DIFFRACTION BY A PERFECTLY CONDUCTING RECTANGULAR CYLINDER WHICH IS ILLUMINATED BY AN ARRAY OF LINE SOURCES

by R. G. Kouyoumjian and N. Wang

Prepared by
THE OHIO STATE UNIVERSITY ELECTROSCIENCE LABORATORY
Columbus, Ohio 43212
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1974
1. **Report No.**
   NASA CR-2105

2. **Government Accession No.**

3. **Recipient's Catalog No.**

4. **Title and Subtitle**
   DIFFRACTION BY A PERFECTLY CONDUCTING RECTANGULAR CYLINDER WHICH IS ILLUMINATED BY AN ARRAY OF LINE SOURCES

5. **Report Date**
   June 1974

6. **Performing Organization Code**

7. **Author(s)**
   R. G. Kouyoumjian and N. Wang

8. **Performing Organization Report No.**
   TR 3001-7

9. **Performing Organization Name and Address**
   The Ohio State University
   ElectroScience Laboratory
   Columbus, Ohio 43212

10. **Work Unit No.**
    502-33-13-02

11. **Contract or Grant No.**
    NGR 36-008-144

12. **Sponsoring Agency Name and Address**
    National Aeronautics and Space Administration
    Washington, D.C. 20546

13. **Type of Report and Period Covered**
    Contractor Report

14. **Sponsoring Agency Code**

15. **Supplementary Notes**
    Topical report.

16. **Abstract**
    The geometrical theory of diffraction (GTD) is employed to analyze the radiation from a perfectly-conducting rectangular cylinder illuminated by an array of line sources. The excitation of the cylinder by a single electric or magnetic current line source is considered first, and a solution which includes contributions from the geometrical optics rays and all singly- and doubly-diffracted rays is obtained. A new diffraction coefficient valid in the transition regions of the shadow and reflection boundaries is employed to obtain a continuous total field, except for negligible discontinuities in the doubly-diffracted field at its shadow boundaries. Patterns calculated by the GTD method are found to be in excellent agreement with those calculated from an integral equation formulation. Using superposition the solution for array or aperture excitation of the rectangular cylinder is obtained. A computer program for this solution is included.

17. **Key Words (Suggested by Author(s))**
    Antenna, Spacecraft and Aircraft Antennas
    Applied Electromagnetic Theory

18. **Distribution Statement**
    Unclassified - Unlimited

19. **Security Classif. (of this report)**
    Unclassified

20. **Security Classif. (of this page)**
    Unclassified

21. **No. of Pages**
    71

22. **Price**
    $3.75

*For sale by the National Technical Information Service, Springfield, Virginia 22151*
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>II. METHOD OF SOLUTION</td>
<td>3</td>
</tr>
<tr>
<td>A. Geometrical Optics Rays - Direct and Reflected</td>
<td>3</td>
</tr>
<tr>
<td>B. Singly-Diffracted Rays</td>
<td>5</td>
</tr>
<tr>
<td>C. Doubly-Diffracted Rays</td>
<td>7</td>
</tr>
<tr>
<td>III. NUMERICAL RESULTS</td>
<td>18</td>
</tr>
<tr>
<td>IV. CONCLUSIONS</td>
<td>26</td>
</tr>
<tr>
<td>APPENDIX I</td>
<td>27</td>
</tr>
<tr>
<td>THE FIELD AT THE SHADOW BOUNDARY OF A THICK SCREEN FOR GRAZING INCIDENCE</td>
<td>27</td>
</tr>
<tr>
<td>APPENDIX II</td>
<td>31</td>
</tr>
<tr>
<td>DESCRIPTION OF THE COMPUTER PROGRAM</td>
<td>31</td>
</tr>
<tr>
<td>A. Input Variables</td>
<td>31</td>
</tr>
<tr>
<td>B. Output Variables</td>
<td>31</td>
</tr>
<tr>
<td>C. Instructions for Representing the Aperture Field Distribution by a 2-D Line Source Array</td>
<td>32</td>
</tr>
<tr>
<td>D. Instructions for Using the &quot;Obliquity Factor&quot;</td>
<td>34</td>
</tr>
<tr>
<td>E. Instructions for Computing the Incident Field</td>
<td>34</td>
</tr>
<tr>
<td>F. Sample Programs</td>
<td>35</td>
</tr>
<tr>
<td>G. Listing of the Computer Programs</td>
<td>40</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>69</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

In this report the geometrical theory of diffraction (GTD) \[1\] is used to treat the diffraction by a perfectly-conducting rectangular cylinder which is illuminated by an array of electric or magnetic current line sources. The illumination by a single line source of the array is considered first with the geometry of the problem shown in Fig. 1. The scattered and total fields are calculated at all points exterior to the rectangular cylinder, except for the shaded regions around the source and edges, which are excluded because of the nature of the high-frequency approximation. More will be said about this later. The solution is then generalized to calculate the field of linear arrays of such line sources radiating in the presence of the cylinder.

The scattering by a rectangular cylinder has been considered previously for the special case of plane wave incidence. Mei and VanBladel \[2,3\] formulated the problem in terms of an integral equation which they solved numerically to find the surface currents on the rectangular cylinder. They give radiation patterns, scattering cross sections, and surface currents for both E- and H-polarized incident waves. There are two disadvantages associated with this method: 1) as the frequency increases, difficulties are encountered with the convergence of the solution (this is particularly true when the technique is employed to solve a three-dimensional scattering problem), 2) the solution provides no physical insight into the scattering mechanism. Morse \[4\] also studied this problem using the ordinary GTD to obtain expressions for the diffracted field away from shadow and reflection boundaries. Since the ordinary theory fails at shadow and reflection boundaries, he introduced supplementary solutions there. He employed Oberhettinger's uniform asymptotic solution \[5\] near the boundaries of the incident and reflected fields, and he employed an integral representation of the field near the shadow boundaries of the fields of the diffracted rays. Thus, he did not obtain a compact high-frequency solution to this problem. The difficulties encountered by Morse at these boundaries may be overcome with a new edge diffraction coefficient derived by Kouyoumjian and Pathak \[6,7\]. This diffraction coefficient can be applied in the transition regions adjacent to the shadow and reflection boundaries so that one obtains a total field which is valid and continuous everywhere away from edges and caustics. Their diffraction coefficient is employed in this analysis.

Using Keller's Generalized Fermat's Principle, we include contributions to the total field from the geometrical optics fields (incident and reflected), as well as singly-diffracted fields which appear to emanate from the edges. Doubly-diffracted fields have also been included to describe the interactions between the edges; however, multiply-diffracted rays of higher order have been neglected because, in general, their fields contribute insignificantly, for the problem defined here. The incident, reflected and diffracted rays may be shadowed in the geometrical optics sense, and hence they contribute to the total field only in their respective regions of illumination. Discontinuities in the
Fig. 1. Line source in the presence of the rectangular cylinder.

field are introduced at shadow boundaries and at the reflection boundaries, but they are systematically removed by employing the new diffraction coefficient for the edge diffracted field mentioned previously. It should be pointed out that there are some residual discontinuities due to uncompensated discontinuities in the field of the doubly-diffracted rays at their shadow boundaries. However, these discontinuities are so small that they are not apparent in the plotted patterns. The patterns calculated from our GTD solution are found to be in excellent agreement with those calculated from numerical solutions.

