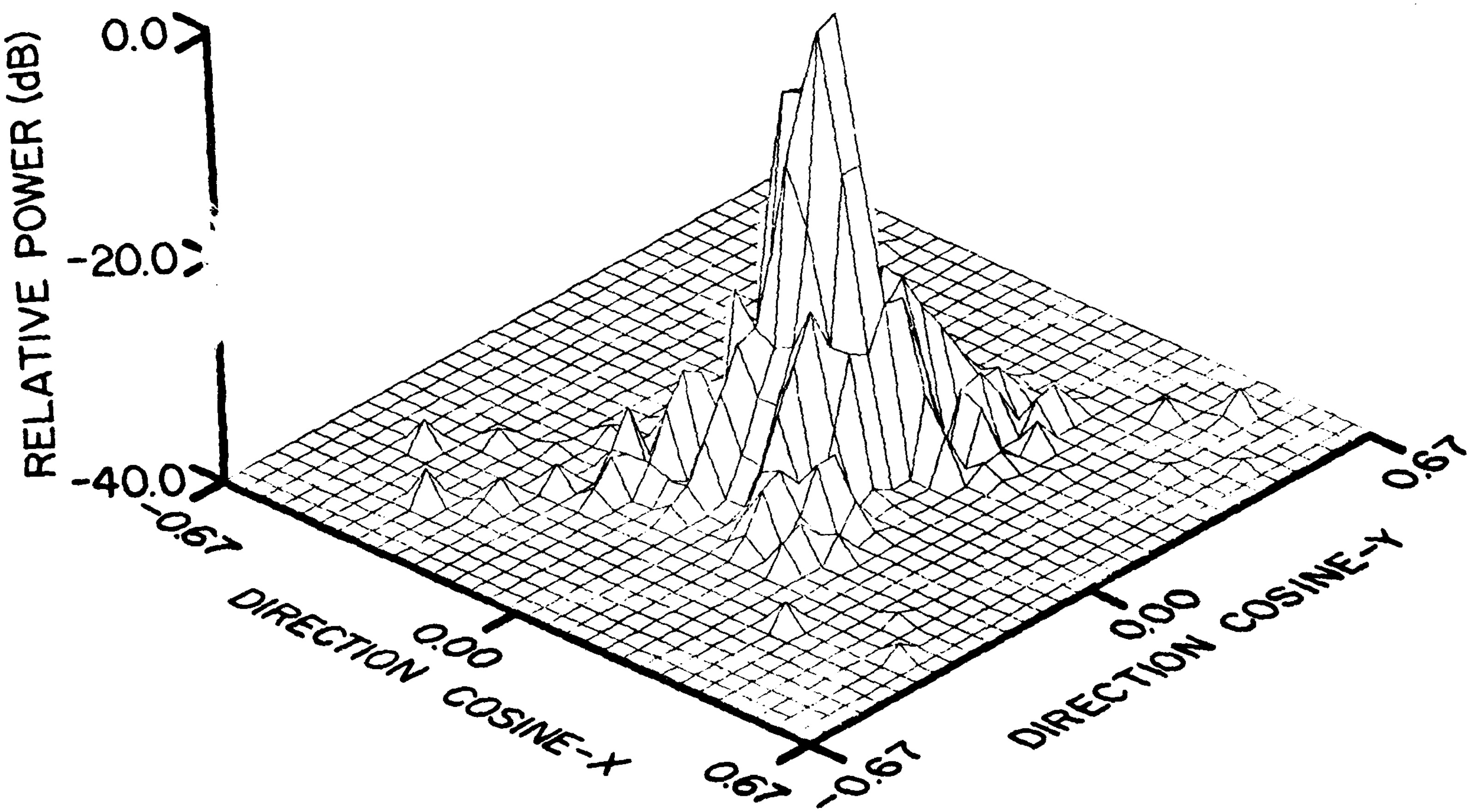

Figure 13. The spectral power pattern of the parallel polarized component for modes TE_{10}, TE_{11}, TE_{21}, and TM_{11} of antenna 1 calculated by Monte Carlo frequency average over 10 frequencies Gaussian distributed between 5.5 and 6.5 GHz.

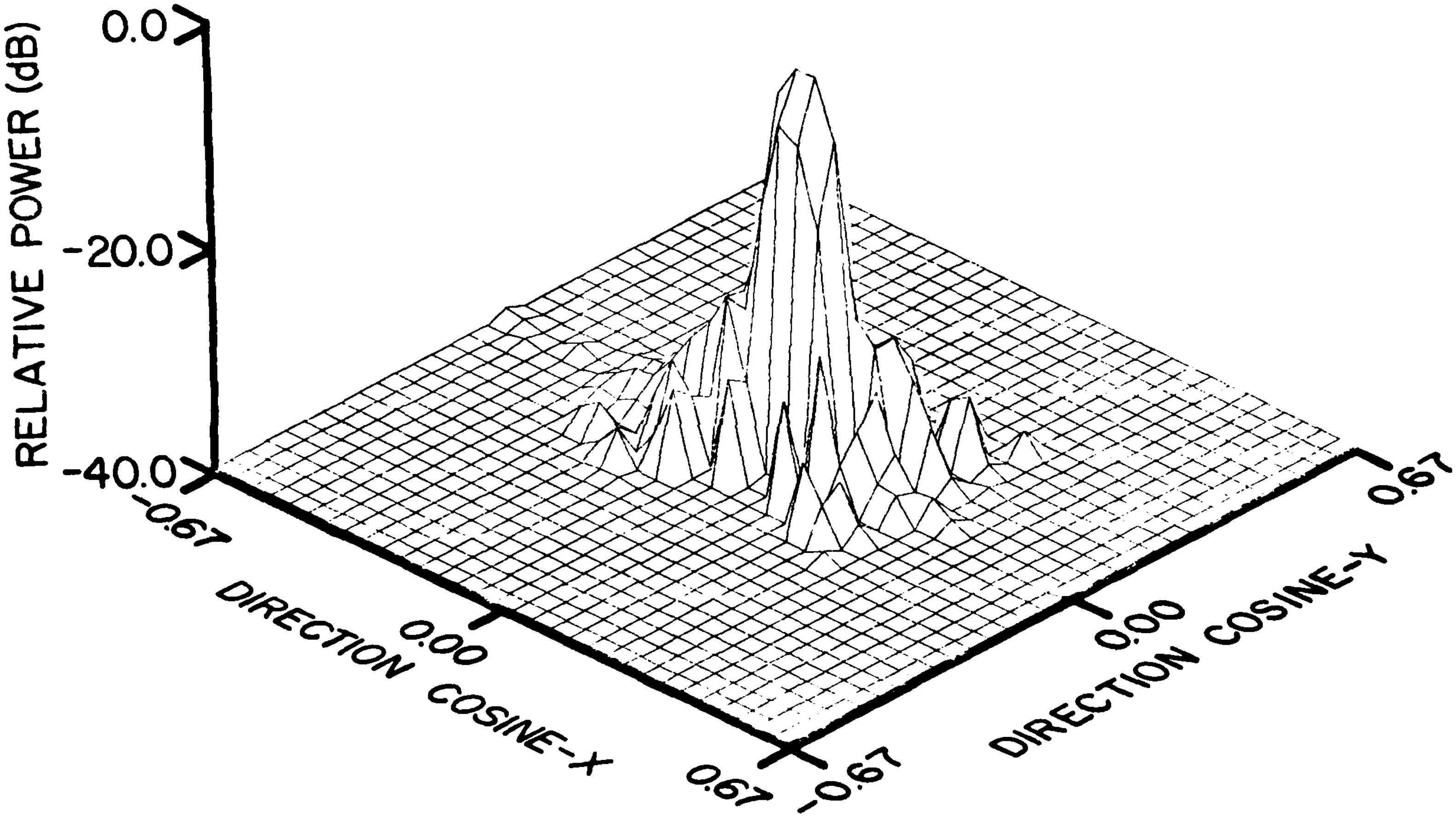

Figure 14. The spectral power pattern of the cross polarized component for modes TE_{10}, TE_{11}, TE_{21}, and TM_{11} of antenna 1 calculated by Monte Carlo frequency average over 10 frequencies Gaussian distributed between 5.5 and 6.5 GHz.

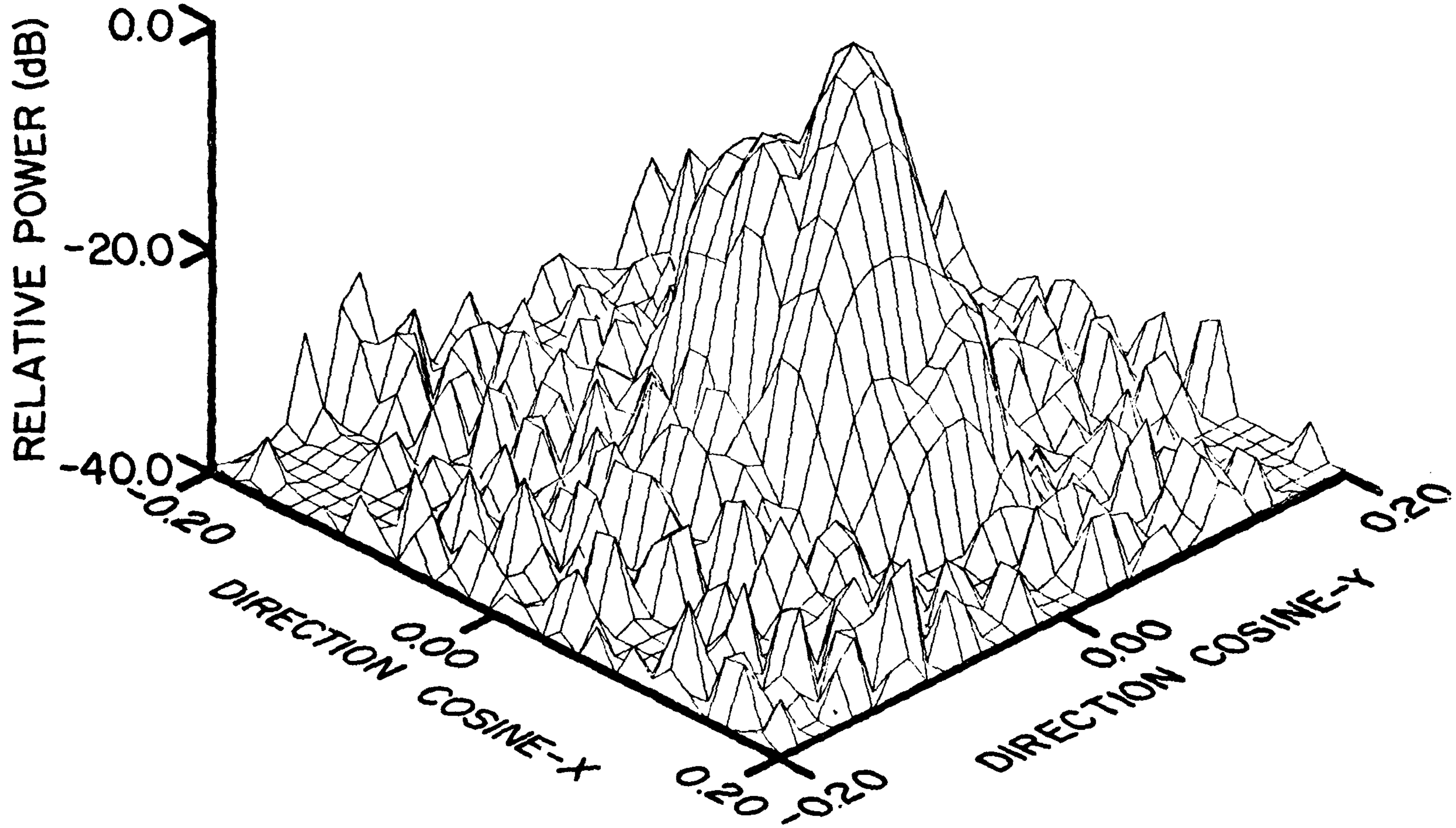

Figure 15. The spectral power pattern of the parallel polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 20°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}.

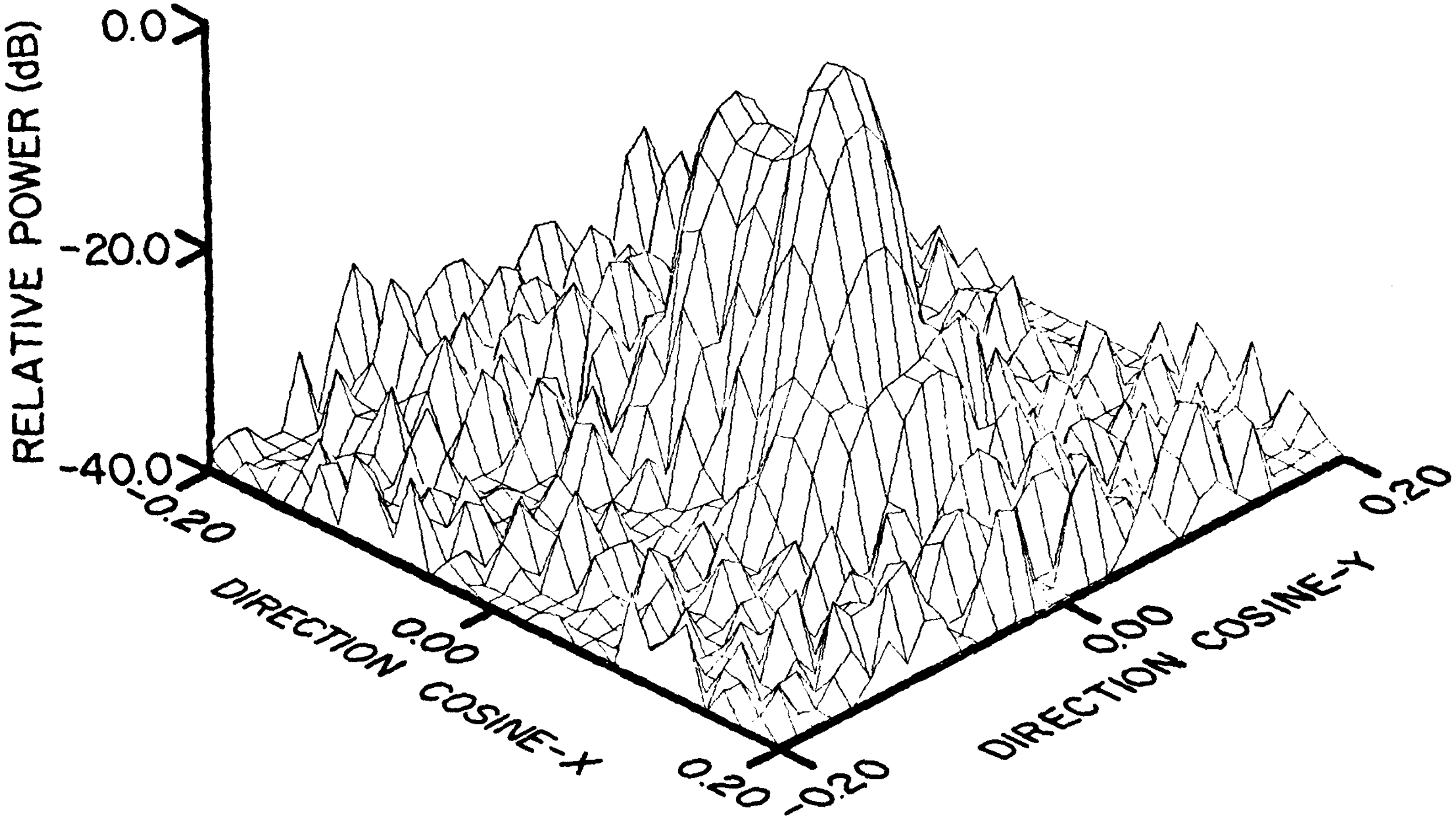

Figure 16. The spectral power pattern of the cross polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 20°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}.

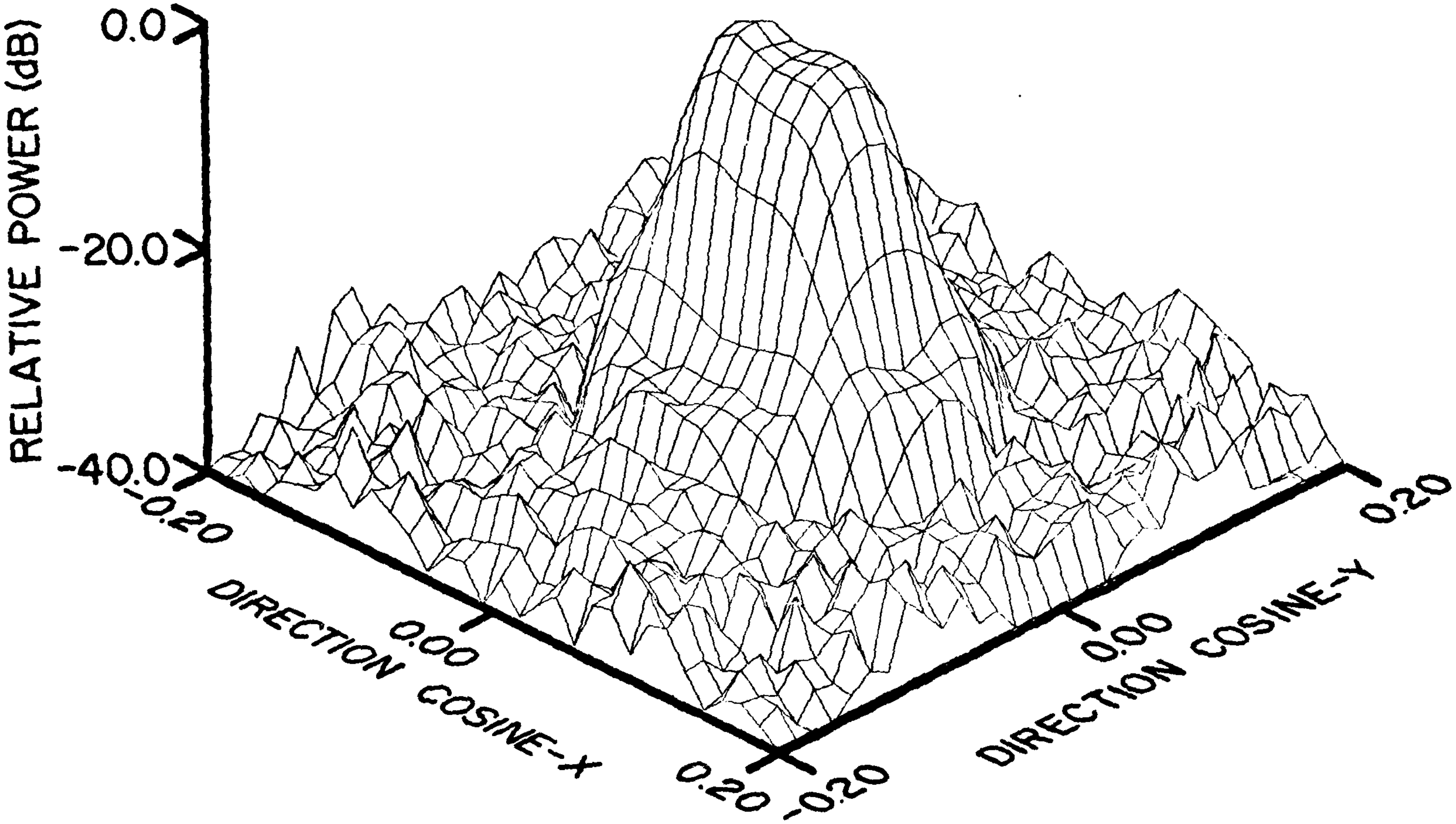

Figure 17. The spectral power pattern of the parallel polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 180°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, $\bar{TM}_{11}$, and TM_{21}.

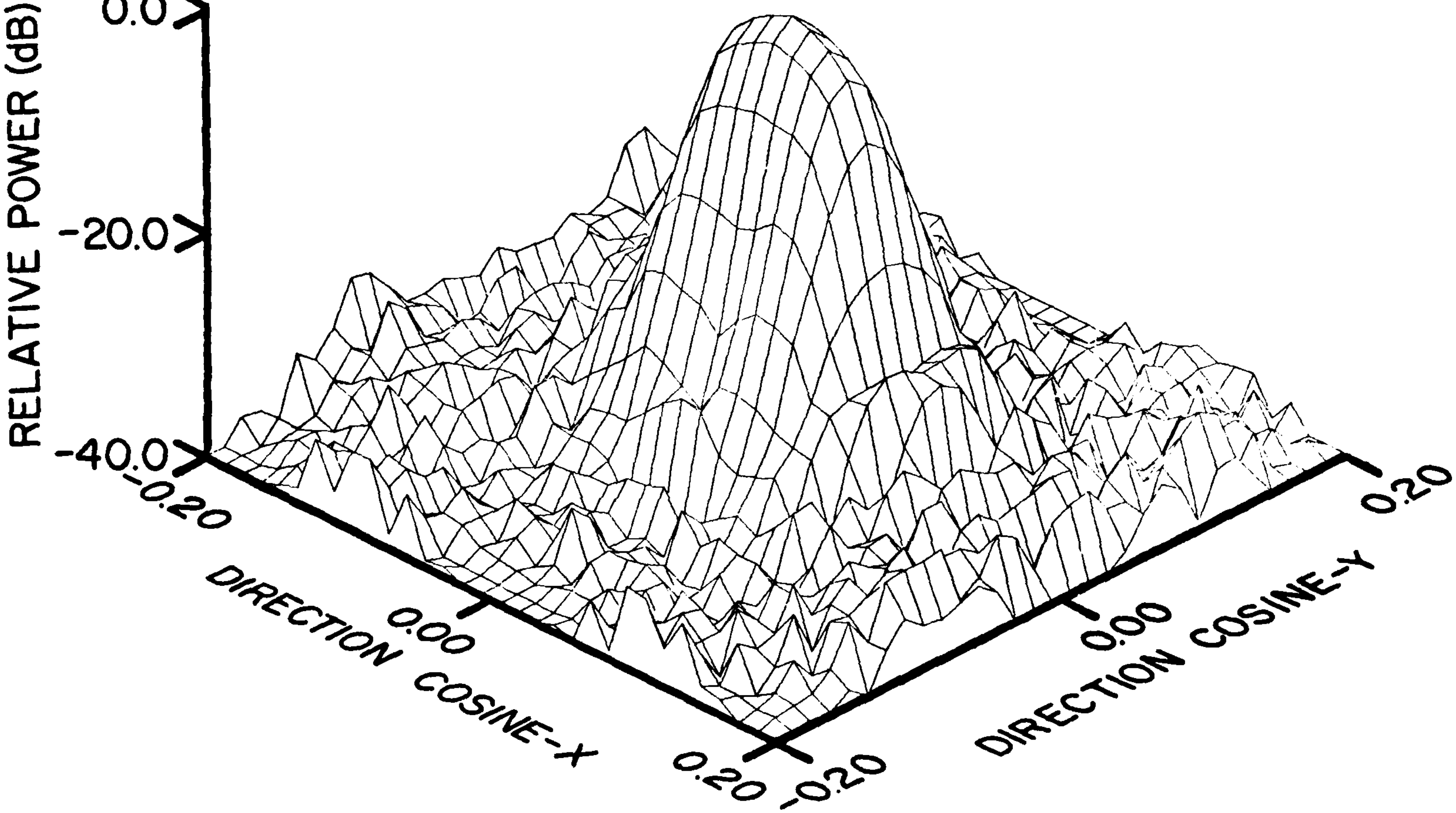

Figure 18. The spectral power pattern of the cross polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 180°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}.

dB. Consideration of Equation (34), in light of the comments about Equation (24) above make it evident that such large deviations are to be expected. The near-field derived patterns are deterministic patterns of the antenna but have no detailed relation to far-field averaged patterns. The parallel near-field derived component is shown in Figure 19.

The near-field derived results for the limited $\pm 20^{\circ}$ phase variation are more interesting. These are given in Figures 20 and 21 and are to be compared to Figures 15 and 16, respectively. The associted standard deviations are -27 dB and -27 dB. The patterns are quite similar to the far-field averages down to this level ($\sim$-27 dB) except in the boresight direction. The near-field derived result predicts considerably less power in the boresight direction than actually occurs. This is evidence of a large boresight contribution from the neglected cross correlation terms.

Reducing the phase deviation to $\pm 5^{\circ}$ has little effect. For instance, the standard deviations of the near-field derived patterns are -27 dB and -28 dB. The conclusion is that the phase deviation of the modal coefficients is the most crucial factor to be supplied by the analysis of the feed system for any specific application.

The *same coefficient* averaging with a phase deviation of $\pm 20^{\circ}$ has been performed with restricted mode sets. At 14 GHz only the TE_{10} and TE_{30} modes were used and at 16 GHz only the TE_{10}, TE_{30}, and TE_{50} were used. The obeservations are qualitatively the same as for the unrestricted mode set. In particular, the near-field derived result is smaller about the boresight direction than the *actual* result. Patterns for these cases are not presented herein.

D. Summary

Examples of results and of the use of the program have been given. Specifically, means of validating the convergence of integrals and of the statistical factors have been demonstrated and typical values of parameters producing satisfactory results have been given.

The principle observations of this preliminary study are as follows. The far-field frequency average has as its most noticeable effect the reduction of the far out sidelobes. This is most apparent for single mode calculations. The patterns derived from near-field averages are not strictly applicable in the case of frequency averaging because the same set of aperture points corresponds to different far-field directions for different frequencies.

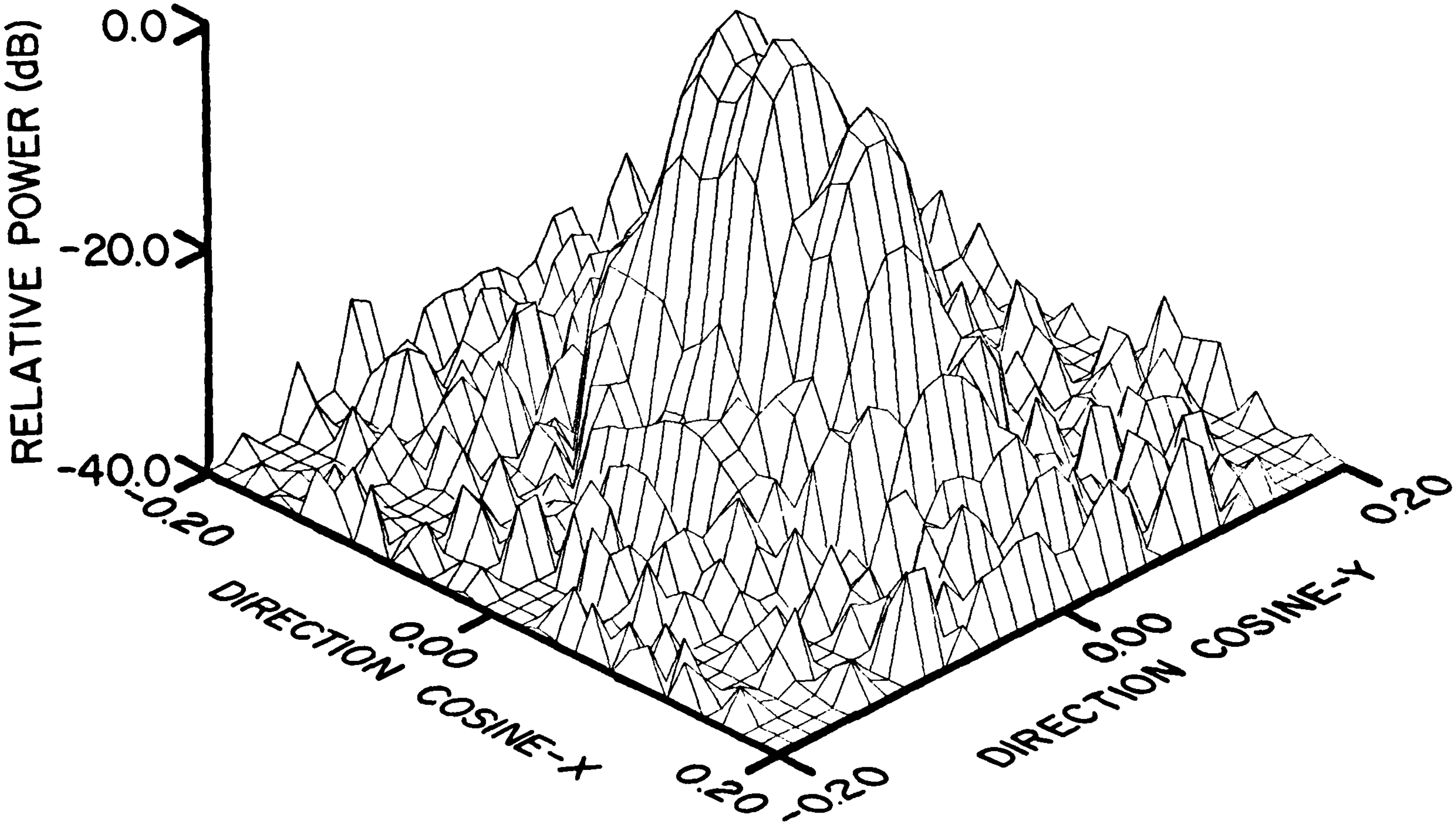

Figure 19. The near-field derived spectral power pattern of the parallel polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 180°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}.

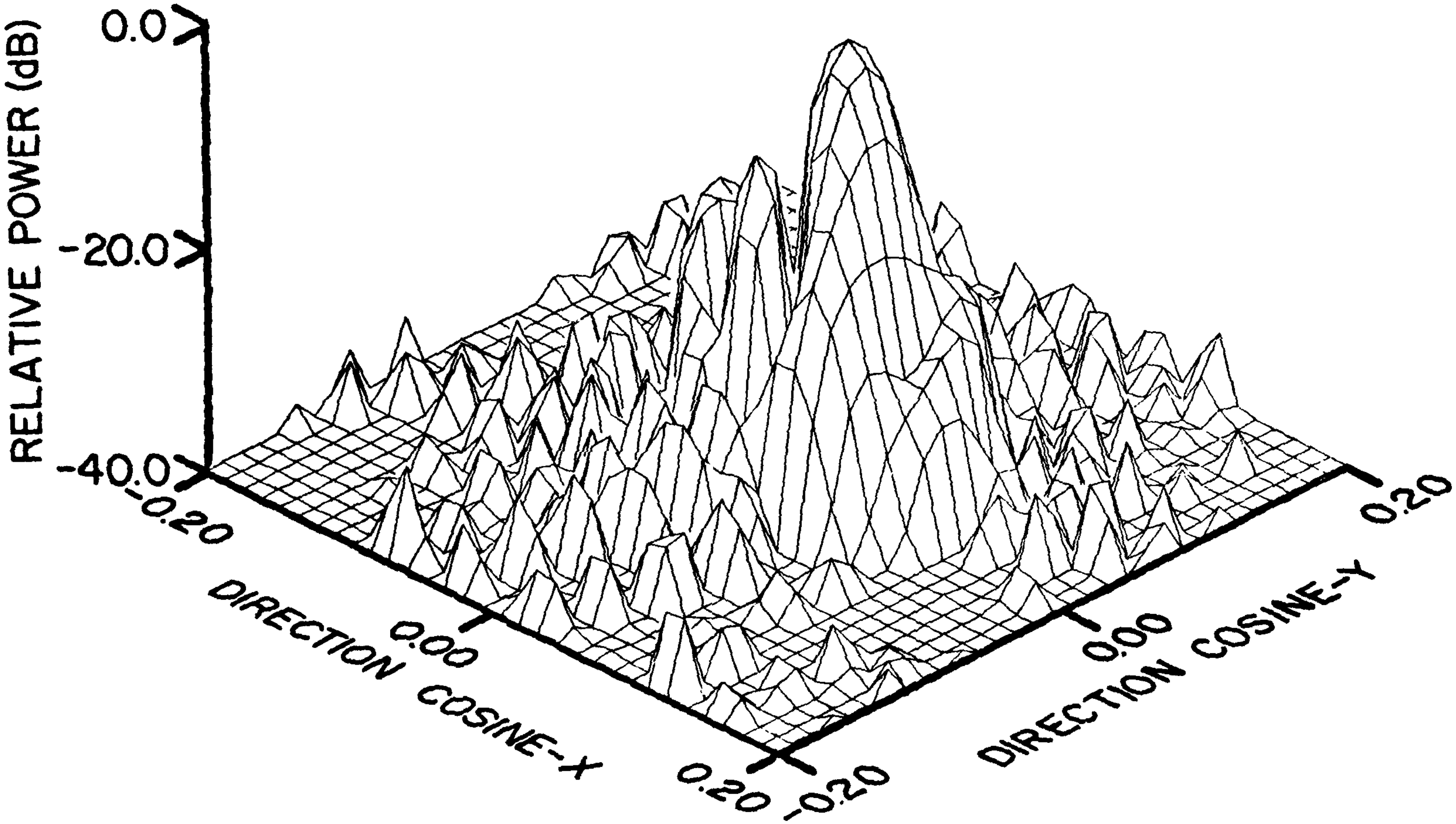

Figure 20. The near-field derived spectral power pattern of the parallel polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 20°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}.

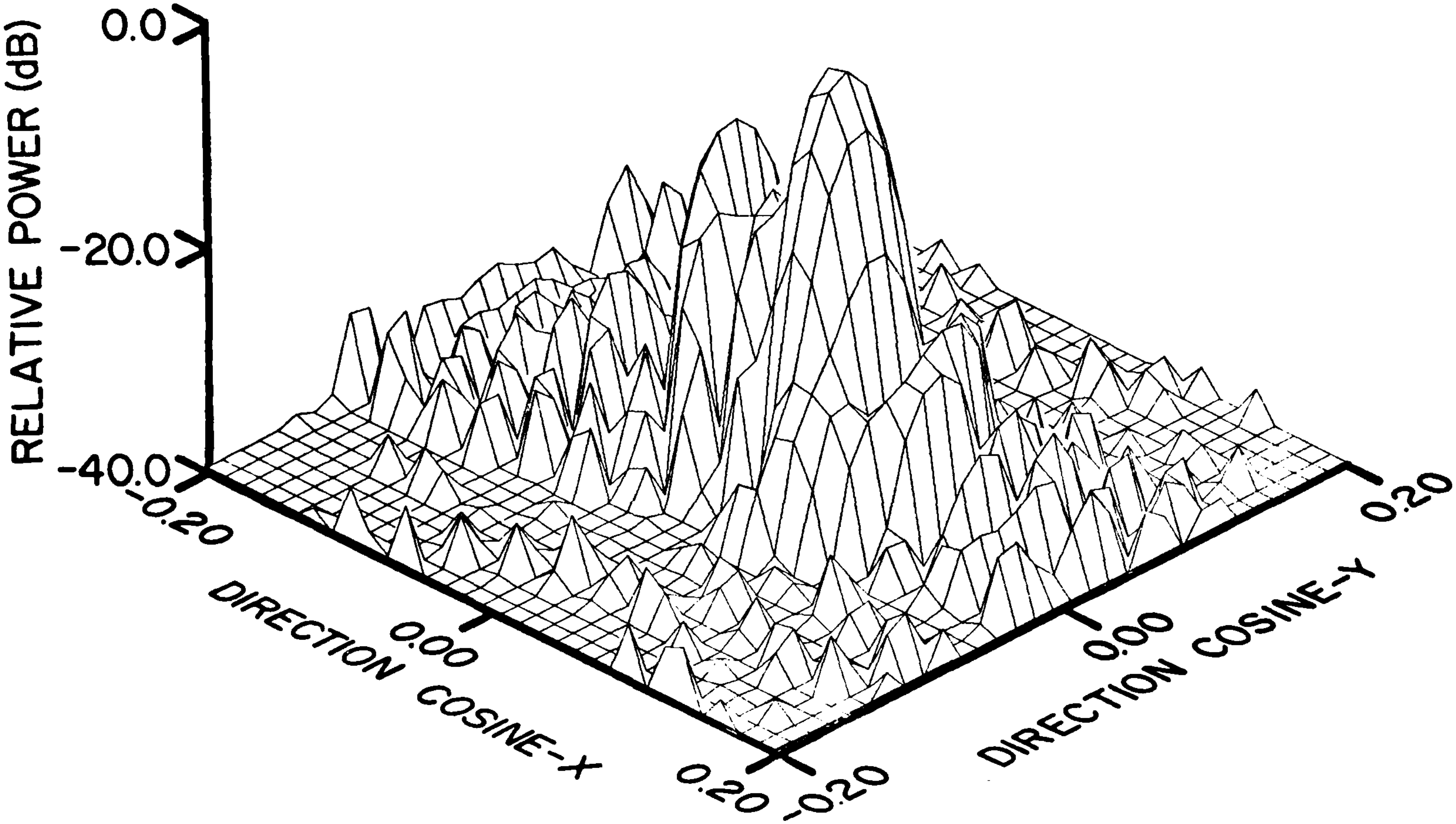

Figure 21. The near-field derived spectral power pattern of the cross polarized component for antenna 2 operating at a frequency of 9.6 GHz calculated by Monte Carlo average over 25 coefficient sets distributed as 1/(m+1)(n+1) in amplitude and uniformly distributed in phase over the interval $\pm 20°$. The modes are TE_{10}, TE_{20}, TE_{30}, TE_{01}, TE_{11}, TE_{21}, TM_{11}, and TM_{21}.

Thus, for frequency averaged results, the near-field derived and far-field patterns differ by amounts greater than the standard deviation and are not expressible as the neglected cross correlation terms. For coefficient averages, the cross correlation terms are apparently comparable to the standard deviations except about the boresight direction where large cross correlations are observed. Thus, the far-field averaging, employing a Monte Carlo procedure is the presently preferred method for utilizing the out-of-band reflector antenna computer model.

The total number of computations is roughly proportional to the sum of the feed horn array dimensions and the product of the aperture plane array dimensions. If N computation cylces are required for the deterministic calculation with a single mode, then roughly M N cycles are required for M modes and N_f M N for a frequency average of an N_f element ensemble of M modes. The coefficient average is much more efficient requiring perhaps M $N(1+N_c/5o)$ computation cycles for a coefficient average over an ensemble of N_c coefficient sets for M modes.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

The numerical code PARAB developed during this project provides the capability to simulate statistical out-of-band performance of paraboloidal reflector antennas under very general excitation conditions. Determination of these conditions, specifically the frequency and modal coefficient distributions, is the essential step in adapting this capability to a particular problem. The numerical simulations reported herein indicate that the far-field patterns are not particularly sensitive to frequency averaging alone. The patterns are sensitive to averages over modal coefficients at a single frequency or to both modal coefficient and frequency averaging. The greatest observed sensitivity is to the phase coherence of the modal coefficients comprising the statistical ensemble. This result indicates that the out-of-band pattern changes observed in measurements performed over frequency bands are primarily due to the phase coherence of the modes.

The code was developed to calculate statistical averages either in the near-field or far-field of the antenna. The results can thus be applied to a wide class of electromagnetic interference problems. The code also provides an approximate evaluation of the statistical far-field in terms of these statistical near-field. The simulations indicate that far-field patterns derived from the near-field averages are valid away from boresight if the computed standard deviation is small. An examination of the standard deviation thus provides a means of evaluating whether near-field measurements of antennas operating at out-of-band frequencies will yield satisfactory results.

It is recommended that other parameters, such as average sidelobe level over specified regions, beam pointing direction, and probability curves for signal strength applicable to specific problems be developed. The effects of geometrical blockage and edge diffraction can be incorporated in the code and may be of importance in many applications. The program may also be extended for offset fed reflectors. In addition, it is recommended that future modifications of the program be made to incorporate a library of statistical distributions which model specific transmission line components such as coax-to-waveguide adapters, E- and H-plane bends, etc. This "library" would permit the modeling of specific feed/transmission systems.

SECTION VI
REFERENCES

1. F. L. Cain, C. E. Ryan, B. J. Cown, and E. E. Weaver, "Electromagnetic Effectiveness Investigations of Near-Field Obstacle Effects, Antenna Coupling, and Phased Arrays," Georgia Institute of Technology, Final Engineering Report, Contract No. N00024-72-C-1274, June 1973.

2. "Far-Field Measurements to Characterize Out-of-Band Reflector Antenna Pattern Performance," work in progress, Contract No. F19628-80-C-0024.

3. F. L. Cain, B. J. Cown, and E. E. Weaver, "Out-of-Band Frequency Investigations of Near-Field Obstacle Effects and Phased Arrays," Georgia Institute of Technology, Final Engineering Report, Contract No. N00024-73-C-1141, February 1974.

4. F. L. Cain, B. J. Cown, E. E. Weaver, and C. E. Ryan, "Far-Field Antenna Performance Concerning In-Band Effects of Near-Field Structures and Out-of-Band Phased Arrays," Georgia Institute of Technology, Final Engineering Reort, Contract No. N00024-74-C-1215, January 1975.

5. B. J. Cown, F. L. Cain, and E. F. Duffy, "Statistical Prediction Model for EMC Analysis of Out-of-Band Phased Array Antennas," IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-18, No. 4, November 1976.

6. B. J. Cown and C. E. Ryan, "Near-Field Theory and Techniques for Wideband Radiating Systems at In-Band and Out-of-Band Frequencies," Georgia Institute of Technology, Interim Technical Report No. 1, Contract No. DAAG29-78-C-0029, January 1979.

7. R. E. Collin and F. J. Zucker, Antenna Theory, Inter-University Electronics Series, Vol. 7, McGraw-Hill Book Company, New York, 1969.