Due to the high-frequency approximations of the incident and diffracted fields, our solution is restricted so that the following distances are greater than 0.7 wavelength.

1) The distance between the line source and the closest edge of the rectangular cylinder,

2) the distance between the observation point P and the closest edge of the rectangular cylinder,

3) the distances between the edges of the rectangular cylinder,

4) the distance between the observation point P and the closest line source, when calculating the incident or total fields.
A computer program based on the GTD solution for the rectangular cylinder in the presence of an array source has been written and is included in the report. With this program, it is possible to obtain numerical results for both the near- and far-fields of the cylinder under quite general conditions of illumination. Thus, the program is directly relevant to both antenna and scattering problems. As an example of its versatility, one notes that the program may be used to compute the pattern of an array of magnetic line sources mounted directly on the rectangular cylinder, provided the sources are not too close to an edge.

II. METHOD OF SOLUTION

Keller's geometrical theory of diffraction [1] is an extension of geometrical optics in which diffracted rays are introduced by a generalization of Fermat's principle, the excitation of the diffracted field is treated as a local phenomenon, and away from the diffracting surface the behavior of the diffracted field along its ray is the same as that of the geometrical optics field. The basic idea of GTD is that the field of the line source illuminates the rectangular cylinder giving rise to a reflected field and an edge diffracted field, which consists of the fields of singly and multiply-diffracted rays. The total field $U(P)$ at a point $P$ is equal to the sum of the fields on all rays through $P$.

\begin{equation}
U(P) = \sum_{\text{rays}} U_i(P)
\end{equation}

which includes the incident field if $P$ is not in the shadow region. The wave function $U(P)$ represents a magnetic field parallel to the edge in case of a magnetic line source, and an electric field parallel to the edge in the case of an electric current line source. The pertinent rays and their associated fields will be discussed briefly in the following paragraphs.

A. Geometrical Optics Rays - Direct and Reflected

Let us consider the field radiated from a line source at $O$ and observed at $P$ as shown in Fig. 2. Fermat's principle predicts only the direct ray $OP$. If a line source is being considered, the field along $OP$ is given by

\begin{equation}
U_i(P) = C \frac{e^{-jks_0}}{\sqrt{s_0}}
\end{equation}

where $s_0$ is the distance between $O$ and $P$, and $C$ is a conveniently chosen normalization constant. For the configuration shown in Fig. 2, the space surrounding the right-angle wedge may be divided into three regions:
Region I \( 0 \leq \phi < \pi - \phi' \),
Region II \( \pi - \phi' < \phi < \pi + \phi' \),
Region III \( \pi + \phi' < \phi < 3\pi/2 \).

Region III is the shadow region, which is not penetrated by the incident ray; the incident field vanishes here.

We know that there is a field reflected from the surface \( AQ_E \). To describe this we introduce an additional class of rays which include on their trajectory a point \( QR \) of the surface \( AQ_E \). Applying Fermat's principle, the distance \( OQRP \) along the ray path is a minimum and the law of reflection results. This simple extension of Fermat's principle which accounts for the reflected ray is so natural that we accept it without question. The field of the reflected ray is readily deduced from image theory as

\[
U^r(p) = U^r(AQ_E) = \pm C \frac{e^{-jks''}}{\nu s''},
\]

where the positive sign is for Neumann (hard) boundary condition associated with the magnetic current line source, the negative sign is for the Dirichlet (soft) boundary condition associated with the electric current source line, and \( s'' \) is the distance between the image \( O' \) and the observation point \( P \). The reflected field vanishes in regions II and III, which the reflected ray does not penetrate. Let us consider now a further extension of Fermat's principle.
B. Singly-Diffracted Rays

It is well known that the ray incident on the edge $Q_E$ in Fig. 2 gives rise to diffraction. To account for this, Keller introduced a class of rays which includes the point $Q_E$ in its trajectory. This completely determines the diffracted ray path in the isotropic, homogeneous medium of this two-dimensional problem, so the law of edge diffraction becomes trivial under these circumstances.

In terms of GTD, the diffracted field at $P$ for the line source at $0$ is

$$U^d(Q_E) = U^i(Q_E) D_s(\phi, \phi') \frac{e^{-jks}}{\sqrt{S}}$$

where $D_s$ is the scalar diffraction coefficient for the acoustically soft (Dirichlet) boundary condition and $D_h$ is the scalar diffraction coefficient for the acoustically hard (Neumann) boundary condition. They are deduced from the general dyadic diffraction coefficient $D(\phi, \phi', \phi_0)$ obtained by Kouyoumjian and Pathak [6,7]. For the special case where the incident ray is perpendicular to a straight edge, the scalar diffraction coefficients are given by

$$D_s(\phi, \phi') = \frac{-e^{-j\pi/4}}{2\pi \sqrt{2\pi k}}$$

$$\begin{pmatrix}
\left(\cot\left(\frac{\pi + (\phi - \phi')}{2n}\right) F[k\lambda^+ (\phi - \phi')] + \cot \left(\frac{\pi - (\phi - \phi')}{2n}\right) F[k\lambda^- (\phi - \phi')]\right) \\
\pm \left[\cot \left(\frac{\pi + (\phi + \phi')}{2n}\right) F[k\lambda^+ (\phi + \phi')] + \cot \left(\frac{\pi - (\phi + \phi')}{2n}\right) F[k\lambda^- (\phi + \phi')]\right]
\end{pmatrix}$$

where $\pi$ is the exterior wedge angle, which equals $3\pi/2$ in this case, and

$$F(x) = 2j|\sqrt{x}| e^{jx} \int_{|\sqrt{x}|}^{\infty} e^{-j\tau^2} d\tau$$

in which

$$a^{\pm}(\phi \pm \phi') = 2 \cos^2 \left(\frac{2n\pi\pm - (\phi \pm \phi')}{2}\right)$$
\( N^\pm \) are the integers which most nearly satisfy the following equations

\[
(8) \quad 2\pi n N^+ = \pi + (\phi \pm \phi')
\]

\[
(9) \quad 2\pi n N^- = -\pi + (\phi \pm \phi')
\]

and \( kL \) is the large parameter in the asymptotic evaluation of the pertinent integrals involved in the derivation of the dyadic diffraction coefficient. The quantity \( L \) may be viewed as a distance parameter which depends upon the type of edge illumination; for line source illumination, \( L \) is given by

\[
(10) \quad L = \frac{ss'}{s + s'}
\]

For grazing incidence \( \phi' = 0 \), \( n\pi \), \( D_h \) is multiplied by a factor of 1/2; furthermore, if the diffracted ray grazes the surface in the case of a soft boundary, \( D_s = 0 \) and the diffracted field vanishes, as it should.

The field of the singly-diffracted ray is discontinuous at the shadow and reflection boundaries in a way which compensates the discontinuities in the geometrical optics fields there. This is readily demonstrated; consider for example the incident and diffracted fields at the shadow boundary, where to simplify the discussion, it is assumed there is no nearby reflection boundary. Let \( \pi + \phi' - \epsilon \) be a point close to the shadow boundary, see Fig. 2. In the illuminated region \( \epsilon > 0 \) and in the shadow region \( \epsilon < 0 \).

\[
U(\phi) = \begin{cases} 
\frac{e^{-jks'}}{\sqrt{s'}} + \frac{e^{-jks}}{\sqrt{s}} D_s(\phi' + \pi - \epsilon, \phi') & , \quad \epsilon > 0 \\
\frac{e^{-jks'}}{\sqrt{s'}} D_s(\phi' + \pi - \epsilon, \phi') & , \quad \epsilon < 0 
\end{cases}
\]

For \( \epsilon \) small it follows from Eq. (5), that

\[
(12) \quad D_s(\phi' + \pi - \epsilon, \phi') = \frac{-e^{-j\pi/4}}{2\sqrt{2\pi k}} \left\{ \cot \frac{\epsilon}{2n} F[kL^-(\pi - \epsilon)] + \text{smaller terms which are continuous at the shadow boundary} \right\}.
\]
From Eq. (9),

\[ N^+ = 0 \]

Also, as \( \varepsilon \to 0 \),

\[ \cot \left( \frac{\varepsilon}{2n} \right) = \frac{2n}{\varepsilon} \]  \hspace{1cm} (13)

\[ a^- (\pi - \varepsilon) = \frac{\varepsilon^2}{2} \]  \hspace{1cm} (14)

\[ F[kL a^- (\pi - \varepsilon)] = \sqrt{\pi kL/2} e^{j\pi/4} \]  \hspace{1cm} (15)

Substituting Eqs. (13) and (15) into Eq. (12) as \( \varepsilon \to 0 \),

\[ D_s (\phi' + \pi - \varepsilon, \phi') = -\frac{1}{2} \frac{s^1}{s + s'} \text{ sgn } \varepsilon + \text{ smaller, continuous terms,} \]  \hspace{1cm} (16)

\[ s_0 = s' + s \]  \hspace{1cm} (17)

Upon substituting Eqs. (16) and (17) into Eq. (11), it is seen that the total field is continuous at the shadow boundary. In an analogous manner it can be shown that the total field is continuous at the reflection boundary.

C. Doubly-Diffracted Rays

When one face of the conducting wedge is terminated at \( Q_F \) as shown in Fig. 3, a second order diffracted-ray will emanate from the edge \( Q_F \). In terms of the GTD, the doubly-diffracted field at \( P \) due to the line source at \( 0 \) can be written as

\[ U^d(Q_E, Q_F) = U^i(Q_F) \frac{D_s(\phi_2, 0)}{h} e^{-jks} \]  \hspace{1cm} (18)

\[ = \left\{ U^i(Q_E) \frac{D_s(\frac{3\pi}{2}, \phi')}{h} e^{-jkh} \right\} \frac{D_s(\phi_2, 0)}{2} e^{-jks} \]  \hspace{1cm} (19)
Since $D_\Sigma(3\pi/2,\phi') = 0$, the contribution from the doubly-diffracted rays vanishes for the soft boundary according to the above expression. If a higher order approximation for the doubly-diffracted field is employed, then this contribution is non-vanishing, as will be explained later.

The field of the ray singly-diffracted at $Q_F$ has a shadow boundary $SB(Q_F)$ as shown in Fig. 3; the singly-diffracted ray does not penetrate the shaded region. It will be shown next that the discontinuity in the field of the singly-diffracted ray at $SB(Q_F)$ is compensated by the ray doubly-diffracted from $Q_F$, so that the total diffracted field is continuous at this boundary. Since the field doubly diffracted vanishes in the case of the soft boundary, we only need to treat the hard boundary here.

Consider a point close to $SB(Q_F)$ so that $\phi_2 = \pi - \varepsilon$, the total diffracted field at this boundary is

$$U^{TD} = \begin{cases} U^i(Q_F) \frac{D_h(\pi - \varepsilon,0) e^{-jks}}{\sqrt{s}} , & \varepsilon < 0 \\ U^i(Q_F) \frac{D_h(\phi_1,\phi') e^{-jks_1}}{\sqrt{s_1}} + U^i(Q_F) \frac{D_h(\pi - \varepsilon,0) e^{-jks}}{\sqrt{s}} , & \varepsilon > 0 \end{cases}$$ (19)
where $s_1, \phi_1$ are the coordinates of the ray diffracted from $Q_E$, and

$$U^i(Q_F) = U^i(Q_E) D_h\left(\frac{3\pi}{2}, \phi_1\right) e^{-jkh}\frac{\sqrt{n}}{J_h}. $$

When $\phi_2 = 0$ and the singly-diffracted ray grazes the vertical surface, the second and fourth terms in the expression for the diffraction coefficient are the same, except for the ± sign of the latter. This is also true for the first and third terms. As a result,

$$D_h(\pi-\epsilon, 0) = \frac{-e^{-j\pi/4}}{n\sqrt{2\pi k}} \left\{ \cot\left(\frac{\epsilon}{2n}\right) F[kL\arctan(1-\epsilon)] 
+ \text{smaller terms which are continuous at } SB(Q_E) \right\}. $$

As $\epsilon \to 0$, it is seen from Eqs. (12), (13), (14) and (15) that

$$D_h(\pi-\epsilon, 0) = -\sqrt{\frac{hs}{s+h}} \text{sgn } \epsilon; $$

furthermore,

$$s_1 = h + s. $$

Substituting Eqs. (22) and (23) into Eq. (19) and making use of Eq. (20), it is seen that the total diffracted field is continuous at the boundary $SB(Q_E)$.

As we have already noted, in the case of a soft boundary the field of an incident-ray grazing the surface vanishes, the edge-diffracted field is then proportional to the normal derivative of the incident field at the edge. The proportionality factor is a diffraction coefficient $D'$ given by Karp and Keller [8]. Thus, for the case of Dirichlet problem, the doubly-diffracted field must be replaced by

$$U^d(Q_E, Q_F) = \frac{\partial U^i(Q_F)}{\partial n} \frac{D'(\phi_2, 0)}{2 \sqrt{2} \frac{ek}{\sqrt{S}}} e^{-jks} $$

where

$$D'(\phi_2, 0) = \frac{1}{jk} \frac{\partial}{\partial \phi_1} D_s(\phi_2, 0). $$
The derivate $3U(Q_p)/an$ is taken with respect to the normal to the surface $Q_pQ_r$. This contribution is weak in comparison with that of the singly-diffracted rays; the contribution of the former is of order $(1/k^2)$, whereas that of the latter is of order $(1/r)$. In calculating the field diffracted from the soft cylinder, it was found that the field of the doubly-diffracted rays did not contribute significantly, so the contribution from these rays can be omitted in this case.