APPENDIX I

SOURCE LISTING OF PROGRAM PARAB

Appendix I

SOURCE LISTING OF PROGRAM PARAB

The calling routine and subroutines that comprise the Fortran code PARAB are listed. The listing is heavily commented and the comments complement the subroutine descriptions of Section III. An example of the input file STANCO is included at the end of the program listing. The example given contains ones as coefficients for each mode. A zero coefficient in STANCO for a specific mode prohibits use of that mode in the calculation. For a frequency only Monte Carlo average (specified by the value IRV=1), the values in STANCO will be used as the modal coefficients for all frequencies.

```
C   THIS PROGRAM IS DESIGNED FOR THE MONTE CARLO ANALYSIS OF
C   OUT-OF-BAND PARABALOIDAL REFLECTOR ANTENNAS. IT IS SPECIFICALLY
C   DESIGNED FOR FOCAL FEED, CIRCULAR PARABALOIDAL REFLECTORS WITH
C   RECTANGULAR FEED HORNS. E-PLANE AND/OR H-PLANE FLARES ARE
C   PERMISSABLE. OFFSET FEEDS COULD BE ACCOMMODATED WITHOUT MAJOR
C   PROGRAM MODIFICATION. THE PRINCIPAL APPROXIMATIONS ARE THE USE
C   OF RAY OPTICS AND OF DISCRETE FOURIER TRANSFORMS.
C
C    THE PROGRAM GENERATES AVERAGES OVER FREQUENCY,MODAL COEFFICIENTS
C    ,OR BOTH. AVERAGES OVER FREQUENCY ARE INHERENTLY MORE COSTLY
C    THE PROGRAM IS STRUCTURED SO THAT THE EFFICIENCY OF THE MODAL
C    COEFFICIENT AVERAGE IS PRESERVED. THIS IS ACCOMPLISHED BY
C    READING AND WRITING ARRAYS RATHER THAN CREATING NEW ONES.
C    MAXIMUM ARRAY SIZE IS THUS ACHIEVED.
C
C    FILES REQUIRED BY THE PROGRAM ARE:
C       STANCO=STANDARD COEFFICIENT SET USED FOR IRV=1 -FREQ AVG ONLY
C              CONTAINS 50 COMPLEX NUMBERS OF WHICH FIRST IMAX ARE USED
C       RCOEFF=HEADER,FREQUENCIES,MODAL COEFFICIENT SETS AS USED
C              IN A PREVIOUS RUN -FILE IS USED WHEN IGEN=0
C    FILES OUTPUT ARE:
C       PXY=MC AVERAGE NF(IAVGFF=0) OR FF(SPECTRAL)(IAVGFF=1) POWER
C       STAT=AVG. NF OR FF(SPECTRAL) FIELD
C       PFFDER=FAR-FIELD POWER PATTERN DERIVED FROM NEAR-FIELD AVERAGE
C       SPECID=PRINCIPLE PLANE CUTS OF THE MODAL PATTERNS IN THE FEED
C       EAPER=MODAL APERTURE FIELDS(IAVGFF=0) OR SPECTRA(IAVGFF=1)
C       EDET=DETERMINISTIC APERTURE FIELDS OR SPECTRA BY SUM OVER
C            MODES. ICSETS*IFSETS OF THESE ARE PRODUCED.
C
C   THE ARRAYS SPECX,SPECY,STATAX,STATAY,HOLDER,PXMC,PYMC,EXOFX,EXOFY,
C   EYOFX,EYOFY ARE ALWAYS CALLED WITH VARIABLE DIMENSIONS.SPECIFICALLY
C   THESE ARRAYS ARE CALLED WITH THE FOLLOWING DIMENSIONS:
C   EXOXF(IFEED),EXOFY(JFEED),EYOFX(IFEED),EYOFY(JFEED),
C   STATAX(IAPER,JAPER),STATAY(IAPER,JAPERR),PXMC(IAPER,JAPER),
C   PYMC(IAPER,JAPER).
C   BOTH    SPECX(IFEED,JFEED),SPECY(IFEED,JFEED)
C   AND     SPECY(IAPER,JAPER),SPECY(IAPER,JAPER)    ARE USED.
C   THE VARIABLES IFEED,JFEED,IAPER,JAPER ARE SUPLIED BY THE USER
C   AND MUST BE LESS THAN OR EQUAL TO 32 IN THE PRESENT PROGRAM.
C   LARGER (OR SMALLER) ARRAYS CAN BE ACCOMODATED BY CHANGES IN
C   THE DIMENSION STATEMENTS OF LINES 99 TO 103.
C
C   I/O SPECIFICATIONS FOR EACH TAPE ARE AS FOLLOWS:
C
C      --INPUT FILES--
C   INPUT(TAPE5)- READ(5,*) "VARIABLE NAME(S)"
C   STANCO(TAPE11)- DO - K=1,2
C                   DO - N1=1,8
C                   DO - M1=1,8
C                  -READ(11,*)M,N,K1,RCOEFF(M1,N1,K)
C   AND FOR IGEN=0 ONLY:
C   RCOEFF(TAPE31)- READ(31)HEADERB          REAL HEADERB(25)
C                   DO - IFMC=1,IFSETS
C                   READ(31)FREQI
C                   DO - IMC=1,ICSETS
C                  -READ(31)RCOEFF           COMPLEX RCOEFF(8,8,2)
C
```

Figure 22. Source listing of routine CALLER (continued).

```
C      --OUTPUT FILES--    (PRIMARY)
C    OUTPUT(TAPE6)-  MIXED FORMATS (DEPENDENT ON "LOUT")
C    PXY(TAPE35)-    WRITE(35)COMDAT           REAL COMDAT(12)
C                    WRITE(35)PXMC             REAL PXMC(IAPER,JAPER)
C                    WRITE(35)PYMC             REAL PYMC(IAPER,JAPER)
C  . STAT(TAPE33)-   WRITE(33)COMDAT           REAL COMDAT(12)
C                    WRITE(33)STATAX           COMPLEX(STATAX(IAPER,JAPER)
C                    WRITE(33)STATAY           COMPLEX STATAY(·IAPER,JAPER)
C    AND FOR IAVGFF=0 ONLY:
C    PFFDER(TAPE13)- WRITE(13)COMDAT           REAL COMDAT(12)
C                    WRITE(13)PXMC             REAL PXMC(IAPER,JAPER)
C                    WRITE(13)PYMC             REAL PYMC(IAPER,JAPER)
C
C      --OUTPUT FILES--    (INTERNAL USE-WRITE AND READ)
C    SPEC1D(TAPE25)- DO - K=1,2
C                    DO - N1=1,8
C                    DO - M1=1,8
C                   -IF("ALLOWABLE MODE")WRITE(25)EXOFX,EXOFY,EYOFX,EYOFY
C                      COMPLEX EXOFX(IFEED),EXOFY(JFEED),EYOFX(IFEED),
C                      COMPLEX EYOFY(JFEED)
C    EAPER(TAPE29)-  DO - K=1,2
C                    DO - N1=1,8
C                    DO - M1=1,8
C                   -IF("ALLOWABLE MODE")WRITE(29)SPECX,SPECY
C                      COMPLEX SPECX(IAPER,JAPER),SPECY(IAPER,JAPER)
C    EDET(TAPE15)-   DO - K=1,2
C                    DO - N1=1,8
C                    DO - M1=1,8
C                   -WRITE(15)STATAX,STATAY
C                      COMPLEX STATAX(IAPER,JAPER),STATAY(IAPER,JAPER)
C
C
      PROGRAM CALLER(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
     1 SPEC1D,TAPE25=SPEC1D,EAPER,TAPE29=EAPER,RCOEFF,TAPE31=RCOEFF
     1   ,STAT,TAPE33=STAT,PXY,TAPE35=PXY,STANCO,TAPE11=STANCO
     1    ,EDET,TAPE15=EDET,PFFDER,TAPE13=PFFDER)
C
C    PROGRAM CALLER IS ORGANIZED TO INTERACTIVELY ACQUIRE
C    THE PARAMETERS DESCRIBING THE ANTENNA AND THE NUMERICAL
C    PROCESSING.
C
      COMPLEX SPECX(32,32),SPECY(32,32),STATAX(32,32),
     1  STATAY(32,32), EXOFX(32),EXOFY(32),EYOFX(32),EYOFY(32)
     1    ,AVGCOE(8,8,2),RCOEFF(8,8,2),HOLDER(32,32)
      REAL AMODE(8,8,2),HEADER(25),COMDAT(12)
      REAL PXMC(32,32),PYMC(32,32)
      REAL INCM,TEMP(8)
      COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
      COMMON/MODE/AMODE
      COMMON/FEED/AFEED,BFEED,HORLEN
      COMMON/ZMOVE/ZMOVE
      COMMON/PARAB/FOCUS,RMAX,THETAM
      COMMON/APER/AAPER,BAPER
      COMMON/RMODE/ICSETS,IGEN,ICDIST,IPHIRV,PHIDEV
      COMMON/RFREQ/IRV,IFDIST,IAVGFF,IFSETS
      COMMON/HEADER/HEADER
      COMMON/LOUT/LOUT
```

Figure 22. Source listing of routine CALLER (continued).

```
      COMMON/COMDAT/COMDAT
      INCM=2.5401
C
C
C   INTERACTIVELY ESTABLISH LEVEL OF OUTPUT TO BE PRODUCED BY RUN
C
C
      WRITE(6,243)
  243 FORMAT(55X,"VARIABLE NAME"//" DEFINE OUTPUT LEVEL,"/
     1 "    (0)MIN. OUTPUT, (1)NORMAL BATCH OUTPUT,"/
     1 "    (2)COMMENTS ON PROGRAM OPERATION AND LIMITATIONS"
     1 /55X,"LOUT")
      READ(5,*)LOUT
      HEADER(1)=LOUT
C
C
C   INTERACTIVELY ESTABLISH THE RANDOM VARIABLES, THEIR STATISTICS,
C   AND THE SIZE OF THE MONTE CARLO ENSEMBLE.
C
C   NOTE THAT ALL USER SUPPLIED PARAMETERS ARE STORED IN AN
C   ARRAY "HEADER"
C
C
      WRITE(6,244)
  244 FORMAT(" ARE THE RANDOM VARIABLES THE FREQ(1),THE MODAL"/
     1 "    COEFFICIENTS(2),OR BOTH(3)?"/55X,"IRV")
      READ(5,*) IRV
      HEADER(2)=IRV
      ICDIST=0
      IPHIRV=0
      PHIDEV=0.0
      IFDIST=0
      ICSETS=1
      IFSETS=1
      IF(IRV.LT.2) GO TO 246
      WRITE(6,247)
  247 FORMAT(" IS THE COEFFICIENT AMPLITUDE DISTRIBUTION (1)UNIFORM,"
     1     /"    (2)GAUSSIAN,(3)1/((M+1)*(N+1))"
     1 /55X,"ICDIST")
      READ(5,*) ICDIST
      WRITE(6,295)
  295 FORMAT(" IS THE COEFFICIENT PHASE DISTRIBUTION (1)UNIFORM,"
     1       /"    (2)GAUSSIAN"/55X,"IPHIRV")
      READ(5,*)IPHIRV
      WRITE(6,296)
  296 FORMAT(" WHAT IS THE DEVIATION(DEG) OF THE COEFF. PHASE   "
     1 /55X,"PHIDEV")
      READ(5,*)PHIDEV
      IF(IRV.EQ.3) GO TO 246
      WRITE(6,285)
  285 FORMAT(" ENTER NUMBER OF COEFFICIENT SETS TO BE USED"/
     1        "    IN MONTE CARLO CALCULATION"/55X,"ICSETS")
      READ(5,*) ICSETS
  246 IF(IRV.EQ.2) GO TO 248
      WRITE(6,249)
  249 FORMAT(" IS THE FREQUENCY DISTRIBUTION (1)UNIFORM,(2)GAUSSIAN"
     1 /55X,"IFDIST")
```

Figure 22. Source listing of routine CALLER (continued).

```
      READ(5,*) IFDIST
      WRITE(6,261)
  261 FORMAT(" ENTER TOTAL NUMBER OF MONTE CARLO SETS,"/
     1 "    EACH AT A DIFFERENT FREQUENCY, TO BE USED"/55X,"IFSETS")
      READ(5,*) IFSETS
  248 CONTINUE
      HEADER(3)=ICDIST
      HEADER(24)=IPHIRV
      HEADER(25)=PHIDEV
      HEADER(4)=ICSETS
      HEADER(5)=IFDIST
      HEADER(6)=IFSETS
C
C   THE PRECEEDING LOGIC PRODUCES THE FOLLOWING CONDITIONS
C   CONTROLLED BY THE VALUE OF IRV
C          IRV      1      2      3
C       ICDIST      0     VAR.   VAR.
C       ICSETS      1     VAR.    1
C       IFDIST    VAR.     0     VAR.
C       IFSETS    VAR.     1     VAR.
C                   0 MEANS STANDARD SET OF COEFFICIENTS IS READ IN
C                          0 MEANS FREQUENCY=FREQ IS USED
C
C   ICDIST IS A SHORTHAND FOR THE SEVERAL PARAMETERS(ICDIST,
C   IPHIRV,PHIDEV) DESCRIBING THE DISTRIBUTIONS OF THE AMPLITUDE
C   AND PHASE OF THE MODAL COEFFICIENTS
C
      WRITE(6,251)
  251 FORMAT(" ARE NEAR-FIELD(0) OR FAR-FIELD(1) AVERAGES"
     1    /"    TO BE CALCULATED?"/55X,"IAVGFF")
      READ(5,*) IAVGFF
      HEADER(7)=IAVGFF
C
C
C   INTERACTIVELY ESTABLISH PHYSICAL DIMENSIONS OF
C   PARABALOID REFLECTOR AND FEED SYSTEM AND
C   ARRAY SIZES FOR NUMERICAL PROCESSING.
C
C
      WRITE(6,255)
  255 FORMAT(" ENTER OUT-OF-BAND FREQUENCY (GHZ) AND SPREAD   "
     1 /55X,"FREQ,DELFREQ")
      READ(5,*) FREQ,DELFREQ
      HEADER(8)=FREQ
      HEADER(9)=DELFREQ
      WRITE(6,260)
  260 FORMAT(" ENTER DIMENSIONS (IN INCHES) OF RECTANGULAR "
     1"WAVE-GUIDE,"/"    FIRST H-PLANE(WIDTH) THEN E-PLANE(HEIGHT)."
     1 /"    WIDE SIDE TAKEN PARALLEL TO X-AXIS"/55X,"AGUIDE BGUIDE")
      READ(5,*) AGUIDE,BGUIDE
      HEADER(10)=AGUIDE
      HEADER(11)=BGUIDE
      AGUIDE=AGUIDE*INCM
      BGUIDE=BGUIDE*INCM
C     IF(BGUIDE.LT.AGUIDE) GO TO 105
C     TEMP=AGUIDE
C     AGUIDE=BGUIDE
```

Figure 22. Source listing of routine CALLER (continued).

```
C     BGUIDE=TEMP
C 105 CONTINUE
      WRITE(6,265)
  265 FORMAT (" ENTER DIMENSIONS (IN INCHES) OF RECTANGULAR FEED "
     1 "HORN"/"   APERTURE, H-PLANE WIDTH FIRST (PARALLEL TO X-AXIS) "
     1 /55X,"AFEED,BFEED")
      READ(5,*)AFEED,BFEED
      HEADER(12)=AFEED
      HEADER(13)=BFEED
      AFEED=AFEED*INCM
      BFEED=BFEED*INCM
      WRITE(6,267)
  267 FORMAT(" ENTER LENGTH OF HORN(IN.) FOR CALC. OF PHASE TAPERS"/
     1"    FOR NO TAPER ENTER 0.0. "
     1 /55X,"HORLEN")
      READ(5,*) HORLEN
      HEADER(14)=HORLEN
      HORLEN=HORLEN*INCM
      WRITE(6,101)
  101 FORMAT(" ENTER ARRAY SIZE FOR FEED HORN ARRAY:"/55X,"IFEED,JFEED")
      IF(LOUT.GE.2)WRITE(6,102)
  102 FORMAT("    FEED ARRAY DIMENSIONS ARE TO BE 32 OR LESS.")
      READ(5,*) IFEED,JFEED
      HEADER(15)=IFEED
      HEADER(16)=JFEED
      WRITE(6,250)
  250 FORMAT(" ENTER FOCAL LENGTH AND RADIUS(INCHES) OF "/
     1    " PARABALOIDAL REFLECTOR"/55X,"FOCUS,RMAX")
      READ(5,*) FOCUS,RMAX
      HEADER(17)=FOCUS
      HEADER(18)=RMAX
      FOCUS=FOCUS*INCM
      RMAX=RMAX*INCM
      THETAM=ACOS((4.*FOCUS**2-RMAX**2)/(4.*FOCUS**2+RMAX**2))
      WRITE(6,270)
  270 FORMAT(" ENTER DIMENSIONS (INCHES) OF APERTURE PLANE,"
     1        " X THEN Y"/55X,"AAPER,BAPER")
      IF(LOUT.GE.2)WRITE(6,272)
  272 FORMAT("    AAPER AND BAPER MUST EACH BE GREATER THAN
     1 "/"    DIAMETER OF PARABALOID=2*RMAX")
      READ(5,*) AAPER,BAPER
      HEADER(19)=AAPER
      HEADER(20)=BAPER
      AAPER=AAPER*INCM
      BAPER=BAPER*INCM
      DIA=2.0*RMAX
      IF(AAPER.LT.DIA.OR.BAPER.LT.DIA) WRITE(6,275)
  275 FORMAT(" APERTURE PLANE IS NOT AS LARGE AS REFLECTOR")
      WRITE(6,280)
  280 FORMAT(" ENTER ARRAY SIZE FOR APERTURE ARRAY:"/55X,"IAPER,JAPER")
      IF(LOUT.GE.2)WRITE(6,282)
  282 FORMAT("    THE SET OF VALUES THAT IAPER AND JAPER CAN
     1 "/"    TAKE IS 4,8,16,32")
C
C   SUBROUTINE FFT REQUIRES THAT THE ARRAY DIMENSIONS BE AN INTEGER
C   POWER OF TWO. SUBROUTIINE FFTDOUB DOES NOT ACCEPT ARRAY DIMENSIONS
C   LESS THAN 4.
```

Figure 22. Source listing of routine CALLER (continued).

```
C
      READ(5,*) IAPER,JAPER
      HEADER(21)=IAPER
      HEADER(22)=JAPER
      WRITE(6,290)
  290 FORMAT(" ARE RANDOM VARIABLES TO BE GENERATED"/
     1 "    INTERNALLY(1) OR READ FROM FILE COEFF(0)"/55X,"IGEN"/)
      IF(LOUT.GE.2)WRITE(6,292)
  292 FORMAT("    THE RANDOM VARIABLES (MODE COEFFICIENTS AND/OR
     1 "/"    FREQUENCIES) ARE NORMALLY GENERATED INTERNALLY
     1 "/"    FOR EACH RUN, SAVE WHEN THE RESULTS OF NEAR-FIELD
     1 "/"    AND FAR FIELD AVERAGING ARE TO BE COMPARED.")
      READ(5,*) IGEN
      HEADER(23)=IGEN
      C=29.979
      COMDAT(1)=-HEADER(19)/2.0
      COMDAT(2)=HEADER(19)/IAPER
      COMDAT(3)=IAPER
      COMDAT(4)=-HEADER(20)/2.0
      COMDAT(5)=HEADER(20)/JAPER
      COMDAT(6)=JAPER
      COMDAT(7)=-0.5*C*IAPER/AAPER/FREQ
      COMDAT(8)=C/AAPER/FREQ
      COMDAT(10)=-0.5*C*JAPER/BAPER/FREQ
      COMDAT(11)=C/BAPER/FREQ
      COMDAT(12)=IAVGFF
C
C   INTERPRETATION OF THE ELEMENTS OF COMDAT IS AS FOLLOWS:
C      COMDAT(1)=XMIN
C      COMDAT(2)=DELX
C      COMDAT(3)=IAPER
C      COMDAT(4)=YMIN
C      COMDAT(5)=DELY
C      COMDAT(6)=JAPER
C      COMDAT(7)=KXMIN      FOR NORMAL FFT,CHANGED BY FFTDOUB
C      COMDAT(8)=DELKX      FOR NORMAL FFT,CHANGED BY FFTDOUB
C      COMDAT(10)=KYMIN     FOR NORMAL FFT,CHANGED BY FFTDOUB
C      COMDAT(11)=DELKY     FOR NORMAL FFT,CHANGED BY FFTDOUB
C      COMDAT(12)=IAVGFF
C
      FREQMIN=FREQ-DELFREQ
      FREQMAX=FREQ+DELFREQ
      DO 408 K=1,2
      DO 408 N1=1,8
      DO 408 M1=1,8
        RCOEFF(M1,N1,K)=CMPLX(1.0,0.0)
  408 CONTINUE
      CALL COUNT(IMAX,AMODE,FREQMAX,RCOEFF)
      IF(LOUT.GE.1) WRITE(6,402) FREQMAX
  402 FORMAT(/"    FOR A FREQUENCY OF",E11.4/
     1        "    THE ALLOWABLE MODES ARE:"/
     1         4X,"M",6X,"N",6X,"TE(1),TM(2)",6X,"CUTOFF FREQ")
      DO 404 K=1,2
      DO 404 N1=1,8
      DO 404 M1=1,8
        IF(AMODE(M1,N1,K).LT.-0.5) GO TO 404
        M=M1-1
```

Figure 22. Source listing of routine CALLER (continued).

```
        N=N1-1
        FC=29.979*SQRT((0.5*M/AGUIDE)**2+(0.5*N/BGUIDE)**2)
        IF(LOUT.GE.1)WRITE(6,403)M,N,K,FC
  404 CONTINUE
  403 FORMAT(3X,I2,5X,I2,10X,I2,11X,E12.4)
      IF(LOUT.GE.2)WRITE(6,992)
  992 FORMAT(" AN INPUT FILE STANCO MUST BE PROVIDED. IT IS"/
     1       "    READ HERE. RESTRICTIONS ON MODAL CONTENT, OTHER"/
     1       "    THAN THAT OF CUT-OFF FREQUENCY AS IMPOSED BY"/
     1       "    COUNT, ARE IMPLEMENTED BY MAKING MODAL "/
     1       "    COEFFICCIENTS ZERO IN STANCO.")
      REWIND 11
      READ(11,1000)TEMP
 1000 FORMAT(8A10)
      DO 999 K=1,2
      DO 999 N1=1,8
      DO 999 M1=1,8
        READ(11,*)M,N,K1,RCOEFF(M1,N1,K)
  999 CONTINUE
      REWIND 11
      CALL COUNT(IMIN,AMODE,FREQMIN,RCOEFF)
  407 FORMAT(3X,I2,5X,I2,10X,I2)
      CALL COUNT(IMAX,AMODE,FREQMAX,RCOEFF)
      IF(LOUT.GE.1) WRITE(6,401)
  401 FORMAT(//"    THE INPUT FILE STANCO IS USED TO RESTRICT"/
     1         "    THE MODES USED IN THE CALCULATION."//
     1         "    MODES USED IN THIS CALCULATION ARE:"/
     1         4X,"M",6X,"N",6X,"TE(1),TM(2)")
      DO 414 K=1,2
      DO 414 N1=1,8
      DO 414 M1=1,8
        M=M1-1
        N=N1-1
        IF(AMODE(M1,N1,K).LT.-0.5) GO TO 414
        IF(LOUT.GE.1)WRITE(6,407)M,N,K
  414 CONTINUE
      IF(IMAX.GT.IMIN) WRITE(6,410)
  410 FORMAT(//" NUMBER OF MODES CHANGED OVER FREQ. BAND"/)
      WRITE(6,415) IMIN,IMAX
  415 FORMAT(/" MIN AND MAX NUMBER OF MODES TO BE USED ARE",2I4/)
      IF(LOUT.LT.1) GO TO 550
      WRITE(6,501)LOUT
      WRITE(6,502)IRV
      WRITE(6,503)ICDIST,ICSETS
      WRITE(6,524)IPHIRV,PHIDEV
      WRITE(6,505)IFDIST,IFSETS
      WRITE(6,507)IAVCFF
      WRITE(6,508)FREQ,DELFREQ
      WRITE(6,510)HEADER(10),HEADER(11)
      WRITE(6,512)HEADER(12),HEADER(13)
      WRITE(6,514)HEADER(14)
      WRITE(6,515)IFEED,JFEED
      WRITE(6,517)HEADER(17),HEADER(18)
      WRITE(6,519)HEADER(19),HEADER(20)
      WRITE(6,521)IAPER,JAPER
      WRITE(6,523)IGEN
  501 FORMAT(" LOUT              ",I3)
```

Figure 22. Source listing of routine CALLER (continued).

```
      502 FORMAT(" IRV              ",I3)
      503 FORMAT(" ICDIST,ICSETS    ",2I3)
      505 FORMAT(" IFDIST,IFSETS    ",2I3)
      507 FORMAT(" IAVGFF           ",I3)
      508 FORMAT(" FREQ,DELFREQ     ",2E11.4)
      510 FORMAT(" AGUIDE,BGUIDE    ",2E11.4)
      512 FORMAT(" AFEED,BFEED      ",2E11.4)
      514 FORMAT(" HORLEN           ",E11.4)
      515 FORMAT(" IFEED,JFEED      ",2I3)
      517 FORMAT(" FOCUS,RMAX       ",2E11.4)
      519 FORMAT(" AAPER,BAPER      ",2E11.4)
      521 FORMAT(" IAPER,JAPER      ",2I3)
      523 FORMAT(" IGEN             ",I3/)
      524 FORMAT(" IPHIRV,PHIDEV    ",I3,E11.4)
      550 CONTINUE
C
      ZMOVE=0.0
C
      CALL  MCSUM(RCOEFF,AVGCOE,SPECX,SPECY,STATAX,STATAY,
     1      IAPER,JAPER,PXMC,PYMC,IFEED,JFEED,EXOFX,EXOFY,EYOFX,EYOFY
     1      ,HOLDER)
      STOP
      END
```

Figure 22. Source listing of routine CALLER.

```
      SUBROUTINE COUNT(IMODE,AMODE,FREQI,RCOEFF)
C
C   SUBROUTINE COUNT DETERMINES IF MODES TE(M,N) AND TM(M,N)
C   CORRESPONDING TO AMODE(M+1,N+1,1) AND AMODE(M+1,N+1,2)
C   ARE ALLOWABLE.  MODES ARE ALLOWABLE IF THEY CAN PROPAGATE
C   IN THE WAVE-GUIDE AND IF THE GIVEN VALUE OF "RCOEFF"
C   IS NOT ZERO.  THUS RCOEFF IS USED TO ARBITRARILY RESTRICT
C   THE MODAL CONTENT.
C
      DIMENSION AMODE(8,8,2)
      COMPLEX RCOEFF(8,8,2)
      COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
C
C   DETERMINE FOR A GIVEN FREQI AND AGUIDE,BGUIDE IF
C   THE TE(M,N) AND TM(M,N) MODES CAN PROPAGATE.  NOTE
C   THAT TE(0,0), TM(M,0), TM(0,N) MODES DO NOT EXIST.
C
      C=29.979
      IMODE=0
      DO 5 K=1,2
      DO 5 N1=1,8
      DO 5 M1=1,8
    5 AMODE(M1,N1,K)=-1.0
      CONST=(2.0*FREQI/C)**2
      DO 10 N1=1,8
        N=N1-1
        DO 10 M1=1,8
          M=M1-1
          IM=M+N
          IF(IM.EQ.0) GO TO 10
          IM=M*N
          TEMP1=CONST-(M/AGUIDE)**2-(N/BGUIDE)**2
          IF(TEMP1) 10,10,20
   20     AMODE(M1,N1,1)=1.0
          AMODE(M1,N1,2)=1.0
          IF(IM.EQ.0) AMODE(M1,N1,2)=-1.0
C         IMODE=IMODE+AMODE(M1,N1,1)+(AMODE(M1,N1,2)+1)/2
   10 CONTINUE
C
C    IF CABS(RCOEFF(M+1,N+1,K)) = 0.0, DO NOT USE
C    THE MODE TE(M,N) FOR K=1 OR TM(M,N) FOR K=2
C
C    MODES TO BE USED ARE CATALOGED BY
C    AMODE(M+1,N+1,K) = 1.0
C
       DO 12 K=1,2
       DO 12 N1=1,8
       DO 12 M1=1,8
         IF(REAL(RCOEFF(M1,N1,K)).EQ.0.0.AND.AIMAG(
     1   RCOEFF(M1,N1,K)).EQ.0.0)AMODE(M1,N1,K)=-1.0
         IMODE=IMODE+(AMODE(M1,N1,K)+1)/2
   12  CONTINUE
       RETURN
       END
```

Figure 23. Source listing of subroutine COUNT.

```
      SUBROUTINE MCSUM(RCOEFF,AVGCOE,SPECX,SPECY,STATAX,
     1 STATAY,IAPER,JAPER,PXMC,PYMC,IFEED,JFEED,EXOFX,EXOFY,EYOFX,EYOFY
     1      ,HOLDER)
C
C   SUBROUTINE MCSUM IS RESPONSIBLE FOR THE STATISTICAL
C   ASPECTS OF THE CALCULATION.  IT CONTAINS TWO MAJOR
C   BRANCHES.  THESE BRANCHES DIFFER BY WHETHER VALUES
C   OF THE RANDOM VARIABLES ARE GENERATED AND WRITTEN
C   ON FILE ("IGEN"=1 BRANCH) OR READ FROM FILE ("IGEN"=0
C   BRANCH).
C
C   NEAR- OR FAR-FIELD AVERAGES OVER THE RANDOM VARIABLES
C   SELECTED IN THE INTERACTIVE PORTION OF THE PROGRAM
C   ARE CALCULATED AND APPROPRIATE AVERAGE NORMALIZED
C   FAR-FIELD POWER PATTERNS ARE WRITTEN.
C
      COMPLEX SPECX(IAPER,JAPER),SPECY(IAPER,JAPER),
     1        STATAX(IAPER,JAPER),STATAY(IAPER,JAPER)
     1   ,EXOFX(IFEED),EXOFY(JFEED),EYOFX(IFEED),EYOFY(JFEED),MAXSTA
     1   ,RCOEFF(8,8,2),AVGCOE(8,8,2),HOLDER(IAPER,JAPER)
      REAL AMODE(8,8,2),HEADER(25),HEADERB(25),COMDAT(12)
      REAL PXMC(IAPER,JAPER),PYMC(IAPER,JAPER)
      REAL MAX,MAXX,MAXY
      COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
      COMMON/APER/AAPER,BAPER
      COMMON/MODE/AMODE
      COMMON/RMODE/ICSETS,IGEN,ICDIST,IPHIRV,PHIDEV
      COMMON/RFREQ/IRV,IFDIST,IAVGFF,IFSETS
      COMMON/MAX/MAX,MAXX,MAXY
      COMMON/HEADER/HEADER
      COMMON/LOUT/LOUT
      COMMON/COMDAT/COMDAT
      REWIND 31
      ISETFC=ICSETS*IFSETS
      DO 100 IA=1,IAPER
        DO 100 JA=1,JAPER
          PXMC(IA,JA)=0.0
          PYMC(IA,JA)=0.0
  100 CONTINUE
C
      IF(IGEN.EQ.1) GO TO 200
C
      READ(31) HEADERB
      EPS=0.0001
      DO 105 I=8,22
        TEST=HEADERB(I)-HEADER(I)
        TEST=TEST**2
        IF(TEST.LT.EPS) GO TO 105
        WRITE(6,50)
   50   FORMAT(" *** DIFFERENT ANTENNAS, FREQUENCIES, OR APERTURES***"/
     1      "     ***ARE BEING USED WITH SAME SET OF RANDOM VARIABLES***")
        RETURN
  105 CONTINUE
      REWIND 15
C
C   THE FOLLOWING LOOP ENDS WITH THE SUMMATION OVER RANDOM FREQUENCY
C   AND/OR MODAL COEFFICIENT SETS OF THE N.F. OR F.F. POWERS.
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
C
      DO 112 IFMC=1,IFSETS
        READ(31)FREQI
        IF(LOUT.GE.1)WRITE(6,905)FREQI
        CALL COUNT(IMODE,AMODE,FREQI,RCOEFF)
        CALL CUTMODE(IFEED,JFEED,AMODE,FREQI,EXOFX,EXOFY,EYOFX,EYOFY)
C
C   FOR EACH FREQUENCY, THE MODAL PATTERN OF EACH ALLOWABLE
C   MODE IS CALCULATED AND WRITTEN ON TAPE29 AS DISCUSSED IN
C   SUBROUTINE REFLEC.
C
        CALL REFLEC(FREQI,SPECX,SPECY,IFEED,JFEED,IAPER,JAPER
     1    ,EXOFX,EXOFY,EYOFX,EYOFY,HOLDER)
        DO 110 IMC=1,ICSETS
          DO 170 IA=1,IAPER
            DO 170 JA=1,JAPER
              STATAX(IA,JA)=CMPLX(0.0,0.0)
              STATAY(IA,JA)=CMPLX(0.0,0.0)
  170     CONTINUE
          READ(31) RCOEFF
          IF(LOUT.LT.1) GO TO 265
          DO 270 K=1,2
          DO 270 N1=1,8
          DO 270 M1=1,8
            M=M1-1
            N=N1-1
            IF(AMODE(M1,N1,K).GT.-0.5)WRITE(6,910)RCOEFF(M1,N1,K),M,N,K
  270     CONTINUE
  265     CONTINUE
          REWIND 29
C
C   THE FOLLOWING LOOP ENDS WITH THE DETERMINISTIC N.F. OR F.F.
C   FOR THE SPECIFIC FREQUENCY AND MODAL COEFFICIENTS AS FORMED
C   BY SUMMING THE MODAL FIELDS OVER THE ALLOWABLE MODES.
C
          DO 115 K=1,2
          DO 115 N1=1,8
          DO 115 M1=1,8
            IF(AMODE(M1,N1,K).LT.-0.5) GO TO 115
            READ(29) SPECX,SPECY
            DO 120 IA=1,IAPER
              DO 120 JA=1,JAPER
                STATAX(IA,JA)=STATAX(IA,JA)+SPECX(IA,JA)*RCOEFF(M1,N1,K)
                STATAY(IA,JA)=STATAY(IA,JA)+SPECY(IA,JA)*RCOEFF(M1,N1,K)
  120       CONTINUE
  115     CONTINUE
          WRITE(15) STATAX,STATAY
C
C   DETERMINISTIC (NEAR OR FAR) FIELD WRITTEN FOR EACH MEMBER OF
C   MONTE CARLO SET
C
          DO 180 IA=1,IAPER
            DO 180 JA=1,JAPER
              PXMC(IA,JA)=PXMC(IA,JA)+REAL(STATAX(IA,JA))**2/ISETFC+
     1          AIMAG(STATAX(IA,JA))**2/ISETFC
              PYMC(IA,JA)=PYMC(IA,JA)+REAL(STATAY(IA,JA))**2/ISETFC+
     1          AIMAG(STATAY(IA,JA))**2/ISETFC
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
C
C   AVERAGE POWER PATTERN (NEAR OR FAR) FOR MONTE CARLO SET
C
  180       CONTINUE
  110     CONTINUE
  112 CONTINUE
      REWIND 15
      IF (ICSETS.EQ.1) GO TO 306
      DO 300 IA=1,IAPER
        DO 300 JA=1,JAPER
          STATAX(IA,JA)=CMPLX(0.0,0.0)
          STATAY(IA,JA)=CMPLX(0.0,0.0)
  300 CONTINUE
      READ(31) AVGCOE
      IF(LOUT.LT.1) GO TO 245
      DO 250 K=1,2
      DO 250 N1=1,8
      DO 250 M1=1,8
        M=M1-1
        N=N1-1
        IF(AMODE(M1,N1,K).GT.-0.5)WRITE(6,915)AVGCOE(M1,N1,K),M,N,K
  250 CONTINUE
  245 CONTINUE
      REWIND 29
      DO 305 K=1,2
      DO 305 N1=1,8
      DO 305 M1=1,8
        IF(AMODE(M1,N1,K).LT.-0.5) GO TO 305
        READ(29) SPECX,SPECY
        DO 310 IA=1,IAPER
          DO 310 JA=1,JAPER
            STATAX(IA,JA)=STATAX(IA,JA)+SPECX(IA,JA)*AVGCOE(M1,N1,K)
            STATAY(IA,JA)=STATAY(IA,JA)+SPECY(IA,JA)*AVGCOE(M1,N1,K)
C
C   STATAX(Y) ABOVE IS MONTE CARLO FIELD AVERAGED OVER COEFFICIENTS.
C   THIS IS STILL A DETERMINISTIC QUANTITY CORRESPONDING TO
C   ILLUMINATION BY THE AVERAGE COEFFICIENT IN EACH MODE.
C
  310   CONTINUE
  305 CONTINUE
  306 CONTINUE
      IF(IFSETS.EQ.1) GO TO 330
      GO TO 311
C
C
C   THE CALCULATIONS ABOVE ARE REPRODUCED BELOW WITH THE INTERNAL
C   GENERATION OF THE RANDOM VARIABLES.
C
C
  200 WRITE(31) HEADER
      REWIND 13
C
C   THE FOLLOWING LOOP ENDS WITH THE SUMMATION OVER RANDOM FREQUENCY
C   AND/OR MODAL COEFFICIENT SETS OF THE N.F. OR F.F. POWERS.
C
      DO 147 IFMC=1,IFSETS
        CALL FRANDOM(FREQI)
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
          IF(IFSETS.EQ.1) FREQI=FREQ
          WRITE(31) FREQI
          IF(LOUT.GE.1)WRITE(6,905)FREQI
  905     FORMAT(/" FOR A FREQUENCY OF",E10.4)
          CALL COUNT(IMODE,AMODE,FREQI,RCOEFF)
          CALL CUTMODE(IFEED,JFEED,AMODE,FREQI,EXOFX,EXOFY,EYOFX,EYOFY)
C
C   FOR EACH FREQUENCY, THE MODAL PATTERNS OF EACH ALLOWABLE
C   MODE IS CALCULATED AND WRITTEN ON TAPE29 AS DISCUSSED IN
C   SUBROUTINE REFLEC.
C
          CALL REFLEC(FREQI,SPECX,SPECY,IFEED,JFEED,IAPER,JAPER
     1     ,EXOFX,EXOFY,EYOFX,EYOFY,HOLDER)
          DO 150 K=1,2
          DO 150 N1=1,8
          DO 150 M1=1,8
  150     AVGCOE(M1,N1,K)=CMPLX(0.0,0.0)
          DO 145 IMC=1,ICSETS
            DO 175 IA=1,IAPER
              DO 175 JA=1,JAPER
                STATAX(IA,JA)=CMPLX(0.0,0.0)
                STATAY(IA,JA)=CMPLX(0.0,0.0)
  175       CONTINUE
C
C   IF ONLY FREQUENCY AVERAGING IS USED (IRV=1), THEN
C   A STANDARD SET OF MODAL COEFFICIENTS IS USED (RCOEFF
C   AS READ FROM TAPE11) OTHERWISE THE NON-ZERO VALUES IN RCOEFF
C   (AS READ FROM TAPE11) ARE RANDOMIZED BY CRANDOM
C
            IF(IRV.EQ.1) GO TO 410
            CALL CRANDOM(RCOEFF,AMODE)
  410       CONTINUE
        WRITE(31)RCOEFF
        IF(LOUT.LT.1) GO TO 225
        DO 230 K=1,2
        DO 230 N1=1,8
        DO 230 M1=1,8
              M=M1-1
              N=N1-1
              IF(AMODE(M1,N1,K).GT.-0.5)WRITE(6,910)RCOEFF(M1,N1,K),M,N,K
  230       CONTINUE
  225       CONTINUE
  910       FORMAT(" THE MODAL COEFFICIENTS ARE",2E11.4," M=",I2," N=",I2,
     1        " TE,TM=",I2)
            REWIND 29
C
C   THE FOLLOWING LOOP ENDS WITH THE DETERMINISTIC N.F. OR F.F.
C   FOR THE SPECIFIC FREQUENCY AND MODAL COEFFICIENTS AS FORMED
C   BY SUMMING THE MODAL FIELDS OVER THE ALLOWABLE MODES.
C
            DO 135 K=1,2
            DO 135 N1=1,8
            DO 135 M1=1,8
              IF(AMODE(M1,N1,K).LT.-0.5) GO TO 135
C
C   FOR EACH ALLOWABLE MODE, FORM SUM OF COMPLEX COEFFICIENTS.
C
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
                AVGCOE(M1,N1,K)=AVGCOE(M1,N1,K)+RCOEFF(M1,N1,K)
                READ(29) SPECX,SPECY
                DO 140 IA=1,IAPER
                  DO 140 JA=1,JAPER
                    STATAX(IA,JA)=STATAX(IA,JA)+SPECX(IA,JA)*RCOEFF(M1,N1,K)
                    STATAY(IA,JA)=STATAY(IA,JA)+SPECY(IA,JA)*RCOEFF(M1,N1,K)
  140           CONTINUE
  135         CONTINUE
              WRITE(15) STATAX,STATAY
C
C   DETERMINISTIC (NEAR OR FAR) FIELD WRITTEN FOR EACH MEMBER OF
C   MONTE CARLO SET
C
C
C   PXMC(IA,JA)=SUM(EX(IA,JA)**2)/ISETFC -SIMILIARLY FOR PYMC
C
              DO 185 IA=1,IAPER
                DO 185 JA=1,JAPER
                  PXMC(IA,JA)=PXMC(IA,JA)+REAL(STATAX(IA,JA))**2/ISETFC+
     1               AIMAG(STATAX(IA,JA))**2/ISETFC
                  PYMC(IA,JA)=PYMC(IA,JA)+REAL(STATAY(IA,JA))**2/ISETFC+
     1               AIMAG(STATAY(IA,JA))**2/ISETFC
C
C   AVERAGE POWER PATTERN (NEAR OR FAR) FOR MONTE CARLO SET
C
  185         CONTINUE
  145       CONTINUE
  147 CONTINUE
      REWIND 15
      IF (ICSETS.EQ.1) GO TO 321
      DO 312 K=1,2
      DO 312 N1=1,8
      DO 312 M1=1,8
  312 AVGCOE(M1,N1,K)=AVGCOE(M1,N1,K)/ICSETS
      WRITE(31) AVGCOE
      IF(LOUT.LT.1) GO TO 235
      DO 240 K=1,2
      DO 240 N1=1,8
      DO 240 M1=1,8
        M=M1-1
        N=N1-1
        IF(AMODE(M1,N1,K).GT.-0.5)WRITE(6,915)AVGCOE(M1,N1,K),M,N,K
  240 CONTINUE
  235 CONTINUE
  915 FORMAT(/" AVERAGE COEFFICIENT IS",2E11.4," FOR M=",I2,
     1   " N=",I2,," TE,TM=",I2)
      DO 315 IA=1,IAPER
        DO 315 JA=1,JAPER
          STATAX(IA,JA)=CMPLX(0.0,0.0)
          STATAY(IA,JA)=CMPLX(0.0,0.0)
  315 CONTINUE
      REWIND 29
      DO 398 K=1,2
      DO 398 N1=1,8
      DO 398 M1=1,8
        IF(AMODE(M1,N1,K).LT.-0.5) GO TO 398
        READ(29) SPECX,SPECY
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
            DO 320 IA=1,IAPER
              DO 320 JA=1,JAPER
                STATAX(IA,JA)=STATAX(IA,JA)+SPECX(IA,JA)*AVGCOE(M1,N1,K)
                STATAY(IA,JA)=STATAY(IA,JA)+SPECY(IA,JA)*AVGCOE(M1,N1,K)
C
C    STATAX(Y) ABOVE IS MONTE CARLO FIELD AVERAGED OVER COEFFICIENTS.
C    THIS IS STILL A DETERMINISTIC QUANTITY CORRESPONDING TO
C    ILLUMINATION BY THE AVERAGE COEFFICIENT IN EACH MODE.
C
  320     CONTINUE
  398 CONTINUE
  321 CONTINUE
      IF(IFSETS.EQ.1) GO TO 330
  311 DO 815 IA=1,IAPER
        DO 815 JA=1,JAPER
          STATAX(IA,JA)=CMPLX(0.0,0.0)
          STATAY(IA,JA)=CMPLX(0.0,0.0)
  815 CONTINUE
      DO 810 IFMC=1,IFSETS
        READ(15) SPECX,SPECY
        DO 820 IA=1,IAPER
          DO 820 JA=1,JAPER
            STATAX(IA,JA)=STATAX(IA,JA)+SPECX(IA,JA)/IFSETS
            STATAY(IA,JA)=STATAY(IA,JA)+SPECY(IA,JA)/IFSETS
C
C    MONTE CARLO FREQUENCY AVERAGE OF NEAR OR FAR FIELD PATTERN,
C    NOT DETERMINISTIC.
C
  820     CONTINUE
  810 CONTINUE
      REWIND 15
  330 CONTINUE
      REWIND 33
      COMDAT(12)=IAVGFF
      WRITE(6,920)
  920 FORMAT(/" FOR MONTE CARLO AVERAGED FIELD")
      CALL NORMIM(STATAX,STATAY,IAPER,JAPER,MAXSTA)
      WRITE(33)COMDAT
      WRITE(33)STATAX
      WRITE(33)STATAY
      DO 472 IA=1,IAPER
        DO 472 JA=1,JAPER
          STATAX(IA,JA)=STATAX(IA,JA)*MAXSTA
          STATAY(IA,JA)=STATAY(IA,JA)*MAXSTA
  472 CONTINUE
C
C    MONTE CARLO AVERAGE FIELD IS WRITTEN.DETERMINISTIC IF NO
C    FREQUENCY AVERAGING IS EMPLOYED
C
      REWIND 35
      WRITE(6,925)
  925 FORMAT(/" FOR MONTE CARLO AVERAGED POWER")
      CALL NORMXY(PXMC,PYMC,IAPER,JAPER)
      WRITE(35)COMDAT
      WRITE(35)PXMC
      WRITE(35)PYMC
      DO 470 IA=1,IAPER
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
          DO 470 JA=1,JAPER
            PXMC(IA,JA)=PXMC(IA,JA)*MAX
            PYMC(IA,JA)=PYMC(IA,JA)*MAX
  470 CONTINUE
      REWIND 29
      REWIND 31
      REWIND 33
      REWIND 35
      IF(IAVGFF.EQ.0) GO TO 199
      RETURN
  199 CONTINUE
      SDXSQ=0.0
      SDYSQ=0.0
      DO 204 IA=1,IAPER
        DO 204 JA=1,JAPER
          SDXSQ=SDXSQ+PXMC(IA,JA)-REAL(STATAX(IA,JA))**2
     1           -AIMAG(STATAX(IA,JA))**2
          SDYSQ=SDYSQ+PYMC(IA,JA)-REAL(STATAY(IA,JA))**2
     1           -AIMAG(STATAY(IA,JA))**2
C
C   ANGLE INDEPENDENT STANDARD DEVIATION OF SPECTRUM
C
  204 CONTINUE
      SDXSQ=SDXSQ/IAPER/JAPER
      SDYSQ=SDYSQ/IAPER/JAPER
C
C   THE FFT SUBROUTINE HAS NORMALIZATION 1/SQRT(IAPER*JAPER) IN
C   TRANSFORM AND INVERSE TRANSFORM. NORMALIZATION OF STANDARD
C   DEVIATIONS MUST BE CONSISTENT WITH THIS.
C
C
C   SUBROUTINE FFTDOUB USES THE FFT IN A LESS THAN STRAIGHTFORWARD
C   MANNER TO PRODUCE GREATER RESOLUTION IN THE BORESIGHT DIRECTION.
C   DELKX AND DELKY ARE HALF WHAT THEY WOULD BE FOR THE FFT.
C
      CALL FFTDOUB(STATAX,HOLDER,IAPER,JAPER,-1)
      CALL FFTDOUB(STATAY,HOLDER,IAPER,JAPER,-1)
      C=29.979
      COMDAT(7)=-0.25*C*IAPER/AAPER/FREQ
      COMDAT(8)=0.5*C/AAPER/FREQ
      COMDAT(10)=-0.25*C*JAPER/BAPER/FREQ
      COMDAT(11)=0.5*C/BAPER/FREQ
C
C     CALL FFT(STATAX,IAPER,JAPER,-1)
C     CALL FFT(STATAY,IAPER,JAPER,-1)
      DO 205 IA=1,IAPER
        DO 205 JA=1,JAPER
          PXMC(IA,JA)=REAL(STATAX(IA,JA))**2+AIMAG(STATAX(IA,JA))**2
          PYMC(IA,JA)=REAL(STATAY(IA,JA))**2+AIMAG(STATAY(IA,JA))**2
  205 CONTINUE
C
C   FOR THE CASE OF N.F. AVERAGING, THE APPROXIMATE STATISTICAL
C   F.F. SPECTRAL POWER PATTERN IS DERIVED (ABOVE) AS THE SQUARE
C   MAGNITUDE OF THE FFT OF THE MONTE CARLO AVERAGED NEAR-FIELD.
C
      WRITE(6,930)
  930 FORMAT(/" FOR FAR-FIELD POWER DERIVED FROM M.C. AVERAGED N.F.")
```