Let us now turn to the diffraction by a rectangular cylinder illuminated by a line source. Depending on the location of the line source, the whole domain surrounded by the cylinder will be divided into regions by the various shadow boundaries and the reflection boundaries. Each of these boundaries is labeled to indicate how it originates. For example, referring to Fig. 4, the notation $SB$ means the shadow boundary of the incident geometrical optics field $U_r(P)$, $RB(A-B)$ is the shadow boundary of the geometrical optics field $U(A-B)$ reflected from the surface $A-B$, $SB(A)$ is the shadow boundary of the singly-diffracted $U^d(A)$, which emanates from the edge $A$, and $SB(A,B)$ is the shadow boundary of the doubly-diffracted field $U^d(A,B)$ which emanates from the edge $B$. The shadow boundary of the reflected field is referred to simply as the reflection boundary.

Fig. 4. Shadow and reflection boundaries of the GTD fields.
<table>
<thead>
<tr>
<th>REGION</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>XIII</th>
<th>XIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu^i$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$\mu^r(A-B)$</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu^d(A)$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$\mu^d(B)$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$\mu^d(A,B)$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$\mu^d(B,A)$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$\mu^d(A,D)$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$\mu^d(B,C)$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

A check (✓) means the field is non-vanishing in the region

**TABLE I**
In what follows we may locate the line source in the upper left hand quadrant of the space surrounding the cylinder, without loss of generality. Three cases will be considered.

1) First, the line source is located directly above the cylinder. The whole domain around the cylinder is divided into 14 regions as shown in Fig. 4. Table I shows the regions covered by each type of ray. To demonstrate the use of the table, let us consider an observation point P in region IX. Examining the column under region IX of Table I, one finds checks(\(\checkmark\)) for \(U^d(A)\), \(U^d(B,A)\), \(U^d(A,D)\), and \(U^d(B,C)\). Thus the total field at P is equal to \(U^t(P) = U^d(A) + U^d(B,A) + U^d(A,D) + U^d(B,C)\).

2) The line source is located to the upper left of the cylinder as shown in Fig. 5. In this case there are 18 regions. Table II shows the regions where a particular ray exists and its field makes a non-vanishing contribution.

3) Line source at grazing incidence. Let the line source be located in the plane which contains the A-D side of the rectangular cylinder as shown in Fig. 6. This case is of special interest because the trailing edge D lies in the shadow of the leading edge A. Also, it lies on the shadow boundary of the direct geometrical optics field. The behavior of the field at the boundary DP must be treated separately, see Appendix I. As before, the domain surrounding the cylinder is divided into regions as shown in Fig. 6 and Table III gives the regions covered by the individual rays.

Recall that one or more of the various field components is discontinuous at each boundary shown in Figs. 4, 5 and 6 but that all except the discontinuities in the doubly diffracted fields are compensated; e.g., the discontinuities in the geometrical optics field are compensated by the field of the singly-diffracted rays and the discontinuities in the field of the singly-diffracted rays are compensated by the fields of the doubly-diffracted rays.

As a final step in the analysis, the fields of the individual line sources are superimposed to give the field of a linear array of line sources radiating in the presence of the cylinder, see Fig. 7. A computer program has been written to calculate the incident, total and scattered fields once the linear array is specified. Unlike its earlier definition for geometrical optics, the term incident field used here means the field of the array in the absence of the cylinder, and the scattered field is simply the difference between the total field and this incident field. The versatility of such a program is evident; the scattering from the cylinder for a wide variety of illuminations can be studied, and the radiation from antennas in the presence of the rectangular cylinder also can be studied. As a matter of fact, the program
was written originally so that the linear array of line sources, when densely packed, closely approximates the field of an aperture antenna of finite width \( W \). The aperture antenna (more precisely its axis) is directed toward a point \( Q \) on the surface of the rectangular cylinder as shown in Fig. 7. A description of the aperture radiation in terms of an array of discrete line sources is discussed in the following paragraphs.

The aperture distribution may be approximated by a discrete array of line sources which are properly weighted in amplitude and phase. The width of the aperture denoted by \( W \), is divided into \( 2M \) segments; \( M = \) integer). The line sources are positioned at the ends of these segments, which introduces \( 2M + 1 \) line sources. In approximating a continuous distribution, the number \( M \) is selected so that \( 2M + 1 > 10 \frac{W}{\lambda} \), where \( \lambda \) = free space radiated wavelength.

Three types of line sources are available in this program:

Type I  An electric current line source
Type II  A magnetic current line source
Type III  A magnetic current moment line source.

As described earlier, the electric current line source radiates an omnidirectional electric field which is parallel to the edge of the rectangular cylinder, and the magnetic current line source radiates an omnidirectional magnetic field which is parallel to the edge of the rectangular cylinder. The magnetic current moment line source consists of a continuous array of magnetic current moments directed perpendicular to the line of the array and parallel to the aperture in question. This line source radiates an electric field parallel to the edge of the cylinder; however, the field has a pattern, \( |\cos \theta| \), where \( \theta \) is shown in Fig. 7. The strength of these magnetic type line sources is determined from the equivalent magnetic surface currents in the aperture. \( K_S = \mathbf{E} \times \hat{n} \), where \( \mathbf{E} \) is the electric field distribution in the aperture (assumed known) and \( \hat{n} \) is the outward normal to the aperture.

The field of the two-dimensional aperture can be adequately represented in the forward direction by a densely-packed array of type II and type III line sources, but such an array fails to approximate the field adequately at aspects behind the aperture. This limitation is particularly troublesome when calculating the total field. To overcome this difficulty an obliquity factor has been included in the program which multiplies the pattern of each line source. The obliquity factor is \( f(\theta) = \cos^n \frac{\theta}{2} \), where \( n = 0, \frac{1}{2}, 1, 2 \). When \( n = 0 \), the obliquity factor is unity so that the array radiates symmetrically with respect to the axis of its elements. The case \( n = 2 \) occurs naturally in the description of the radiation fields of aperture antennas via the Kirchhoff-Huygens' approximation (for the forward region). The cases \( n = \frac{1}{2}, \) and \( n = 1 \) are added so that the \( n \) which best approximates the measured aperture pattern may be used. It is evident that the obliquity factor results in a pattern null in the direction directly behind the aperture at \( \theta = \pi \). In most practical cases, there is no such null in the backward direction.
Fig. 5. Shadow and reflection boundaries of the GTD fields.
<table>
<thead>
<tr>
<th>REGION</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>XIII</th>
<th>XIV</th>
<th>XV</th>
<th>XVI</th>
<th>XVII</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>μ_i</td>
<td>μ_{d(A,B)}</td>
<td>μ_{d(A-D)}</td>
<td>μ_{d(A)}</td>
<td>μ_{d(B)}</td>
<td>μ_{d(A,B)}</td>
<td>μ_{d(B,A)}</td>
<td>μ_{d(A,D)}</td>
<td>μ_{d(D,A)}</td>
<td>μ_{d(B,C)}</td>
<td>μ_{d(D,C)}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II**
Fig. 6. Shadow and reflection boundaries of the GTD fields.
<table>
<thead>
<tr>
<th>REGION</th>
<th>FIELD</th>
<th>$\mu_i^r(p)$</th>
<th>$\mu_l^r(A-B)$</th>
<th>$\mu_d^r(A)$</th>
<th>$\mu_d^r(B)$</th>
<th>$\mu_d^r(D)$</th>
<th>$\mu_d^r(A,B)$</th>
<th>$\mu_d^r(B,A)$</th>
<th>$\mu_d^r(B,C)$</th>
<th>$\mu_d^r(D,C)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>I</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>II</td>
<td>II</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>III</td>
<td>III</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>IV</td>
<td>IV</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>V</td>
<td>V</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VI</td>
<td>VI</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VII</td>
<td>VII</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VIII</td>
<td>VIII</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>IX</td>
<td>IX</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>XI</td>
<td>XI</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