Figure 24. Source listing of subroutine MCSUM (continued).

```
      CALL NORMXY(PXMC,PYMC,IAPER,JAPER)
      SDXSQ=SDXSQ/MAX
      SDYSQ=SDYSQ/MAX
      DBSDX=10.0*ALOG10(SDXSQ)
      DBSDY=10.0*ALOG10(SDYSQ)
      DBMAXX=10.0*ALOG10(MAXX/MAX)
      DBMAXY=10.0*ALOG10(MAXY/MAX)
      REWIND 13
      COMDAT(12)=1
      WRITE(13)COMDAT
      WRITE(13)PXMC
      WRITE(13)PYMC
      REWIND 13
      WRITE(6,549)SDXSQ,SDYSQ
      WRITE(6,550)DBSDX,DBSDY,DBMAXX,DBMAXY
  549 FORMAT(///"   THE ANGLE INDEPENDENT STANDARD DEVIATIONS"/
     1 "   TO BE APPLIED TO THE FAR FIELD PATTERNS"/
     1 "   CALCULATED FROM NF AVERAGES ARE",2E14.6/)
  550 FORMAT(24X,"X",12X,"Y"/
     1 " STANDARD DEVIATION",2E13.4,"DB"/
     1 " POWER MAXIMUM     ",2E13.4,"DB")
      RETURN
      END
```

Figure 24. Source listing of subroutine MCSUM.

```
        SUBROUTINE CUTMODE(IFEED,JFEED,AMODE,FREQI,EXOFX,EXOFY,EYOFX,
       1 EYOFY)
C
C   SUBROUTINE CUTMODE CALCULATES THE X AND Y COMPONENTS OF
C   THE FIELD ON PRINCIPLE PLANE CUTS IN THE FEED HORN
C   APERTURE FOR THE MODES TO BE USED IN THE CALCULATION.
C
C   THE MODAL PATTERNS IN A RECTANGULAR WAVE-GUIDE ARE
C   SEPARABLE IN X AND Y WHERE THE SIDES OF THE WAVE-GUIDE
C   ARE PARALLEL TO THE X AND Y AXES.  THE FLARE OF THE
C   FEED HORN INTRODUCES A PHASE TAPER IN THE DIMENSION FLARED.
C
C   NOTE THAT MODAL PATTERNS ARE INDEPENDENT OF FREQUENCY
C   EXCEPT IN THE PHASE TAPER TERMS.
C
        DIMENSION AMODE(8,8,2),COMDAT(12)
        COMPLEX EXOFX(IFEED),EXOFY(JFEED),EYOFX(IFEED),EYOFY(JFEED)
        COMMON/FEED/AFEED,BFEED,HORLEN
        COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
        COMMON/LOUT/LOUT
        COMMON/COMDAT/COMDAT
        PI=2.0*ACOS(0.0)
        REWIND 25
C
C   IF THE FEED HORN FLARES IN X OR Y THEN THERE IS
C   A NON-ZERO PHASE TAPER IN THAT DIRECTION.
C
        EPS=0.0001
        AG=AGUIDE+EPS
        BG=BGUIDE+EPS
        AK0=2.0*PI*FREQI/29.979
        TAPEX=0.0
        TAPEY=0.0
        IF(HORLEN.LT.EPS) GO TO 105
        IF(AFEED.GT.AG)TAPEX=0.5*AK0/HORLEN
        IF(BFEED.GT.BG)TAPEY=0.5*AK0/HORLEN
  105   CONTINUE
C
C   CALCULATE CUTS THROUGH MODAL PATTERNS FOR TE MODES
C
        DO 10 N1=1,8
          DO 20 M1=1,8
C
C   TEST TO DETERMINE IF MODE IS ALLOWED
C
            IF (AMODE(M1,N1,1).LT.-0.5) GO TO 20
            M=M1-1
            DO 15 I=1,IFEED
              XRAD=PI*(I-1)/IFEED
              FACTOR=-TAPEX*((I-1-IFEED/2)*AFEED/IFEED)**2
              EXOFX(I)=COS(M*XRAD)*CMPLX(COS(FACTOR),SIN(FACTOR))
              EYOFX(I)=M*PI*SIN(M*XRAD)/AFEED*CMPLX(COS(FACTOR)
       1        ,SIN(FACTOR))
  15        CONTINUE
            FACTOR=-TAPEX*(AFEED/2.0)**2
            EXOFX(1)=0.5*(1.0+COS(M*PI))*CMPLX(COS(FACTOR),SIN(FACTOR))
            N=N1-1
            DO 25 J=1,JFEED
```

Figure 25. Source listing of subroutine CUTMODE (continued).

```
                YRAD=PI*(J-1)/JFEED
                FACTOR=-TAPEY*((J-1-JFEED/2)*BFEED/JFEED)**2
                EXOFY(J)=N*PI*SIN(N*YRAD)/BFEED*CMPLX(COS(FACTOR)
     1            ,SIN(FACTOR))
                EYOFY(J)=COS(N*YRAD)*CMPLX(COS(FACTOR),SIN(FACTOR))
   25         CONTINUE
              FACTOR=-TAPEY*(BFEED/2.0)**2
              EYOFY(1)=0.5*(1.0+COS(N*PI))*CMPLX(COS(FACTOR),SIN(FACTOR))
              WRITE(25) EXOFX,EXOFY,EYOFX,EYOFY
   20       CONTINUE
   10     CONTINUE
C
C   CALCULATE CUTS THROUGH MODAL PATTERN FOR TM MODES
C
          DO 30 N1=2,8
            DO 40 M1=2,8
C
C   TEST TO DETERMINE IF MODE IS ALLOWED
              IF (AMODE(M1,N1,2).LT.-0.5) GO TO 40
              M=M1-1
              DO 35 I=1,IFEED
                XRAD=PI*(I-1)/IFEED
                FACTOR=-TAPEX*((I-1-IFEED/2)*AFEED/IFEED)**2
                EXOFX(I)=M*PI*COS(M*XRAD)/AFEED*CMPLX(COS(FACTOR)
     1            ,SIN(FACTOR))
                EYOFX(I)=SIN(M*XRAD)*CMPLX(COS(FACTOR),SIN(FACTOR))
   35         CONTINUE
              FACTOR=-TAPEX*(AFEED/2.0)**2
              EXOFX(1)=0.5*M*PI*(1.0+COS(M*PI))*CMPLX(COS(FACTOR)
     1            ,SIN(FACTOR))
              N=N1-1
              DO 45 J=1,JFEED
                YRAD=PI*(J-1)/JFEED
                FACTOR=-TAPEY*((J-1-JFEED/2)*BFEED/JFEED)**2
                EXOFY(J)=SIN(N*YRAD)*CMPLX(COS(FACTOR),SIN(FACTOR))
                EYOFY(J)=N*PI*COS(N*YRAD)/BFEED*CMPLX(COS(FACTOR)
     1            ,SIN(FACTOR))
   45         CONTINUE
              FACTOR=-TAPEY*(BFEED/2.0)**2
              EYOFY(1)=0.5*N*PI*(1.0+COS(N*PI))*CMPLX(COS(FACTOR)
     1            ,SIN(FACTOR))
              WRITE(25) EXOFX,EXOFY,EYOFX,EYOFY
   40       CONTINUE
   30     CONTINUE
C
C   THE CUTS THROUGH MODAL PATTERNS FOR ALLOWABLE MODES
C   HAVE BEEN WRITTEN ON TAPE 25(SPEC10) IN THE ORDER
C   THAT THE ALLOWABLE MODES OCCUR WITHIN THE "NORMAL"
C   DO LOOP SEQUENCE:
C             DO K=1,2
C             DO N1=1,8
C             DO M1=1,8
C
          FACTORX=-TAPEX*(AFEED/2.0)**2*180.0/PI
          FACTORY=-TAPEY*(BFEED/2.0)**2*180.0/PI
          IF(LOUT.GE.2)WRITE(6,106)FACTORX,FACTORY
  106     FORMAT(" THE MAX PHASE TAPER(DEG) IN THE H-,E-PLANES IS ",2E11.4)
          RETURN
          END
```

Figure 25. Source listing of subroutine CUTMODE.

```
      SUBROUTINE FRANDOM(FREQI)
C
C   SUBROUTINE FRANDOM RETURNS A RANDOM VALUE OF THE
C   FREQUENCY BETWEEN THE VALUES "FREQ-DELFREQ" AND
C   "FREQ + DELFREQ".  THE RANDOMNESS IS INTRODUCED
C   THROUGH THE SYSTEM SUBROUTINE "RANF" CALLED FROM
C   SUBROUTINE "UNIFOR" OR "GAUSR".  THE CALLS OF
C   SYSTEM "CLOCK" AND "RANSET" PROVIDE THE KERNAL
C   FOR "RANF".
C
      COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
      COMMON/RFREQ/IRV,IFDIST,IAVGFF,IFSETS
      DATA R1/00000000000000000001B/
      CALL CLOCK(INS)
      INS=OR(R1,INS)
      CALL RANSET(INS)
      FREQMAX=FREQ+DELFREQ
      FREQMIN=FREQ-DELFREQ
    1 IF(IFDIST.GT.1) GO TO 2
      CALL UNIFOR(FREQI,FREQ,DELFREQ)
C
C   FREQI DISTRIBUTED UNIFORMLY BETWEEN
C   FREQ-DELFREQ AND FREQ + DELFREQ.
C
      GO TO 7
    2 IF(IFDIST.GT.2) GO TO 3
      CALL GAUSR(X)
      FREQI=FREQ+X*DELFREQ*0.5
C
C   FREQI GAUSSIAN DISTRIBUTED ABOUT "FREQ" WITH
C   STANDARD DEVIATION DELFREQ/2.  DEVIATIONS GREATER
C   THAN TWO STANDARD DEVIATIONS ARE NOT ALLOWED.
C
    3 CONTINUE
C
C   ADDITIONAL FREQUENCY DISTRIBUTIONS CAN
C   BE INCORPORATED IN THE PROGRAM HERE.
C
    7 CONTINUE
      IF(FREQI.GT.FREQMAX.OR.FREQI.LT.FREQMIN) GO TO 1
      RETURN
      END
```

Figure 26. Source listing of subroutine FRANDOM.

```
      SUBROUTINE CRANDOM(RCOEFF,AMODE)
C
C   SUBROUTINE CRANDOM GENERATES A SET OF COMPLEX
C   MODAL COEFFICIENTS FOR THE MODES USED IN THE
C   CALCULATION.  RANDOMNESS IS INTRODUCED IN THE
C   SAME MANNER AS IN SUBROUTINE FRANDOM.
C
C   MODE DEPENDENT COEFFICIENT DISTRIBUTIONS ARE ALLOWABLE
C
      COMPLEX RCOEFF(8,8,2)
      REAL AMODE(8,8,2)
      COMMON/RMODE/ICSETS,IGEN,ICDIST,IPHIRV,PHIDEV
      COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
      COMMON/RFREQ/IRV,IFDIST,IAVGFF,IFSETS
      DATA R1/000000000000000000001B/
      IF(IRV.EQ.1) RETURN
C
C   NOTE THAT THE ABSOLUTE MAGNITUDE OF THE AMPLITUDE AND THE
C   ZERO PHASE REFERENCE ARE ARBITRARY
C
      PI=2.0*ACOS(0.0)
      DEVRAD=PHIDEV*PI/180.0
      CALL CLOCK(INS)
      INS=OR(R1,INS)
      CALL RANSET(INS)
      DO 100 K=1,2
      DO 100 N1=1,8
      DO 100 M1=1,8
        IF(AMODE(M1,N1,K).LT.-0.5) GO TO 100
    1   IF(ICDIST.GT.1) GO TO 2
        CALL UNIFOR(AMPCOE,1.0,1.0)
C
C   AMPLITUDE OF MODAL COEFFICIENTS UNIFORMLY DISTRIBUTED
C   OVER INTERVAL (0.0,2.0) FOR ICDIST=1
C
        GO TO 7
    2   IF(ICDIST.GT.2) GO TO 3
        CALL GAUSR(X)
        AMPCOE=1.0+X*0.5
        IF(AMPCOE.LT.0.0) GO TO 2
C
C   FOR ICDIST=2, AMPLITUDE OF MODAL COEFFICIENTS OBEY GAUSSIAN
C   DISTRIBUTION WITH MEAN 1.0 AND STANDARD DEVIATION=0.5,
C   NEGATIVE AMPLITUDES REJECTED
C
        GO TO 7
    3   IF(ICDIST.GT.3) GO TO 4
        CALL UNIFOR(AMPCOE,1.0,1.0)
        AMPCOE=AMPCOE/M1/N1
C
C   FOR ICDIST=3, AMPLITUDE OF M,N MODAL COEFFICIENT IS
C   DISTRIBUTED AS "RV"/(M+1)/(N+1) WHERE "RV" IS UNIFORMLY
C   DISTRIBUTED OVER THE INTERVAL (0.0,2.0)
C
    4   CONTINUE
C
C   ADDITIONAL AMPLITUDE DISTRIBUTIONS CAN BE INCORPORATED
```

Figure 27. Source listing of subroutine CRANDOM (continued).

```
C   IN THE PROGRAM HERE.
C
  7     CONTINUE
        IF(IPHIRV.GT.1) GO TO 12
        CALL UNIFOR(PHICOE,0.0,DEVRAD)
C
C   PHASE OF MODAL COEFFICIENTS UNIFORMLY DISTRIBUTED
C   OVER INTERVAL (-PHIDEV,PHIDEV) FOR IPHIRV=1
C
        GO TO 17
  12    IF(IPHIRV.GT.2) GO TO 13
        CALL GAUSR(X)
        PHICOE=X*DEVRAD
C
C   PHIDEV=ONE STANDARD DEVIATION. PHASE OF MODAL COEFFICIENTS
C   IS GAUSSIAN DISTRIBUTED ABOUT ZERO FOR IPHIRV=2
C
        GO TO 17
  13    CONTINUE
C
C   ADDITIONAL PHASE DISTRIBUTIOMS CAN BE INCORPORATED IN
C   THE PROGRAM HERE.
C
  17    CONTINUE
        RCOEFF(M1,N1,K)=AMPCOE*CMPLX(COS(PHICOE),SIN(PHICOE))
  100 CONTINUE
      RETURN
      END
```

Figure 27. Source listing of subroutine CRANDOM.

```
      SUBROUTINE UNIFOR(RV,CENTER,SPREAD)
C
C    SUBROUTINE UNIFOR RETURNS A RANDOM VALUE "RV"
C    UNIFORMLY DISTRIBUTED BETWEEN "CENTER + SPREAD"
C    AND "CENTER-SPREAD".
C
      RAN=RANF(RV)
C
C    RAN IS PURPORTLY DISTRIBUTED RANDOMLY OVER THE
C    INTERVAL (0.0,1.0)
C
      RV=CENTER+2.0*SPREAD*(RAN-0.5)
      RETURN
      END
```

```
      SUBROUTINE GAUSR(XSUBP)
C
C    THIS ROUTINE COMPUTES A RANDOM GAUSSIAN DISTRIBUTED NUMBER
C    (XSUBP). THE MEAN=0.0 AND THE STANDARD DEVIATION=1.0 FROM
C    HANDBOOK OF MATHEMATICAL FUNCTIONS, NATIONAL BUREAU OF
C    STANDARDS, APPLIED MATHEMATICS SERIES 55, PAGE 933 SECT. 26.223
C
      REAL NUM
      DATA C0,C1,C2,D1,D2,D3/2.515517,0.802853,0.010328,1.432788,
     1 0.189269,0.001308/
      RAN=RANF(XSUBP)
C
C    RAN IS PURPORTLY DISTRIBUTED RANDOMLY OVER THE
C    INTERVAL (0.0,1.0)
C
      RNM1=RAN-0.5
      IF(RNM1) 10,20,30
   10 T=SQRT(-2.0*ALOG(RAN))
      NUM=C0+T*(C1+T*C2)
      DENOM=1.0+T*(D1+T*(D2+T*D3))
      XSUBP=T-NUM/DENOM
      RETURN
   20 XSUBP=0.0
      RETURN
   30 RAN=1.0-RAN
      T=SQRT(-2.0*ALOG(RAN))
      NUM=C0+T*(C1+T*C2)
      DENOM=1.0+T*(D1+T*(D2+T*D3))
      XSUBP=NUM/DENOM-T
      RETURN
      END
```

Figure 28. Source listing of subroutines UNIFOR and GAUSR.

```
      SUBROUTINE REFLEC(FREQI,SPECX,SPECY,IFEED,JFEED,IAPER,JAPER
     1   ,EXOFX,EXOFY,EYOFX,EYOFY,HOLDER)
C
C   SUBROUTINE REFLEC PERFORMS THE PRINCIPLE
C   DETERMINISTIC PORTIONS OF THE CALCULATION.
C   SPECIFICALLY THE VALUES OF THE DIRECTION
C   COSINES ABOUT THE FEED HORN SUCH THAT RAYS
C   IN THESE DIRECTIONS WILL BE REFLECTED BY THE
C   PARABALOID ONTO A RECTANGULAR GRID IN THE
C   APERTURE ARE CALCULATED.  THE FAR-FIELD OF THE
C   FEED HORN FOR THESE VALUES OF "KXAPER" AND
C   "KYAPER" IS CALCULATED BY 1-D FOURIER INTEGRALS
C   OVER THE SEPARABLE FEED HORN FIELD.
C   THE CALCULATION IS A VECTOR CALCULATION.
C   IF FAR-FIELD AVERAGES ARE BEING CALCULATED,
C   THE APERTURE FIELD IS FOURIER TRANSFORMED.
C
      COMPLEX SPECX(IAPER,JAPER),SPECY(IAPER,JAPER),
     1  CEX,CSUM11,CSUM12,CSUM21,CSUM22,HOLDER(IAPER,JAPER)
      COMPLEX EXOFX(IFEED),EXOFY(JFEED),EYOFX(IFEED),EYOFY(JFEED)
      REAL K0,K0SQ,KR,KXAPER,KXASQ,KYAPER,KYASQ
      REAL AMODE(8,8,2),COMDAT(12)
      COMMON/GUIDE/AGUIDE,BGUIDE,FREQ,DELFREQ
      COMMON/MODE/AMODE
      COMMON/FEED/AFEED,BFEED,HORLEN
      COMMON/ZMOVE/ZMOVE
      COMMON/APER/AAPER,BAPER
      COMMON/PARAB/FOCUS,RMAX,THETAM
      COMMON/LOUT/LOUT
      COMMON/COMDAT/COMDAT
      COMMON/RFREQ/IRV,IFDIST,IAVGFF,IFSETS
      PI=2.0*ACOS(0.0)
      TPI=2.0*PI
      RLAM=29.979/FREQI
      K0=TPI/RLAM
      K0SQ=K0*K0
      REWIND 25
      REWIND 29
      FFFACT=1.0
      IF(IAVGFF.EQ.1)FFFACT=FREQ/FREQI
C
C   THIS ACCOUNTS FOR SAME NUMERICAL KX,KY CORRESPONDING TO
C   DIFFERENT VALUES OF KX/K0,KY/K0 (=FAR-FIELD DIRECTION
C   COSINES) AT DIFFERENT FREQUENCIES. IT IS ONLY APPROPRIATE
C   TO MAKE THIS CORRECTION FOR FAR-FIELD AVERAGES. FOR THE
C   NEAR-FIELD AVERAGES IT IS IMPORTANT THAT THE APERTURE POINTS
C   BE THE SAME.
C
      DELXAP=AAPER*FFFACT/IAPER
      DELYAP=BAPER*FFFACT/JAPER
      DELXF=AFEED/IFEED
      DELYF=BFEED/JFEED
      DO 95 IA1=1,IAPER
        DO 95 JA1=1,JAPER
          SPECX(IA1,JA1)=CMPLX(0.0,0.0)
          SPECY(IA1,JA1)=CMPLX(0.0,0.0)
   95 CONTINUE
```