* See Appendix I
On the other hand, the pattern in the forward region is quite satisfactory when the obliquity factor is included, and as one moves away from the forward region, the pattern drops to a level where the differences between the simulated and measured patterns are unimportant when computing the total field surrounding the rectangular cylinder.

The scattered, and the total fields are computed as a function of \( \theta_s ( - \pi \leq \theta_s \leq \pi ) \) at a range \( R_s \). The incident field pattern on the other hand is available for a phase reference at the center of the array (aperture) at 0 in Fig. 7 and computed at a range measured from 0, as well as for a phase reference at Q with a range \( R_s \) (just as for the scattered and the total fields).

The input and output variables for the computer program are described in Appendix II, and the listing of the computer program is given. Also, a sample case is treated in this appendix to illustrate the use of the program.

III. NUMERICAL RESULTS

To assess the accuracy of the GTD solution described in the preceding section, it was applied to several simple examples, where the rectangular cylinder is illuminated by either an electric or magnetic current line source. Far-zone patterns for the total field are calculated by this method and also from numerical solutions of the pertinent integral equation*.* The cylinders are square with a side length of 1.6

*The computer programs for the integral equation solutions were provided by Prof. J.H. Richmond of the ElectroScience Laboratory.
wavelength, and in each case the line source illuminates the cylinder from a distance of 0.8 wavelength. These small distances provide a stringent test of our GTD solution; also they give us an opportunity to examine the accuracy of the new scalar diffraction coefficients in a situation where the edges are illuminated by curved wavefronts and where the transition regions are relatively broad. The pattern calculated from the integral equation solution must be considered more accurate for the small dimensions chosen for these examples, since the integral equation method is convergent whereas the GTD solution is an asymptotic approximation.

Patterns for magnetic current line source excitation (hard boundary case) are given in Figs. 8, 9 and 10, where the line source is positioned on the diagonal of the square cylinder, on the centerline directly above the cylinder, and at a point of glancing incidence on one of its surfaces. The agreement between the patterns calculated by the GTD and the integral equation method is remarkable—every detail is the same within the limits of graphical accuracy. The corresponding patterns for electric current line source excitation (soft boundary case) are presented in Figs. 11, 12 and 13. Again there is excellent agreement between the two pattern calculations, except in the vicinity region of forward scatter in Figs. 12 and 13. Note that the level of the patterns is very low in these regions, so that small errors in the solution become significant. We hope to look into the reason for these differences at a later time.

The numerical examples considered here confirm the accuracy and applicability of our GTD solution; this is further demonstrated by an example treated in Appendix II. As the size of the cylinder and the distance between the edges of the cylinder and the source (or sources) increases in terms of a wavelength, one can expect the accuracy of the GTD solution to increase, because it is an asymptotic approximation where $k = 2\pi/\lambda$ is a large parameter.

In the case of magnetic current line source excitation there is little evidence of shadowing in the forward direction by the small square cylinder; however, there is distinct evidence of shadowing in the case of electric current line source excitation, where the total electric field is parallel to the cylinder and must vanish at its surface. One should expect this.
Fig. 8. Pattern of a magnetic current line source in the presence of a rectangular cylinder.

$L = 1.6\lambda$
$R_i = 0.8\lambda$
$\theta_i = 45^\circ$
Fig. 9. Pattern of a magnetic current line source in the presence of a rectangular cylinder.
Fig. 10. Pattern of a magnetic current line source in the presence of a rectangular cylinder.
Fig. 11. Pattern of an electric current line source in the presence of a rectangular cylinder.
Fig. 12. Pattern of an electric current line source in the presence of a rectangular cylinder.
Fig. 13. Pattern of an electric current line source in the presence of a rectangular cylinder.
IV. CONCLUSIONS

The GTD has been applied to calculate the radiation from a perfectly-conducting rectangular cylinder in the presence of a linear array of line sources, which may be of the electric current, magnetic current or magnetic current moment type. When densely packed, these sources may be used to approximate the radiation from an aperture. To insure good accuracy in the fields calculated from the solution described here, the separation of source and field points from the edges of the cylinder and the separation of the edges from each other should be not less than 0.7 wavelength. However, for far-zone pattern calculations, the line sources can be only a few tenth of a wavelength from the nearest edge.

The use of new scalar diffraction coefficients valid in the transition regions makes it possible to calculate continuous patterns in the region surrounding the cylinder away from its edges. Radiation patterns calculated from this solution and from an integral equation solution are found to be in excellent agreement for a number of stringent test cases. This demonstrates the utility and accuracy of the new diffraction coefficients and the overall accuracy of GTD as it has been applied to this problem.
APPENDIX I

THE FIELD AT THE SHADOW BOUNDARY OF A THICK SCREEN FOR GRAZING INCIDENCE

In this appendix we derive an expression for the field near the shadow boundary of a thick, perfectly conducting screen illuminated by a line source at grazing incidence, as shown in Fig. 14. The solution near the shadow boundary in the forward direction is of interest. In the following development we employ Eqs. (5) through (10) in the text, the subscript h on the hard scalar diffraction coefficient has been omitted, and it is convenient to use the function

\[ f(x) = e^{-jkx} \sqrt{x} \]

![Diagram of shadow boundary of a thick screen for grazing incidence.](Image)

Fig. 14. Shadow boundary of a thick screen for grazing incidence.
Let the strength of the line source be such that the incident field at \( P \) is

\[ U^i(P) = f(\xi_0) . \tag{A-2} \]

The total field at \( P \) is the sum of the incident field plus the field of the ray singly-diffracted from edge 1 and the field of the ray doubly-diffracted from edge 2. In the illuminated region, \( \varepsilon > 0 \),

\[ U(P) = f(\xi_0) + f(\xi_1) D(\phi_1, \frac{\pi}{2}, L_1) f(\xi_1) + \frac{1}{2} U^i(2) D(\phi_2, 0, L) f(\xi_2) . \tag{A-3a} \]

In the shadow region, \( \varepsilon < 0 \),

\[ U(P) = \frac{1}{2} U^i(2) D(\phi_2, 0, L) f(\xi_2) . \tag{A-3b} \]

Here,

\[ \phi_2 = \pi - \varepsilon , \tag{A-4a} \]

\[ L_1 = \frac{\xi_1 \xi_1}{\xi_1 + \xi_1} , \tag{A-4b} \]

\[ U^i(2) = f(\xi_1 + h) + f(\xi_1) \left[ -\frac{2}{3} e^{-j\frac{\pi}{4}} \cot\left(\frac{2\pi}{3} F(2kL_1)\right) f(h) \right] , \tag{A-4c} \]

in which

\[ L_1' = \frac{\xi_1 h}{\xi_1 + h} . \tag{A-4d} \]

Thus for \( \varepsilon > 0 \),

\[ U(P) = f(\xi_0) + f(\xi_1) D(\phi_1, 0, L_1) f(\xi_1) + \frac{1}{2} f(\xi_1 + h) D(\phi_2, 0, L_2) f(\xi_2) \]

\[ + \frac{1}{2} f(\xi_1) f(h) \left[ -\frac{2}{3} e^{-j\frac{\pi}{4}} \cot\left(\frac{2\pi}{3} F(2kL_1)\right) D(\phi_2, 0, L) f(\xi_2) \right] . \tag{A-5a} \]
and for \( \varepsilon < 0 \),

\[
(A-5b) \quad U(P) = \frac{1}{2} f(\ell_1 + h) \ D(\phi_2, 0, L_2) \ f(\ell_2) + \frac{1}{2} f(\ell_1) f(h) \cdot \left[ -\frac{2}{3} e^{-\frac{j}{\varepsilon}} \ \pi/4 \ \cot\left(\frac{2\pi}{3}\right) \ F(2kL_1) \right] D(\phi_2, 0, L) \ f(\ell_2),
\]

where

\[
(A-6) \quad L_2 = \frac{(\ell_1 + h) \ell_2}{\ell_1 + h + L_2}.
\]

and \( \ell \) is a distance parameter determined by the wavefront curvature of the field incident on edge 2 which has been singly-diffracted from edge 1. Since edge 2 is in the transition region of this field, the curvature of this wavefront is not simply that of a cylindrical wave emanating from edge 1; i.e., \( \ell \neq h \ell_2 / (h + L_2) \). We will determine \( \ell \) by requiring \( U(P) \) to be continuous at the shadow boundary.

As \( \varepsilon \to 0 \),

\[
(A-7) \quad D(\phi_2, 0, L_2) = \frac{-e^{-\frac{j}{\varepsilon}} \ \pi/4 \ 2n}{n\sqrt{2\pi k}} \ \sqrt{\frac{\pi k L_2}{2}} \ |\varepsilon| \ e^{j \pi/4}.
\]

\[
= -\sqrt{\ell_2} \ sgn \ \varepsilon.
\]

In a similar manner,

\[
(A-8) \quad D(\phi_2, 0, L) = -\sqrt{\ell} \ sgn \ \varepsilon.
\]

Furthermore, as \( \varepsilon \to 0 \)

\[
(A-9) \quad D(\phi_1, 0; L) = -\frac{2}{3} e^{-\frac{j}{\varepsilon}} \ \pi/4 \ \cot\left(\frac{2\pi}{3}\right) \ F(2kL_1) \ \sqrt{2\pi k}.
\]

Substituting Eqs. (A-7), (A-8) and (A-9) into Eqs. (A-5a), (A-5b) and requiring \( U(P) \) to be continuous at the shadow boundary \( \varepsilon = 0 \), we see that
\[
(A-10) \quad \frac{e^{jk(l_1 + l_2)}}{\sqrt{2l_1 l_2}} \left\{ -\frac{2}{3} e^{-j \pi/4} \cot\left(\frac{2\pi}{3}\right) \frac{F(2kL_1)}{\sqrt{2\pi k}} \right\} = \\
\quad \frac{e^{-jk(l_1 + h + l_2)}}{\sqrt{2l_1 h l_2}} \left\{ -\frac{2}{3} e^{-j \pi/4} \cot\left(\frac{2\pi}{3}\right) \frac{F(2kL_1)}{\sqrt{2\pi k}} \right\} \sqrt{\frac{l_1}{l_2}}
\]

where \( h + l_2 = l_1 \) at \( \varepsilon = 0 \).

From which

\[
(A-11) \quad \frac{l_1}{l_2} = \left(\frac{h}{h + l_2}\right) m
\]

with

\[
(A-12) \quad m = \left[\frac{F(2kL_1)}{F(2kL_1')}\right]^2
\]
APPENDIX II
DESCRIPTION OF THE COMPUTER PROGRAM

A. Input Variables

N : is the number of sources in the array which approximates the aperture distribution. Here N = 2M+1, where M is an integer (. . N is an odd integer), and M has been introduced earlier in section II. The DIMENSION cards at the beginning of the program must be dimensioned as N or larger.

TYPE : is a reference parameter. TYPE is set equal to 1.0 when sources of type I (see section II) are used. TYPE is likewise set equal to 2.0 for type II, and is set equal to 3.0 for type III sources, respectively.

AL : is the aperture width (= W of Fig. 7).

AM(I): is the magnitude of the Ith source in the array which approximates a given aperture distribution.

AP(I): is the phase of the Ith line source in the array (which approximates a given aperture distribution), in RADIANS.

X : is the point of incidence on the 2-D box and corresponds to X shown in Fig. 7.

XL : is the length of the box (corresponding to XL of Fig. 7).

H : is the height of the box (it corresponds to h in Fig. 7).

RI : is the incident range (corresponding to R_i in Fig. 7).

RS : is the scattered range (corresponding to R_s in Fig. 7).

THI : is the angle of incidence (corresponding to $\theta_i$ in Fig. 7).

XLAMDA: is the transmitted wavelength.

Note that the variables AL, XL, H, X, RI and RS have the same units as XLAMDA.

B. Output Variables

THS : is the angle of scattering (corresponding to $\theta_s$ in Fig. 7) in degrees.

ATAL : magnitude of the total field.
DBTAL: magnitude of the total field in dB.

DBSAS: magnitude of the scattered field in dB.

DBGA: incident field with phase center at Q (Fig. 7) as a function of THS, in dB.

PHASE: phase of the total field in degrees.

TH: angular variable corresponding to (Fig. 7), in degrees

DBHA: incident field with phase center at 0 (Fig. 7) in dB, as a function of TH. Note that DBHA is an output variable in the Subroutine TEST.

C. Instructions for Representing Aperture Field Distribution by a 2-D Line Source Array.

When dealing with the input variables AM(I) and AP(I) for Ith source in the planar array used to approximate a given aperture distribution, the ordering of the array elements is done as follows:

Fig. 15. The ordering arrangement of the line sources used to approximate a given aperture distribution.

Let N = 11, where N is the number of line sources approximating a given aperture distribution over the aperture width W. The ordering arrangement for these sources is indicated in Fig. 15. The source at the center of the aperture is the one for which I = 1. I = 2, 3, 4, 5 and 6 for sources to the right of the one designated by I = 1 (as one views the 2-D box from the aperture center). Similarly, I = 7, 8, 9, 10 and 11 for sources to the left of the source at the center (designated by I = 1).