Figure 29. Source listing of subroutine REFLEC (continued).

```
      DO 100 K=1,2
      DO 100 N1=1,8
      DO 100 M1=1,8
        IF(AMODE(M1,N1,K).LT.-0.5) GO TO 100
C
C   THE PRINCIPLE PLANE CUTS FOR X AND Y COMPONENTS OF
C   EACH ALLOWABLE MODE ARE READ.
C
        READ(25) EXOFX,EXOFY,EYOFX,EYOFY
        DO 150 IA1=1,IAPER
          IA=IA1-1-IAPER/2
          DO 150 JA1=1,JAPER
            JA=JA1-1-JAPER/2
            RAPER=SQRT((IA*DELXAP)**2+(JA*DELYAP)**2)
C
C   THE SET OF VALUES TAKEN BY "RAPER" ARE THE DISTANCES
C   FROM THE CENTER OF THE APERTURE PLANE TO THE POINTS
C   OF THE RECTANGULAR APERTURE GRID SPECIFIED BY THE USER.
C
            IF(RAPER.GT.RMAX)GO TO 150
            TEMP=4.0*FOCUS/(RAPER**2+4.0*FOCUS**2)
C
C   THE FOLLOWING K'S ARE NORMALIZED VIA DIVISION BY K0.
C   THEY ARE THE DIRECTION COSINES, AS MEASURED FROM THE
C   FOCAL POINT, OF THE POINTS ON THE SURFACE OF THE
C   PARABALOIDAL REFLECTOR CORRESPONDING TO THE POINTS
C   OF THE RECTANGULAR APERTURE GRID. NOTE THAT THE
C   PARABALOID REFLECTS RAYS FROM THE FOCUS ALONG LINES
C   PARALLEL TO THE Z-AXIS.
C
C   THE SPECTRUM OF THE FEED HORN FOR THESE VALUES OF
C   "KXAPER" AND "KYAPER" IS CALCULATED AS THE PRODUCT
C   OF THE ONE-DIMENSIONAL DISCRETE FOURIER TRANSFORM
C   OF THE PRINCIPAL PLANE CUTS FOR EACH COMPONENT OF
C   THE FEED FIELD.
C
            KXAPER=TEMP*DELXAP*IA
            KYAPER=TEMP*DELYAP*JA
            KXASQ=KXAPER**2
            KYASQ=KYAPER**2
            THETA=ASIN(SQRT(KXASQ+KYASQ))
            RPARA=2.0*FOCUS/(1.0+COS(THETA))
            IAJA=IA**2+JA**2
            PHI=0.0
            IF(IAJA.NE.0) PHI=ATAN2(KYAPER,KXAPER)
            CSUM11=CMPLX(0.0,0.0)
            CSUM21=CMPLX(0.0,0.0)
C
C   IN ORDER TO EVEN UP THE DISCRETE FOURIER
C   TRANSFORM -AND TAKING ADVANTAGE OF THE
C   EXPLICIT FORMS OF THE MODAL FIELDS-
C   MODIFICATIONS OF THE FIRST TERMS OF THE SUMS
C   INVOLING EXOFX AND EYOFY ARE MADE
C
            DO 170 IF1=1,IFEED
              IF=IF1-1-IFEED/2
              CEX=CEXP(CMPLX(0.0,-KXAPER*K0*IF*DELXF))
```

Figure 29. Source listing of subroutine REFLEC (continued).

AD-A099 896   GEORGIA INST OF TECH ATLANTA ENGINEERING EXPERIMENT --ETC F/G 20/14
OUT-OF-BAND REFLECTOR ANTENNA MODEL.(U)
MAY 81 T B WELLS, C E RYAN   DAAG29-80-C-0083
UNCLASSIFIED   GIT/EES-A-2610   ARO-17033.1-EL-A   NL

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```
                   IF(IF1.EQ.1)CEX=CMPLX(COS(KXAPER*K0
     1             *IF*DELXF),0.0)
                   CSUM11=CSUM11+EXOFX(IF1)*CEX
                   CSUM21=CSUM21+EYOFX(IF1)*CEX
  170           CONTINUE
                CSUM12=CMPLX(0.0,0.0)
                CSUM22=CMPLX(0.0,0.0)
                DO 180 JF1=1,JFEED
                   JF=JF1-1-JFEED/2
                   CEX=CEXP(CMPLX(0.0,-KYAPER*K0*JF*DELYF))
                   IF(JF1.EQ.1)CEX=CMPLX(COS(KYAPER*K0
     1             *JF*DELYF),0.0)
                   CSUM12=CSUM12+EXOFY(JF1)*CEX
                   CSUM22=CSUM22+EYOFY(JF1)*CEX
  180           CONTINUE
                CSUM11=CSUM11*CSUM12*DELXF*DELYF
                CSUM22=CSUM21*CSUM22*DELXF*DELYF
                CEX=CMPLX(1.0,0.0)
C
C    MAPPING OF THE FEED SPECTRUM FROM ONE PLANE TO ANOTHER
C    DOES NOT CHANCE THE VALUES OF "KXAPER" AND "KYAPER".
C    IT IS THEREFORE POSSIBLE TO TRANSLATE THE FEED HORN TO
C    THE FOCUS AT THIS POINT OF THE CALCULATION. THE COMMENTED
C    LINES BELOW EFFECT A TRANSLATION OF THE FEED HORN TO THE
C    FOCUS FROM A POSITION "ZMOVE" FROM THE FOCUS. REORIENTATION
C    OF THE FEED AND OFFSET FEEDS CAN ALSO BE DEALT WITH AT
C    THIS POINT.
C
C               ARG=1.0-KYASQ-KXASQ
C               EPS=0.0001
C               IF(ARG) 702,704,701
C 701           KR=ZMOVE*SQRT(ARG)*K0
C               CEX=CEXP(CMPLX(0.0,-KR))
C               GO TO 704
C 702           KR=ZMOVE*SQRT(-ARG)*K0
C               CEX=CMPLX(EXP(-KR),0.0)
C               IF(ZMOVE.LT.-EPS)CEX=CMPLX(0.0,0.0)
C 704           CONTINUE
C
C    THE X,Y COMPONENTS OF THE FEED SPECTRUM ARE MAPPED INTO
C    THETA,PHI COMPONENTS OF THE FAR-FIELDOF THE FEED HORN.
C
                CSUM12=CEX*(CSUM11*COS(PHI)+CSUM22*SIN(PHI))/RPARA
                CSUM21=CEX*(-CSUM11*SIN(PHI)+CSUM22*COS(PHI))*COS(THETA)
     1                    /RPARA
C
C    CSUM12 IS COMPONENT  IN THE PLANE OF THE REFLECTION-THE PHI
C    COMPONENT. AFTER REFLECTION BY THE PARABALOID, THE COMPONENTS
C    ARE RECTANGULAR COMPONENTS IN THE APERTURE PLANE REFERENCED TO
C    COORDINATES ROTATED BY AN ANGLE PHI RELATIVE TO THE
C    X,Y COORDINATE SYSTEM. THE X,Y COMPONENTS ARE RECOVERED.
C
                SPECX(IA1,JA1)=CSUM12*COS(PHI)-CSUM21*SIN(PHI)
                SPECY(IA1,JA1)=CSUM12*SIN(PHI)+CSUM21*COS(PHI)
  150       CONTINUE
            IF(IAVGFF.EQ.0) GO TO 199
C
```

Figure 29. Source listing of subroutine REFLEC (continued).

```
C
C    IF FAR-FIELD AVERAGES ARE BEING CALCULATED, THE APERTURE
C    FIELDS FOR EACH MODE ARE FOURIER TRANSFORMED. SINCE THESE
C    FIELDS ARE NOT SEPARABLE, A TWO-DIMENSIONAL FAST FOURIER
C    TRANSFORM IS NECESSARY.
C
C
C    SUBROUTINE FFTDOUB USES THE FFT IN A LESS THAN STRAIGHTFORWARD
C    MANNER TO PRODUCE GREATER RESOLUTION IN THE BORESIGHT DIRECTION.
C    DELKX AND DELKY ARE HALF WHAT THEY WOULD BE FOR THE FFT.
C
        CALL FFTDOUB(SPECX,HOLDER,IAPER,JAPER,-1)
        CALL FFTDOUB(SPECY,HOLDER,IAPER,JAPER,-1)
          C=29.979
          COMDAT(7)=-0.25*C*IAPER/AAPER/FREQ
          COMDAT(8)=0.5*C/AAPER/FREQ
          COMDAT(10)=-0.25*C*JAPER/BAPER/FREQ
          COMDAT(11)=0.5*C/BAPER/FREQ
C
C    CALL FFT(SPECX,IAPER,JAPER,-1)
C    CALL FFT(SPECY,IAPER,JAPER,-1)
C
C    FOR NEAR-FIELD AVERAGES, THE APERTURE FIELD FOR EACH MODE
C    IS WRITTEN. FOR CALCULATIONS OF FAR-FIELD AVERAGES, THE
C    FOURIER TRANSFORMS OF THESE FIELDS ARE WRITTEN.
C
  199   WRITE(29) SPECX,SPECY
  100 CONTINUE
        REWIND 25
        REWIND 29
        RETURN
        END
```

Figure 29. Source listing of subroutine REFLEC.

```
      SUBROUTINE FFTDOUB(ARRAY,HOLDER,ISPEC,JSPEC,INVFFT)
C
C   SUBROUTINE FFTDOUB IS A SPECIALIZED PROGRAM WHICH UTILIZES
C   THE FFT TO PRODUCE A TRANSFORM ON A HALF-SPACED GRID -E.G.-
C      FOR FFT:     DELKX=PI/(N*DELX)
C      FOR FFTDOUB:DELKX=1/2*PI/(N*DELX)
C
C   THIS GIVES IMPROVED RESOLUTION ABOUT THE BORESIGHT DIRECTION
C   FOR THE TRANSFORMED FUNCTION AT THE COST OF HALVING THE
C   REGION OF THE TRANSFORM VARIABLE OVER WHICH THE FUNCTION IS
C   DETERMINED.
C   THE ALGORYTHYM EMPLOYED IS EQUIVALENT TO PUTTING THE INPUT
C   ARRAY INTO A LARGER ARRAY AND ZERO-FILLING, BUT AVOIDS THE
C   STORAGE WASTE ASSOCIATED WITH THIS.
C
      COMPLEX ARRAY(ISPEC,JSPEC),HOLDER(ISPEC,JSPEC),CEX
      IF(ISPEC.LT.4.OR.JSPEC.LT.4)WRITE(6,100)
  100 FORMAT(1X,//" ISPEC OR JSPEC LESS THAN 4, FFTDOUB FAILS"//)
      IALPHA=ISPEC/4+1
      IOMEGA=3*ISPEC/4
      JALPHA=JSPEC/4+1
      JOMEGA=3*JSPEC/4
      PI=2.0*ACOS(0.0)
      IFFT=-INVFFT
      CALL FFT(ARRAY,ISPEC,JSPEC,INVFFT)
      DO 10 I=IALPHA,IOMEGA
         IB=2*I-ISPEC/2-1
         DO 10 J=JALPHA,JOMEGA
            JB=2*J-JSPEC/2-1
            HOLDER(IB,JB)=ARRAY(I,J)
   10 CONTINUE
      CALL FFT(ARRAY,ISPEC,JSPEC,IFFT)
      DO 19 I=1,ISPEC
         INT=I-1-ISPEC/2
         CEX=CEXP(CMPLX(0.0,INVFFT*INT*PI/ISPEC))
         DO 19 J=1,JSPEC
            ARRAY(I,J)=CEX*ARRAY(I,J)
   19 CONTINUE
      CALL FFT(ARRAY,ISPEC,JSPEC,INVFFT)
      DO 20 I=IALPHA,IOMEGA
         IB=2*I-ISPEC/2
         DO 20 J=JALPHA,JOMEGA
            JB=2*J-JSPEC/2-1
            HOLDER(IB,JB)=ARRAY(I,J)
   20 CONTINUE
      CALL FFT(ARRAY,ISPEC,JSPEC,IFFT)
      DO 29 J=1,JSPEC
         JNT=J-1-JSPEC/2
         CEX=CEXP(CMPLX(0.0,INVFFT*JNT*PI/JSPEC))
         DO 29 I=1,ISPEC
            ARRAY(I,J)=CEX*ARRAY(I,J)
   29 CONTINUE
      CALL FFT(ARRAY,ISPEC,JSPEC,INVFFT)
      DO 30 I=IALPHA,IOMEGA
         IB=2*I-ISPEC/2
         DO 30 J=JALPHA,JOMEGA
            JB=2*J-JSPEC/2
```

Figure 30. Source listing of subroutine FFTDOUB (continued).

```
          HOLDER(IB,JB)=ARRAY(I,J)
30    CONTINUE
      CALL FFT(ARRAY,ISPEC,JSPEC,IFFT)
      DO 39 I=1,ISPEC
        INT=I-1-ISPEC/2
        CEX=CEXP(CMPLX(0.0,-INVFFT*INT*PI/ISPEC))
        DO 39 J=1,JSPEC
          ARRAY(I,J)=CEX*ARRAY(I,J)
39    CONTINUE
      CALL FFT(ARRAY,ISPEC,JSPEC,INVFFT)
      DO 40 I=IALPHA,IOMEGA
        IB=2*I-ISPEC/2-1
        DO 40 J=JALPHA,JOMEGA
          JB=2*J-JSPEC/2
          HOLDER(IB,JB)=ARRAY(I,J)
40    CONTINUE
      DO 49 I=1,ISPEC
        DO 49 J=1,JSPEC
49    ARRAY(I,J)=HOLDER(I,J)
      RETURN
      END
```

Figure 30. Source listing of subroutine FFTDOUB.

```
      SUBROUTINE FFT(SPEC,NX,NY,ISN)
C
C   SUBROUTINE FFT CALCULATES THE FAST FOURIER TRANSFORM OR
C   THE INVERSE FAST FOURIER TRANSFORM OF AN INPUT TWO
C   DIMENSIONAL,COMPLEX ARRAY AND RETURNS THE
C   RESULT IN THE SAME ARRAY
C
C   NX AND NY ARE THE DIMENSIONS OF THE ARRAY AND MUST
C   BE EQUAL TO 2 RAISED TO SOME POSTIVE INTEGER POWER
C
C   ISN IS THE INTEGER CONTROL VARIABLE WHICH MUST BE EITHER
C   +1 OR -1,IF ISN=-1 THE FAST FOURIER TRANSFORM IS
C   CALCULATED,IF ISN=+1 THE INVERSE FAST FOURIER TRANSFORM
C   IS CALCULATED
C
C   THE ORIGIN OF BOTH THE INPUT AND OUTPUT COORDINATE SYSTEMS
C   IS LOCATED AT THE (NX/2+1,NY/2+1) POINT OF THE ARRAY
C
C   THE SYMMETRIC DEFINITION OF THE FOURIER TRANSFORM
C   PAIR IS USED.  THE TRANSFORM AND ITS INVERSE DIFFER
C   ONLY IN THE SIGN OF THE EXPONENTIAL WITHIN THE
C   INTEGRAL.  IN THE DISCRETE FOURIER TRANSFORM, THIS
C   MEANS THAT THE SUMS IN BOTH THE TRANSFORM AND
C   INVERSE ARE MULTIPLIED BY 1/SQRT(NX*NY).
C
C   NOTE THAT THE FFT TAKES A REGULARLY SPACED ARRAY IN X,Y (KX,KY)
C   INTO A REGULARLY SPACED ARRAY INKX,KY (X,Y). FOR A SPACING
C   DELX AND N SAMPLES ALONG X, DELKX=PI/(N*DELKX)
C
      COMPLEX SPEC(NX,NY),T1,T2
      REAL PI2,SO,CO,SI,CI,SN,CS,SOISN
      IF(IABS(ISN).NE.1)GO TO 24
      PI2=2.*ACOS(-1.)
      IX=0
    1 IX=IX+1
      M=2**IX
      IF(NX-M) 2,4,1
    2 WRITE(6,3)
    3 FORMAT("NX IS NOT EQUAL TO 2 RAISED TO ANY POSTIVE INTEGER POWER")
      GO TO 24
    4 IY=0
    5 IY=IY+1
      M=2**IY
      IF(NY-M) 6,8,5
    6 WRITE(6,7)
    7 FORMAT("NY IS NOT EQUAL TO 2 RAISED TO ANY POSTIVE INTEGER POWER")
      GO TO 24
    8 NX2=NX/2
      NY2=NY/2
      DO 9 I=1,NX2,1
        I1=I+NX2
        DO 9 J=1,NY,1
          T1=SPEC(I,J)
          SPEC(I,J)=SPEC(I1,J)
    9 SPEC(I1,J)=T1
      DO 10 J=1,NY2,1
        J1=J+NY2
```

Figure 31. Source listing of subroutine FFT (continued).

```
         DO 10 I=1,NX,1
           T2=SPEC(I,J)
           SPEC(I,J)=SPEC(I,J1)
   10 SPEC(I,J1)=T2
      NXBIT=60-IX
      NX1=NX-2
      DO 13 I=1,NX1,1
        IFLIP=0
        DO 11 J=NXBIT,59,1
          N=NXBIT-J
          N=N+59
   11   IFLIP=2*IFLIP+AND(SHIFT(I,N+1),1B)
        IF(I.LE.IFLIP) GO TO 13
        I1=I+1
        I2=IFLIP+1
        DO 12 J=1,NY,1
          T1=SPEC(I2,J)
          SPEC(I2,J)=SPEC(I1,J)
   12   SPEC(I1,J)=T1
   13 CONTINUE
      NYBIT=60-IY
      NY1=NY-2
      DO 16 J=1,NY1,1
        JFLIP=0
        DO 14 I=NYBIT,59,1
          M=NYBIT-I
          M=M+59
   14   JFLIP=2*JFLIP+AND(SHIFT(J,M+1),1B)
        IF(J.LE.JFLIP) GO TO 16
        J1=J+1
        J2=JFLIP+1
        DO 15 I=1,NX,1
          T2=SPEC(I,J2)
          SPEC(I,J2)=SPEC(I,J1)
   15   SPEC(I,J1)=T2
   16 CONTINUE
      DO 18 I=1,IX,1
        NEL=2**I
        NEL2=NEL/2
        NSET=NX/NEL
        SI=SIN(PI2/NEL)
        CI=COS(PI2/NEL)
        DO 18 K=1,NSET,1
          INCR=(K-1)*NEL
          SO=0.0
          CO=1.0
          DO 18 L=1,NEL2,1
            I1=L+INCR
            I2=I1+NEL2
            DO 17 J=1,NY,1
              T1=SPEC(I1,J)
              SOISN=SO*(FLOAT(ISN))
              T2=SPEC(I2,J)*CMPLX(CO,SOISN)
              SPEC(I1,J)=T1+T2
   17       SPEC(I2,J)=T1-T2
            SN=SO*CI+CO*SI
            CS=CO*CI-SO*SI
```

Figure 31. Source listing of subroutine FFT (continued).

```
            CO=CS
18 SO=SN
   DO 20 J=1,IY,1
      NEL=2**J
      NEL2=NEL/2
      NSET=NY/NEL
      SI=SIN(PI2/NEL)
      CI=COS(PI2/NEL)
      DO 20 K=1,NSET,1
         INCR=(K-1)*NEL
         SO=0.0
         CO=1.0
         DO 20 L=1,NEL2,1
            J1=L+INCR
            J2=J1+NEL2
            DO 19 I=1,NX,1
               T1=SPEC(I,J1)
               SOISN=SO*(FLOAT(ISN))
               T2=SPEC(I,J2)*CMPLX(CO,SOISN)
               SPEC(I,J1)=T1+T2
19          SPEC(I,J2)=T1-T2
            SN=SO*CI+CO*SI
            CS=CO*CI-SO*SI
            CO=CS
20 SO=SN
   DO 21 I=1,NX2,1
      I1=I+NX2
      DO 21 J=1,NY,1
         T1=SPEC(I,J)
         SPEC(I,J)=SPEC(I1,J)
21 SPEC(I1,J)=T1
   DO 22 J=1,NY2,1
      J1=J+NY2
      DO 22 I=1,NX,1
         T2=SPEC(I,J)
         SPEC(I,J)=SPEC(I,J1)
22 SPEC(I,J1)=T2
   R=1.0/SQRT(FLOAT(NX)*FLOAT(NY))
   DO 23 I=1,NX,1
      DO 23 J=1,NY,1
23 SPEC(I,J)=SPEC(I,J)*R
24 CONTINUE
   RETURN
   END
```

Figure 31. Source listing of subroutine FFT.