Let the aperture distribution (assumed known) be represented by the quantity F = |F|e^i\psi over the aperture. |F| represents the magnitude of
the field distribution over the width $W$, and $\psi$ represents the phase of the field distribution over the width $W$. Hypothetical plots of $|F|$ and $\psi$ over the aperture are indicated below:

Fig. 16 clearly indicates the amplitudes and phases of the sources designated by $I = 1, 5$ and $9$. For example, the magnitude of the line source strength corresponding to $I = 9$ is given by $AM(9)$, and its phase is given by $AP(9)$. Similarly, one can obtain the amplitudes and phases of all the other line sources. Note that the aperture is divided into $2M$ segments, where $M = 5$. Hence, the number of sources, $N = 2M+1 = 11$. 
D. Instructions for Using the 'Obliquity Factor'

The fields radiated by apertures are non-symmetrical on either side of the aperture, in most practical cases. The fields radiated by the 2-D line source array discussed above are symmetrical on either side of the planar 2-D array. Thus, an obliquity factor of the type \( \cos^n \theta/2 \) (please refer to the discussion in section II) is included for computing the field radiated by each source in the array. The obliquity factor is different for each \( n \), where \( n = 0, 1, 2 \). A function statement \( FB(SX) \) computes this obliquity factor for a given value of \( n \). Specifically, the statement concerning \( FB(SX) \) reads:

\[
FB(SX) = \text{ABS}(\cos(SX/2.0))^{**2.0}
\]

and corresponds to an obliquity factor with \( n = 2.0 \). If any other value of \( n \) is desired, the appropriate value must be punched into a new card which replaces the previous one. Note that the value of \( n \) directly follows the ** symbol in the statement.

The obliquity factor \( \cos^n \theta/2 \) is plotted as a function of \( \theta \) for different values of \( n \) (\( n = 1, 2 \)) in Fig. 17. When the pattern of an isotropic source is multiplied by \( \cos^n \theta/2 \), it is evident from the resultant pattern that the obliquity factor serves to control the level of the radiation pattern primarily in the range \( \pi/3 < \theta < 5\pi/3 \). The case \( n = 0 \) corresponds to the isotropic case.

E. Instructions for Computing the Incident Field

Two incident field patterns are computed, one is for a phase reference at the center of the aperture, and the other is for a phase reference at \( Q \) (see Fig. 7). In the former case, the radiation pattern in dB is designated by \( \text{DBHA} \), and is obtained as a function of \( \theta \) (or \( \text{TH} \) as defined in the computer program). In the latter case, the radiation pattern in dB is designated by \( \text{DBGA} \) and is obtained as a function of \( \theta_s \) (or \( \text{THS} \) as defined in the computer program). \( \text{DBGA} \) is computed at a distance equal to \( R_s \) from \( Q \). \( \text{DBHA} \) has been programmed for a range of \( R_i + R_s \) from \( 0 \) (center of the aperture as shown in Fig. 7); however, if the user wishes to change the present range for \( \text{DBHA} \), only one card in the program deck needs modification. A subroutine designated \( \text{TEST} \) computes \( \text{DBHA} \) at a range of \( R_i + R_s \) from \( 0 \); the call statement for this subroutine is

\[
\text{CALL TEST} \ (N, AL, RS+RI, A, \text{TYPE})
\]

If a different value of the range is desired, one must replace \( RS+RI \) in the call statement above by a number which equals the desired value for the range. Note that the new range should have the same unit as those of \( \lambda \) (corresponding to \( \text{XLAMDA} \) in the computer program).
Fig. 17. Patterns of the obliquity factor for different values of $n$.

F. Sample Programs

In this section, we present a sample case which serves to illustrate the use of our computer program. The example selected involves an array of three magnetic line sources of unit strength which illuminate a rectangular cylinder, as in Fig. 18. We utilize the computer program for calculating the incident field of the array, the field scattered by the 2-D box (rectangular cylinder) and the total field (incident + scattered) surrounding the 2-D box.
Fig. 18. An array of three line sources in the presence of a square cylinder.

The ordering of the array elements is shown in Fig. 18, where the source at the center is labeled source #1. Note that source #1 corresponds to I = 1, and sources #2 and #3 correspond to I = 2, and I = 3, respectively. For this particular problem, AM(1), AM(2) and AM(3) are each equal to 1.0, and AP(1), AP(2) and AP(3) are each equal to 0.0, because the line sources are of unit strength and zero phase. An obliquity factor corresponding to \( n = 2 \) (i.e., obliquity factor = \( \cos^2 \theta_e/2 \)) has been incorporated into the program for the incident field pattern, and the incident field pattern corresponding to DBHA (phase reference at source #1) is plotted in Fig. 19. Also included in Fig. 19 is the incident field pattern without the obliquity factor (\( n = 0 \) case) for the sake of comparison. The pattern of the scattered field designated by DBSAS, and computed for values of \( \theta_s \) (or THS) which lie in the range \(-180^\circ \leq \theta_s \leq 180^\circ\), is plotted in Fig. 20. The scattered field obtained by our method is compared against that obtained from a numerical solution to the integral equation for this problem given by J. H. Richmond; these results agree perfectly. Finally, the total field (incident plus scattered, each being phase referenced at Q) is also obtained, and is designated by DBTAL. DBTAL is computed as a function of \( \theta_s \) (THS in the program) and the results are indicated in Fig. 21 by a dashed curve. The solid curve is added for the sake of comparison; it corresponds to the total field when the incident field has no obliquity factor in it.
Fig. 19. Patterns of an array of three magnetic line sources of equal strength, with and without the obliquity factor.
Fig. 20. Pattern of the field scattered by a square cylinder which is illuminated by an array of three magnetic line sources.
Fig. 21. Pattern of an array of three magnetic line sources in the presence of a square cylinder.
PROGRAM LS05BOX(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
PROGRAM LS05BOX IS PHENIX AUGUST 1972
C
C N THE NUMBER OF LINE SOURCES OR ELEMENTS IN THE ARRAY
C TYPE 1.0 IS ELECTRIC CURRENT LINE SOURCE
C TYPE 2.0 IS MAGNETIC CURRENT LINE SOURCE
C TYPE 3.0 IS MAGNETIC CURRENT MOMENT LINE SOURCE
C AL APERTURE WIDTH
C AM(I) MAGNITUDE OF THE(I)TH ELEMENT
C AP(I) PHASE OF THE(I)TH ELEMENT
C A(I) FIELD STRENGTH OF THE(I)TH ELEMENT
C D(I) SPACING BETWEEN(I+1)TH AND(I)TH ELEMENTS
C XLAMCA TRANSMITTED WAVELENGTH
C X THE POINT OF INCIDENCE
C XL THE LENGTH OF THE BOX
C H THE HEIGHT OF THE BOX
C RI INCIDENCE RANGE
C KS SCATTERING RANGE
C Thi ANGLE OF INCIDENCE 0 TO 65
C Ths ANGLE OF SCATTERING -65 TO 65
C XP,YP OBSERVING POINT
C Xs(I),Ys(I) SOURCE POINT OF THE(I)TH ELEMENT
C DS DIFFRACTION COEFFICIENT FOR SOFT BOUNDARY
C DH DIFFRACTION COEFFICIENT FOR HARD BOUNDARY
C Ga(I) DIRECT INCIDENT FIELD DUE TO(I)TH ELEMENT
C Ra(I) REFLECTED FIELD DUE TO(I)TH ELEMENT
C Dar(I) FIRST ORDER DIFFRACTED FIELD FROM THE RIGHT EDGE DUE TO(I)TH ELEMENT
C Dar2(I) 2ND ORDER DIFFRACTED FIELD FROM THE RIGHT EDGE DUE TO(I)TH ELEMENT
C Dar3(I) 3RD ORDER DIFFRACTED FIELD FROM THE RIGHT EDGE DUE TO(I)TH ELEMENT
C Dal(I) FIRST ORDER DIFFRACTED FIELD FROM THE LEFT EDGE DUE TO(I)TH ELEMENT
C Dal2(I) 2ND ORDER DIFFRACTED FIELD FROM THE LEFT EDGE DUE TO(I)TH ELEMENT
C Dal3(I) 3RD ORDER DIFFRACTED FIELD FROM THE LEFT EDGE DUE TO(I)TH ELEMENT
C Ta(I) THE FIELD AT THE OBSERVING POINT DUE TO(I)TH ELEMENT
C Total TOTAL FIELD AT OBSERVING POINT DUE TO ALL THE ELEMENTS
C Dbital MAGNITUDE OF THE TOTAL FIELD EXPRESSED IN DB
C Dbsas MAGNITUDE OF THE SCATTERED FIELD EXPRESSED IN DB
C Dpha DIRECT INCIDENT FIELD EXPRESSED IN DB
C Phase PHASE OF THE TOTAL FIELD EXPRESSED IN DEGREES
C Atal AMPLITUDE OF TOTAL FIELD AND ALSO OF INCIDENT FIELD IN SUBROUTINE TEST