```
      SUBROUTINE NORMIM(ARRAYX,ARRAYY,ISPEC,JSPEC,MAX)
C
C   SUBROUTINE NORMIM TAKES TWO VARIABLY DIMENSIONED COMPLEX TWO-D
C   ARRAYS DENOTED BY "ARRAYX(ISPEC,JSPEC)" AND "ARRAYY(ISPEC,JSPEC)"
C   AND FINDS THE ELEMENT WITH THE LARGEST MAGNITUDE. THE
C   ARRAY THAT THIS ELEMENT OCCURS IN IS NOTED AND THE
C   LOCATION OF THE ELEMENT IN THIS ARRAY IS RECORDED.
C   BOTH ARRAYS ARE THEN DIVIDED BY THIS COMPLEX ELEMENT.
C
C   THE INTENDED USE OF THIS SUBROUTINE IS NORMALIZATION
C   OF PARALLEL AND CROSS POLARIZED FIELD COMPONENTS WITH
C   THE PRESERVATION OF RELATIVE NORMALIZATION.
C
      COMPLEX ARRAYX(ISPEC,JSPEC),ARRAYY(ISPEC,JSPEC),MAX,MAXX,MAXY
   99 FORMAT(1X,*MAX=*,2(2X,E12.5),* II=*,I3,2X,* JJ=*,I3)
      CABX=0.0
      CABY=0.0
      DO 100 I=1,ISPEC
        DO 100 J=1,JSPEC
          IF(CABX.GT.CABS(ARRAYX(I,J)))GO TO 95
          MAXX=ARRAYX(I,J)
          CABX=CABS(MAXX)
          II=I
          JJ=J
   95     CONTINUE
          IF(CABY.GT.CABS(ARRAYY(I,J)))GO TO 100
          MAXY=ARRAYY(I,J)
          CABY=CABS(MAXY)
          IIY=I
          JJY=J
  100 CONTINUE
      MAX=MAXX
      IF(CABX.GE.CABY) GO TO 111
      MAX=MAXY
      II=IIY
      JJ=JJY
      WRITE(6,98)
   98 FORMAT("    MAX OCCURS IN Y COMPONENT")
  111 CONTINUE
      WRITE(6,99) MAX,II,JJ
      IF(MAX.EQ.CMPLX(1.0,0.0)) RETURN
      DO 101 I=1,ISPEC
        DO 101 J=1,JSPEC
          ARRAYX(I,J)=ARRAYX(I,J)/MAX
  101 ARRAYY(I,J)=ARRAYY(I,J)/MAX
      RETURN
      END
```

Figure 32. Source listing of subroutine NORMIM.

```
      SUBROUTINE NORMXY(ARRAYX,ARRAYY,ISPEC,JSPEC)
C
C   SUBROUTINE NORMXY TAKES TWO VARIABLY DIMENSIONED REAL TWO-D
C   ARRAYS DENOTED BY "ARRAYX(ISPEC,JSPEC)" AND "ARRAYY(ISPEC,JSPEC)"
C   AND FINDS THE ELEMENT WITH THE LARGEST MAGNITUDE. THE
C   ARRAY THAT THIS ELEMENT OCCURS IN IS NOTED AND THE
C   LOCATION OF THE ELEMENT IN THIS ARRAY IS RECORDED.
C   BOTH ARRAYS ARE THEN DIVIDED BY THIS ELEMENT.
C
C   THE INTENDED USE OF THIS SUBROUTINE IS NORMALIZATION
C   OF PARALLEL AND CROSS POLARIZED COMPONENTS OF THE POWER WITH
C   THE PRESERVATION OF RELATIVE NORMALIZATION.
C
      REAL ARRAYX(ISPEC,JSPEC),ARRAYY(ISPEC,JSPEC),MAX,MAXY,MAXX
      COMMON/MAX/MAX,MAXX,MAXY
   99 FORMAT(1X,*MAX=*,E12.5,* II=*,I3,2X,* JJ=*,I3)
      MAXX=0.0
      MAXY=0.0
      DO 100 I=1,ISPEC
        DO 100 J=1,JSPEC
          IF(MAXX.GT.ARRAYX(I,J))GO TO 95
          MAXX=ARRAYX(I,J)
          II=I
          JJ=J
   95     CONTINUE
          IF (MAXY.GT.ARRAYY(I,J)) GO TO 100
          MAXY=ARRAYY(I,J)
          IIY=I
          JJY=J
  100 CONTINUE
      MAX=MAXX
      IF(MAX.GT.MAXY) GO TO 111
      MAX=MAXY
      II=IIY
      JJ=JJY
      WRITE(6,98)
   98 FORMAT("    MAX OCCURS IN Y COMPONENT")
  111 CONTINUE
      WRITE(6,99) MAX,II,JJ
      IF(MAX.EQ.1.0) RETURN
      DO 101 I=1,ISPEC
        DO 101 J=1,JSPEC
          ARRAYX(I,J)=ARRAYX(I,J)/MAX
  101 ARRAYY(I,J)=ARRAYY(I,J)/MAX
      RETURN
      END
```

Figure 33. Source listing of subroutine NORMXY.

```
C
C   THE 129 LINES BEGINNING WITH: "M,N,K,TRIAL ... " ARE A SAMPLE
C   FILE "STANCO". THERE ARE NO ZERO COEFFICIENTS IN THIS LISTING
C   SO THAT THIS VERSION OF "STANCO" IMPOSES NO LIMITATIONS ON
C   MODAL CONTENT. THE COMMENT "C'S" MUST BE REMOVED.
C
CM,N,K,TRIAL COEFF.-USED FOR IRV=1  (ZERO MEANS MODE NOT USED)  K=TE,TM
C0,0,1,(1.0,0.0)
C1,0,1,(1.0,0.0)
C2,0,1,(1.0,0.0)
C3,0,1,(1.0,0.0)
C4,0,1,(1.0,0.0)
C5,0,1,(1.0,0.0)
C6,0,1,(1.0,0.0)
C7,0,1,(1.0,0.0)
C0,1,1,(1.0,0.0)
C1,1,1,(1.0,0.0)
C2,1,1,(1.0,0.0)
C3,1,1,(1.0,0.0)
C4,1,1,(1.0,0.0)
C5,1,1,(1.0,0.0)
C6,1,1,(1.0,0.0)
C7,1,1,(1.0,0.0)
C0,2,1,(1.0,0.0)
C1,2,1,(1.0,0.0)
C2,2,1,(1.0,0.0)
C3,2,1,(1.0,0.0)
C4,2,1,(1.0,0.0)
C5,2,1,(1.0,0.0)
C6,2,1,(1.0,0.0)
C7,2,1,(1.0,0.0)
C0,3,1,(1.0,0.0)
C1,3,1,(1.0,0.0)
C2,3,1,(1.0,0.0)
C3,3,1,(1.0,0.0)
C4,3,1,(1.0,0.0)
C5,3,1,(1.0,0.0)
C6,3,1,(1.0,0.0)
C7,3,1,(1.0,0.0)
C0,4,1,(1.0,0.0)
C1,4,1,(1.0,0.0)
C2,4,1,(1.0,0.0)
C3,4,1,(1.0,0.0)
C4,4,1,(1.0,0.0)
C5,4,1,(1.0,0.0)
C6,4,1,(1.0,0.0)
C7,4,1,(1.0,0.0)
C0,5,1,(1.0,0.0)
C1,5,1,(1.0,0.0)
C2,5,1,(1.0,0.0)
C3,5,1,(1.0,0.0)
C4,5,1,(1.0,0.0)
C5,5,1,(1.0,0.0)
C6,5,1,(1.0,0.0)
C7,5,1,(1.0,0.0)
C0,6,1,(1.0,0.0)
```

Figure 34. Sample (commented) source listing of the input file STANCO (continued).

```
C1,6,1,(1.0,0.0)
C2,6,1,(1.0,0.0)
C3,6,1,(1.0,0.0)
C4,6,1,(1.0,0.0)
C5,6,1,(1.0,0.0)
C6,6,1,(1.0,0.0)
C7,6,1,(1.0,0.0)
C0,7,1,(1.0,0.0)
C1,7,1,(1.0,0.0)
C2,7,1,(1.0,0.0)
C3,7,1,(1.0,0.0)
C4,7,1,(1.0,0.0)
C5,7,1,(1.0,0.0)
C6,7,1,(1.0,0.0)
C7,7,1,(1.0,0.0)
C0,0,2,(1.0,0.0)
C1,0,2,(1.0,0.0)
C2,0,2,(1.0,0.0)
C3,0,2,(1.0,0.0)
C4,0,2,(1.0,0.0)
C5,0,2,(1.0,0.0)
C6,0,2,(1.0,0.0)
C7,0,2,(1.0,0.0)
C0,1,2,(1.0,0.0)
C1,1,2,(1.0,0.0)
C2,1,2,(1.0,0.0)
C3,1,2,(1.0,0.0)
C4,1,2,(1.0,0.0)
C5,1,2,(1.0,0.0)
C6,1,2,(1.0,0.0)
C7,1,2,(1.0,0.0)
C0,2,2,(1.0,0.0)
C1,2,2,(1.0,0.0)
C2,2,2,(1.0,0.0)
C3,2,2,(1.0,0.0)
C4,2,2,(1.0,0.0)
C5,2,2,(1.0,0.0)
C6,2,2,(1.0,0.0)
C7,2,2,(1.0,0.0)
C0,3,2,(1.0,0.0)
C1,3,2,(1.0,0.0)
C2,3,2,(1.0,0.0)
C3,3,2,(1.0,0.0)
C4,3,2,(1.0,0.0)
C5,3,2,(1.0,0.0)
C6,3,2,(1.0,0.0)
C7,3,2,(1.0,0.0)
C0,4,2,(1.0,0.0)
C1,4,2,(1.0,0.0)
C2,4,2,(1.0,0.0)
C3,4,2,(1.0,0.0)
C4,4,2,(1.0,0.0)
C5,4,2,(1.0,0.0)
```

Figure 34. Sample (commented) source listing of the input file STANCO (continued).

```
C6,4,2,(1.0,0.0)
C7,4,2,(1.0,0.0)
C0,5,2,(1.0,0.0)
C1,5,2,(1.0,0.0)
C2,5,2,(1.0,0.0)
C3,5,2,(1.0,0.0)
C4,5,2,(1.0,0.0)
C5,5,2,(1.0,0.0)
C6,5,2,(1.0,0.0)
C7,5,2,(1.0,0.0)
C0,6,2,(1.0,0.0)
C1,6,2,(1.0,0.0)
C2,6,2,(1.0,0.0)
C3,6,2,(1.0,0.0)
C4,6,2,(1.0,0.0)
C5,6,2,(1.0,0.0)
C6,6,2,(1.0,0.0)
C7,6,2,(1.0,0.0)
C0,7,2,(1.0,0.0)
C1,7,2,(1.0,0.0)
C2,7,2,(1.0,0.0)
C3,7,2,(1.0,0.0)
C4,7,2,(1.0,0.0)
C5,7,2,(1.0,0.0)
C6,7,2,(1.0,0.0)
C7,7,2,(1.0,0.0)
```

Figure 34. Sample (commented) source listing of the input file STANCO.

APPENDIX II

DETERMINISTIC SPECTRAL POWFER PATTERNS FOR SOME LOW ORDER MODES

APPENDIX II

DETERMINISTIC SPECTRAL POWER PATTERNS FOR SOME LOW ORDER MODES

The deterministic spectral power patterns for parallel and cross polarized components of the TE_{10}, TE_{01}, TE_{11}, and TM_{11} modes of antenna 1 (see Table I) operating at 6 GHz are shown. These modes and the TE_{20} mode, equivalent patterns of which are given as figures 5 and 6, are all the propagating modes at 6 GHz. Any pattern of antenna 1 at 6 GHz is a sum of these modes with complex coefficients. The null locations and relative sizes of the parallel and cross components provide insight as to allowable modes and pattern effects in various situations. It is also interesting to compare the in-band, figures 3 and 4 and out-of-band, figures 35 and 36, patterns of the TE_{10} mode.

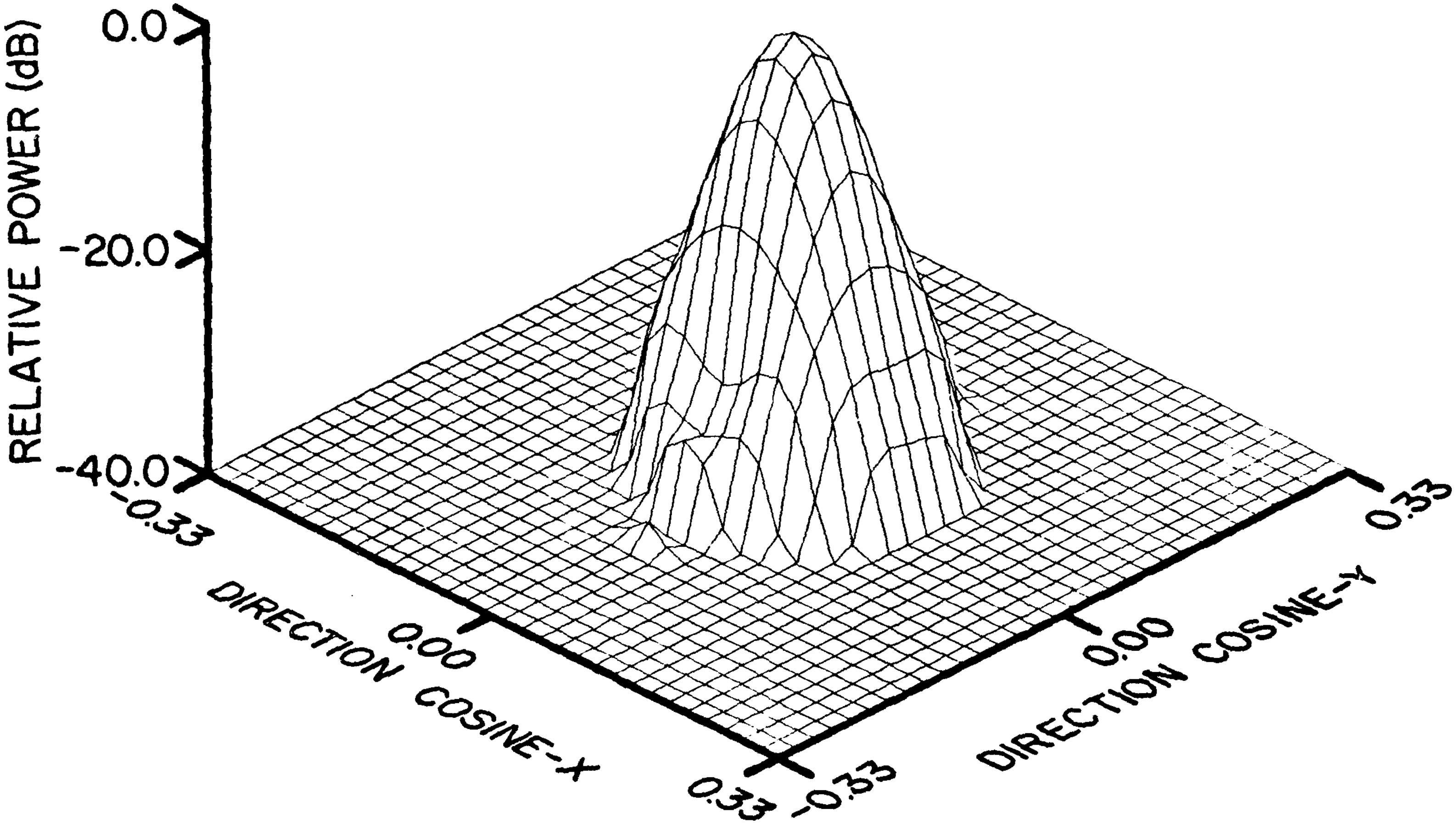

Figure 35. The deterministic spectral power pattern for the parallel polarized component for the TE_{10} mode calculated for antenna 1 operating at a frequency of 6 GHz.

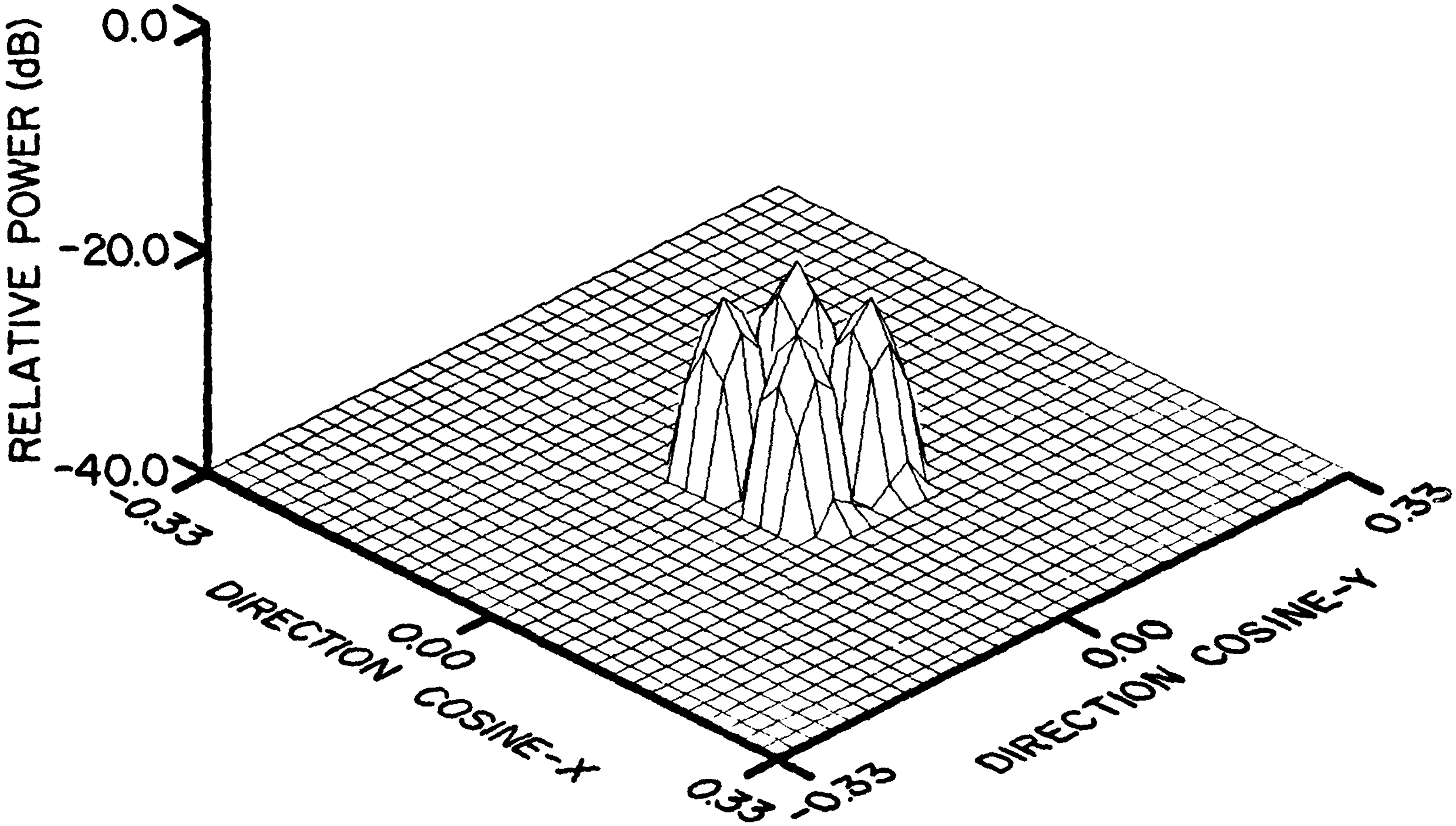

Figure 36. The deterministic spectral power pattern for the cross polarized component for the TE_{10} mode calculated for antenna 1 operating at a frequency of 6 GHz.

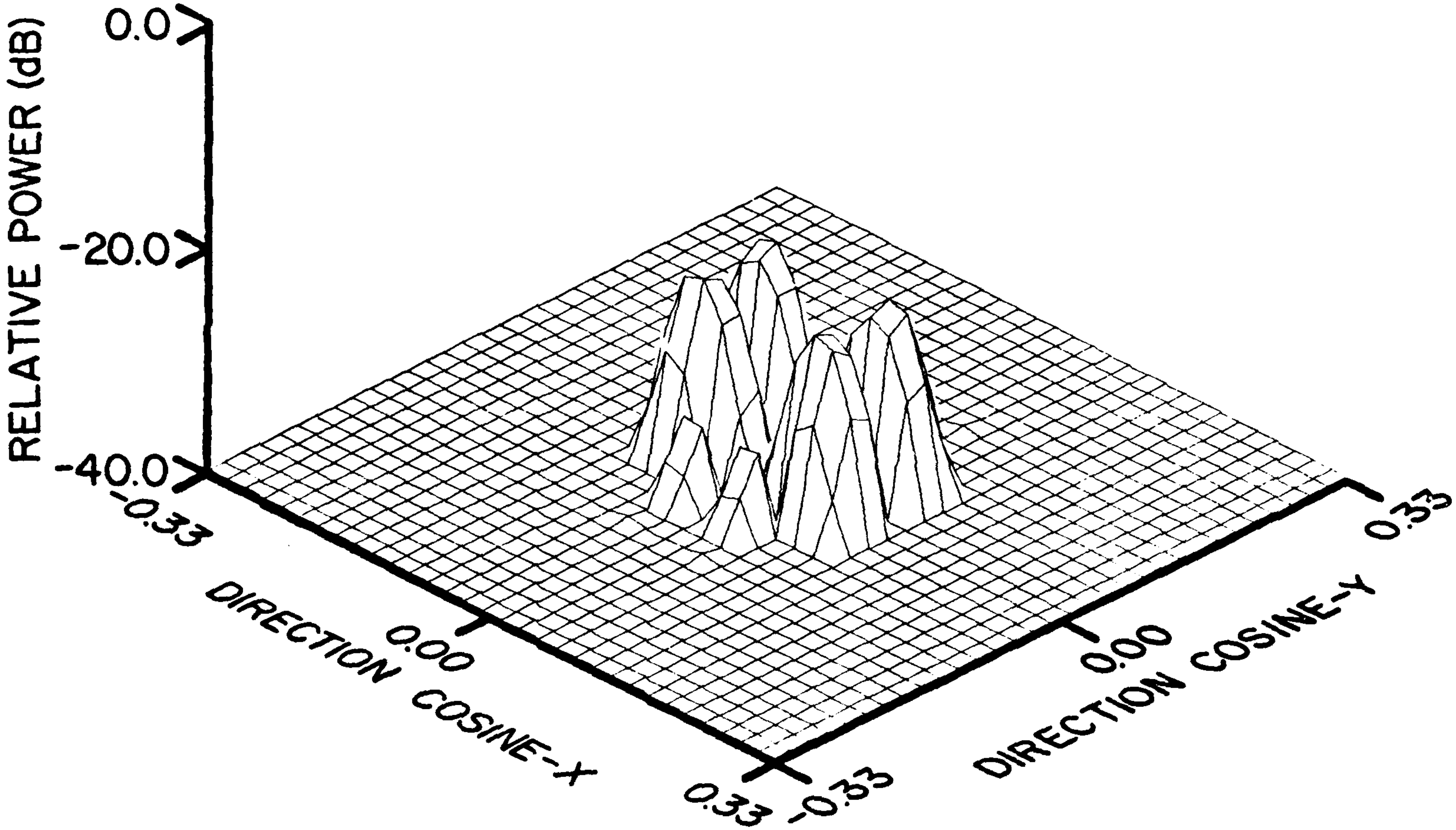

Figure 37. The deterministic spectral power pattern for the parallel polarized component for the TE_{01} mode calculated for antenna 1 operating at a frequency of 6 GHz.

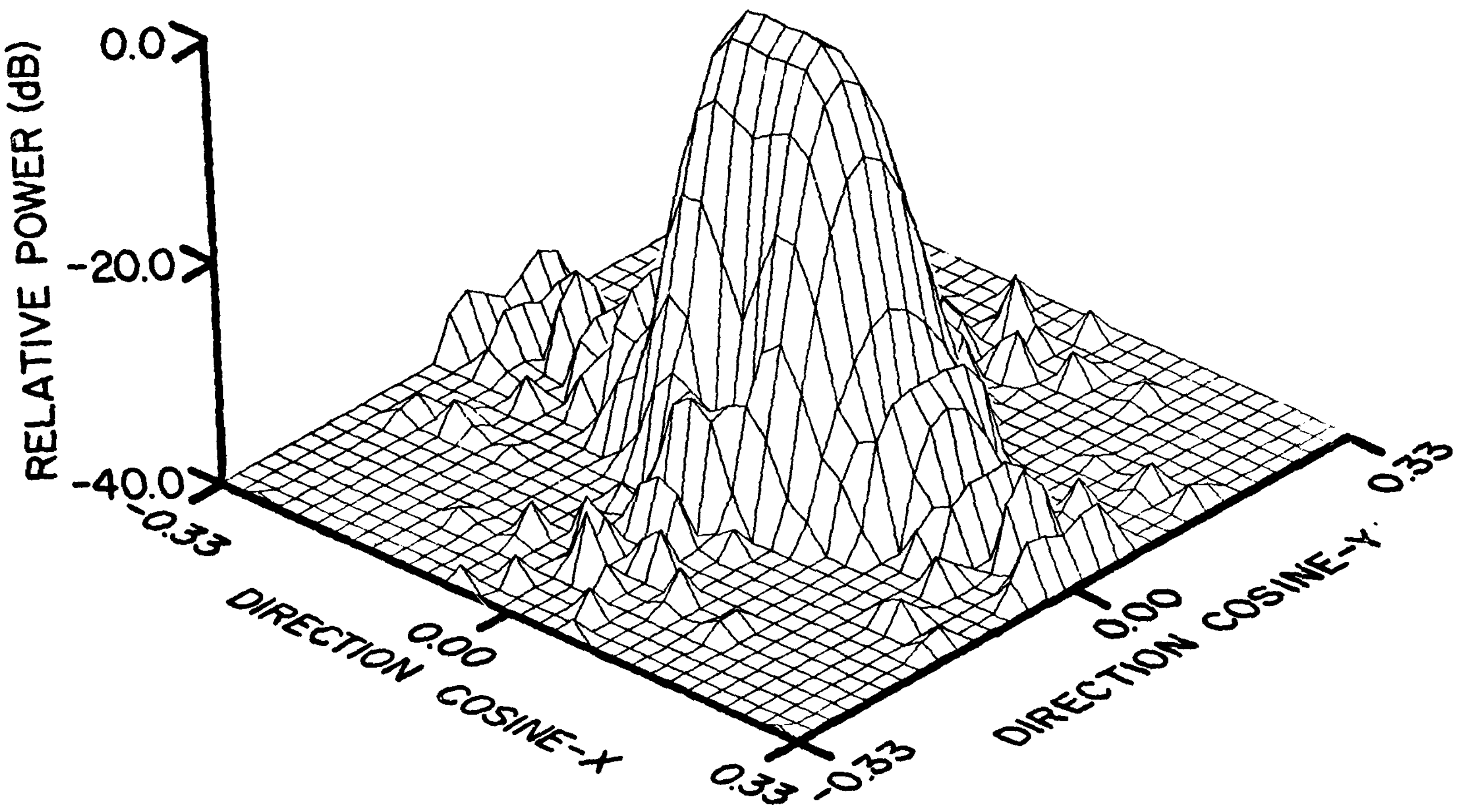

Figure 38. The deterministic spectral power pattern for the cross polarized component for the TE_{01} mode calculated for antenna 1 operating at a frequency of 6 GHz.

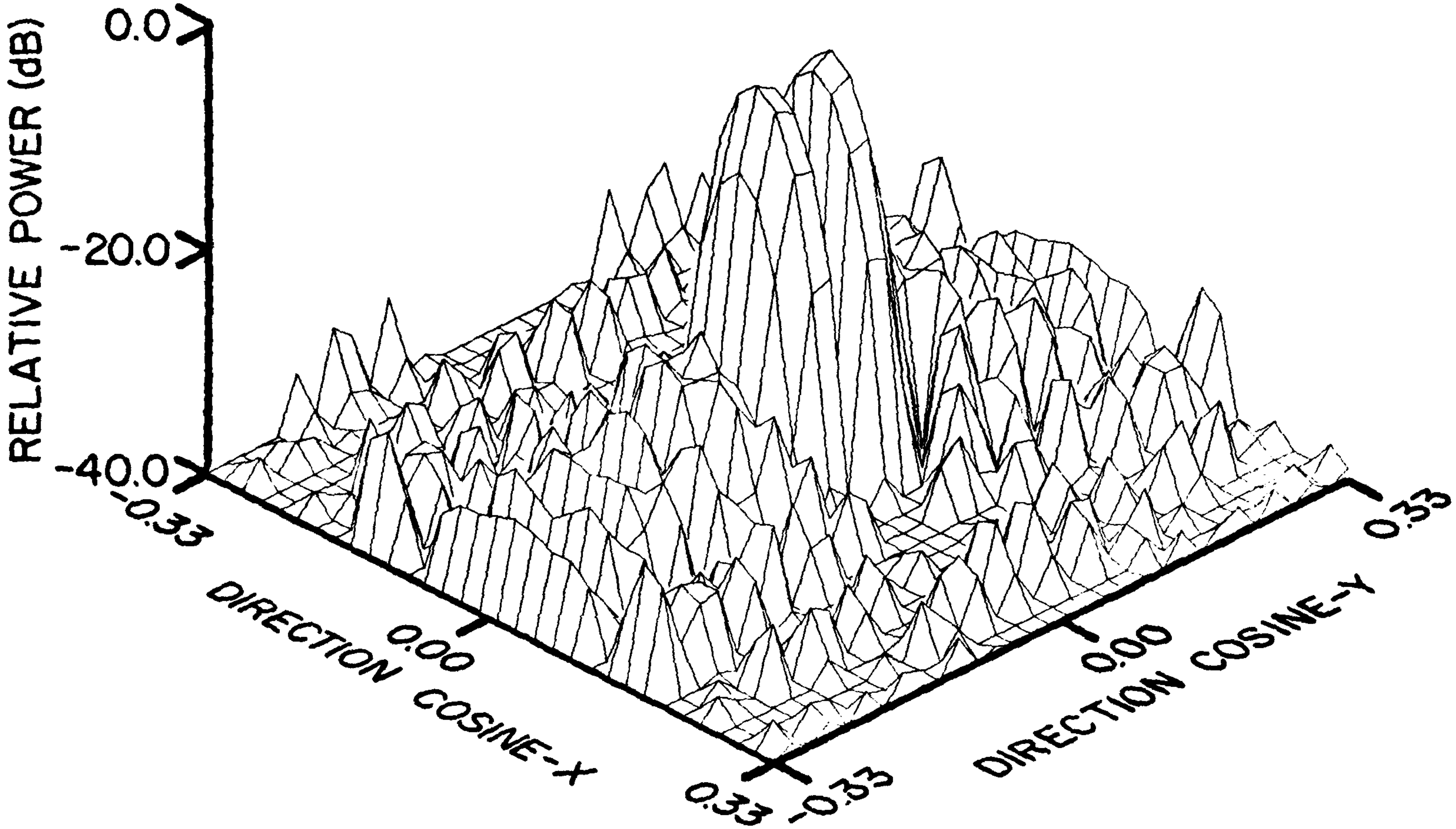

Figure 39. The deterministic spectral power pattern for the parallel polarized component for the TE_{11} mode calculated for antenna *1* operating at a frequency of 6 GHz.

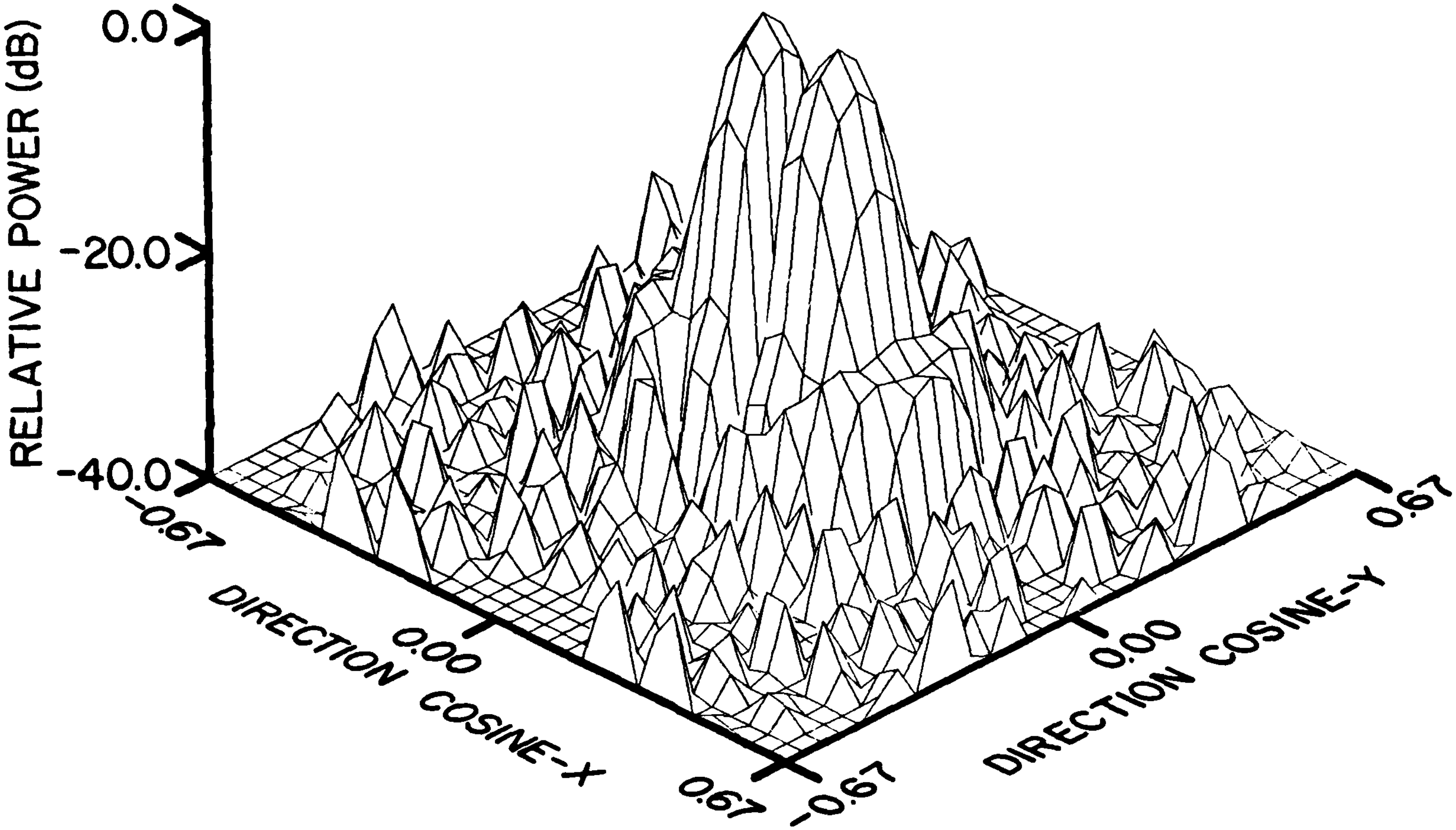

Figure 40. The deterministic spectral power pattern for the cross polarized component for the TE_{11} mode calculated for antenna 1 operating at a frequency of 6 GHz.

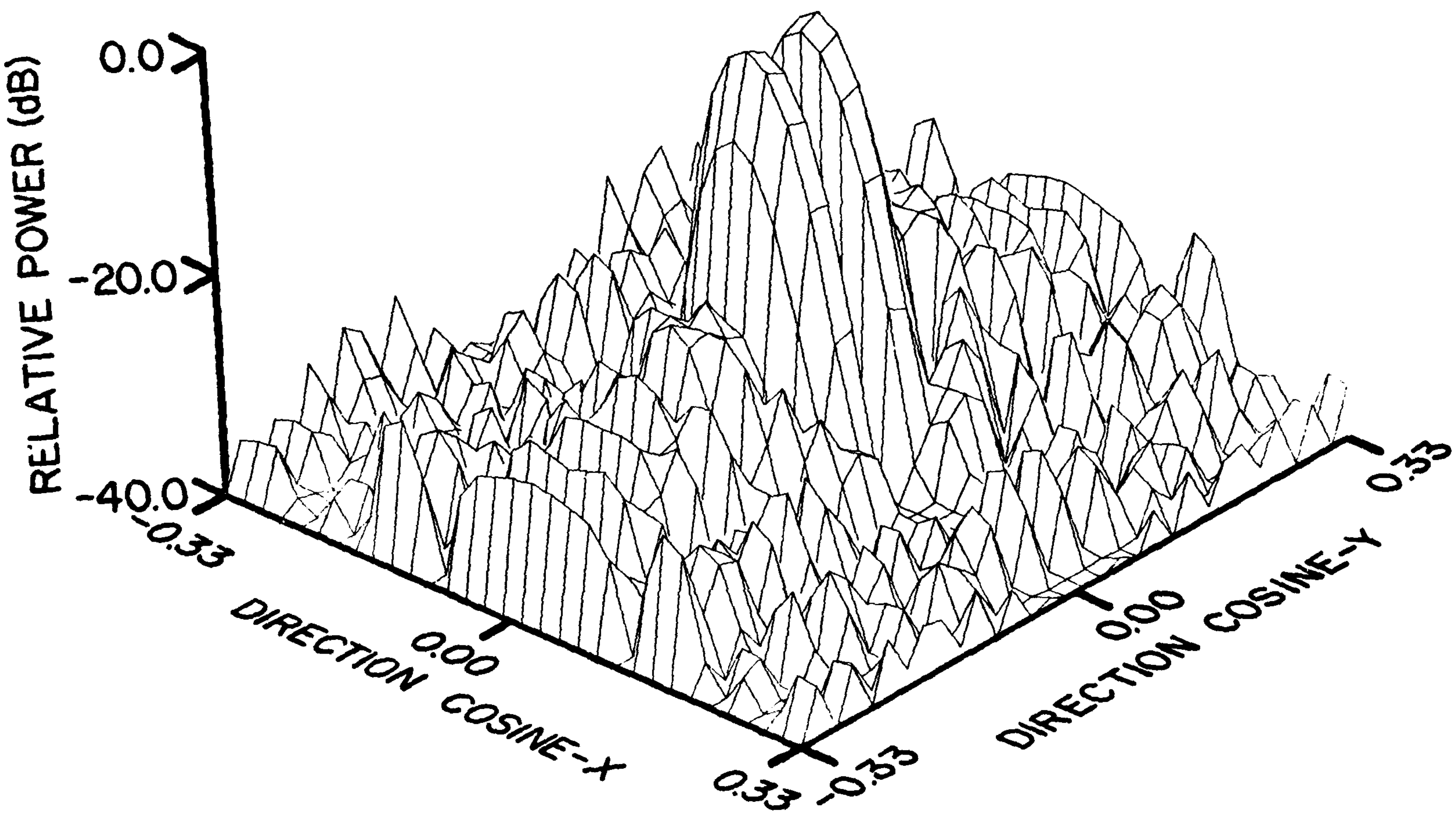

Figure 41. The deterministic spectral power pattern for the parallel polarized component for the TM_{11} mode calculated for antenna 1 operating at a frequency of 6 GHz.

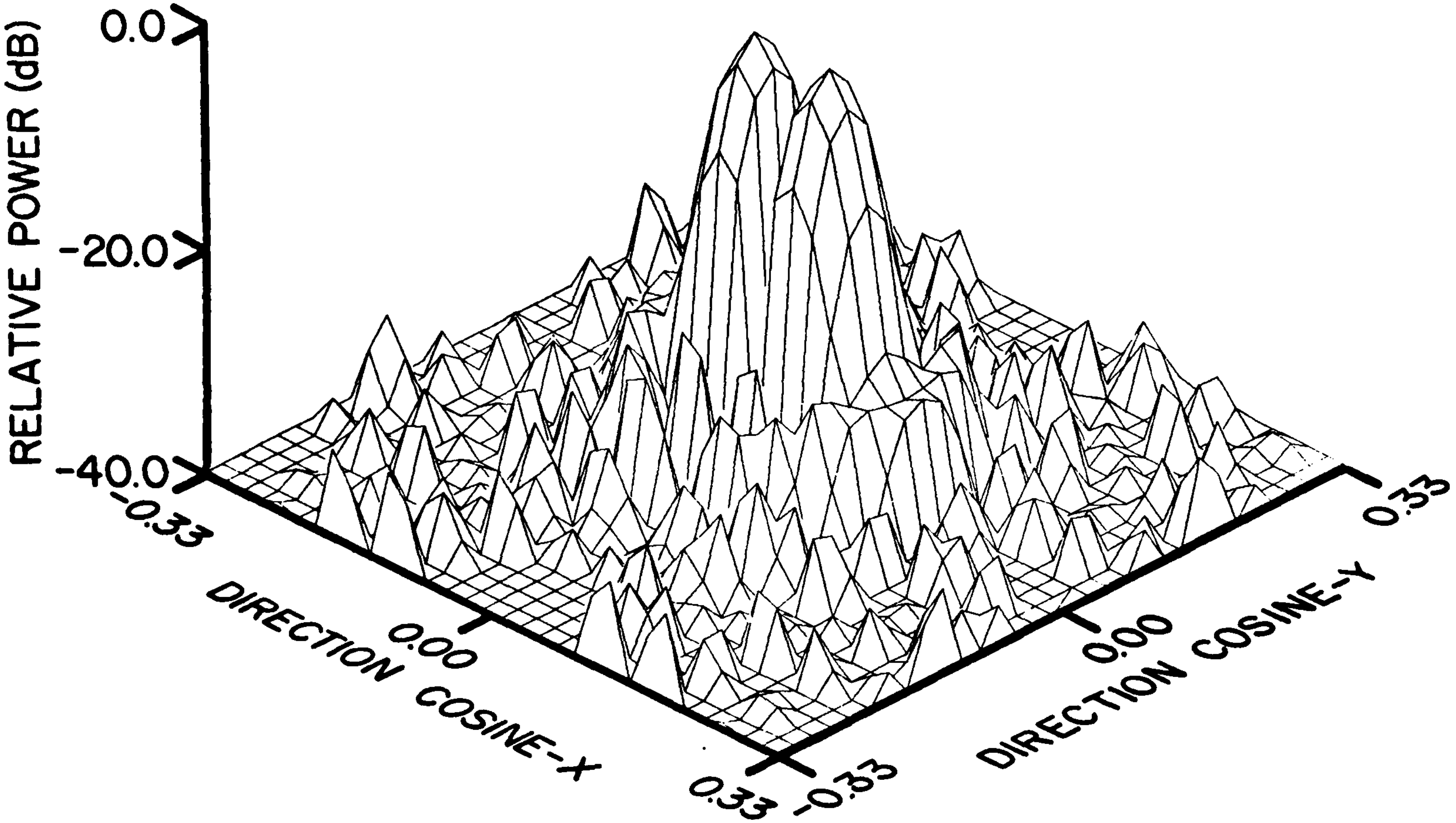

Figure 42. The deterministic spectral power pattern for the cross polarized component for the TM_{11} mode calculated for antenna 1 operating at a frequency of 6 GHz.