000003 DIMENSION DAL(1000)
000003 DIMENSION CAI(51),CA2(51),DAL3(51),Ta(51)
CALL P5F00
READ(5,1111),N,TYPE,AL,SOURCE
110 FORMAT(110,2F10.4,AP)
WRITE(6,2110,N,TYPE,AL,SOURCE
210 FORMAT ///,3IX*ELEMENTS*3X*TYPE= *F3.1,3X*APERTURE WIDTH= *F7.4,3X
1AU* CURRENT LINE SOURCE*/
READ(5,1114),(AM(I),AP(I)),I=1,N)
114 FORMAT(1CF8.4)
PRINT 2114, (I,AM(I),AP(I)),I=1,N )
2114 FORMAT //,15X*AM*10X*AP*/(15X*N(*2*1=2F10.4))
PRINT 8889
8889 FORMAT (1H1)
N=AM=N-1
IF(N.EQ.1) GO TO 6666
DC 1000 JJ=1,N
D(JJ)=AL/FLOAT(NNN)
1600 CNTINUE
GU TO 7777
6066 D(I)=0.0
7777 CNTINUE
DD 1115 M=1,N
AM=M-AM(M)*CEXP(CMPLX(0.0,AP(M)))
WRITE(6,665)M,AM(M)
665 FORMAT (5X,*AM(*12,*)=*,2F10.4)
1115 CNTINUE
6799 CNTINUE
READ(5,1111)XLAMDA,X,XL,H,RI,RS,THI
1111 Format (7F10.4)
IF(EH,5)1112,6790
1112 CNTINUE
6790 CNTINUE
WRITE(6,2111)XLAMDA,X,XL,H,RI,RS,THI
CC0426 2111 Format (H1,5X,*XLAMDA= *,F7.4,*,X= *,F7.4,*,L= *,F7.4,*,R= *,F9.4,*,THI= *,F7.4/////)
CC0426 000426 PI= 2.141592653589
CC0427 TP=2.*PI
CC0431 STP=SORT(TP)
CC0433 SORTPI=SORT(TPI)
CC0435 TT=PI/180.
CC0437 TTDEG=180.*/PI
C
000446 IF(TYPE. GT. 2.0) R = 1.0
C
000452 XLM = XL / XLAMDA
C
000453 HW = H / XLAMDA
C
000455 *"L = THI * TT
C
000457 L IS 1 . GT. THE NUMBER OF POINTS. NPTS. TO BE PLOTTED
C
000460 THS = 181.0
C
000462 GO TO 5998
C
000464 9999 CONTINUE
C
000466 THS = THS * TT / DEG
C
000468 ATAL = G.
C
000464 CBTA1 = 0.
C
000465 DBGA = G.
C
000466 OBSAS = 0.
C
000467 PHASE = 0.
C
000471 PRINT 4, THS, ATAL, CBTA1, DBGA, OBSAS, PHASE
C
000510 IF ( ATAL. EQ. 0.0) GO TO 5
C
000511 9998 CONTINUE
C
000517 I = 1
C
000519 THS = THS - 2.0
C
000514 IF (THS . LT. -180.0) GO TO 1
C
000516 THS = THS * TT
C
000517 XS(i) = X + RI * SIN(THI)
C
000525 YS(i) = R1 * COS(THI)
C
000532 XP = XP + KS * SIN(THS)
C
000536 YP = KS * COS(THS)
C
000541 TE = ATAN2(YP, XP)
C
000544 TB = ATAN2(YP, XP - XL)
C
000552 20 CONTINUE
C
000552 TC = ATAN2(YS(i), XL - XS(i))
C
000557 TD = ATAN2(YS(i), -XS(i))
C
* 000564 BOND = 0.01 * TT
C
*
C

ANY ONE OF THE 11 IF STATEMENTS ENDING IN GO TO 9999 MAY CAUSE THE
CURRENT ODD NUMBERED THIS ANGLE IN DEG TO BE SKIPPED

C

XR=(XP*YS(I)+XS(I))YP/(YS(I)+YP).

C

RO(I)=SQRT((XP-XS(I))*(XP-XS(I))+(YP-YS(I))*(YP-YS(I)))/XLAMDA

C

OE(I)=PI

C

IF(ABS(THS+THI).GT.BCND) OB(I)=FA(RS,R1,RO(I)*XLAMDA)

C

R1=WLNURM*SQRT((XR-XS(I))*(XR-XS(I))+(YS(I))*(YS(I))

C

R2=WLNCRM*SQRT((XP-XK)*(XP-XK)+(YP*YP))

C

R3=WLNORM*SQRT((XL-XS(I))*(XL-XS(I))+(YS(I))*(YS(I))

C

R4=WLNURM*SQRT((XP-XL)*(XP-XL)+(YP*YP))

C

R5=WLCRHM*SQRT((XP-XL)*(XP-XL)+(YP+H)*(YP+H))

C

R6=WLVJR*SQRT((-XS(I))*(-XS(I))+(YS(I))*(-YS(I))

C

R7=WLCRHM*SQRT((XP*XP)+(YP*YP))

C

R8=WLNURM*SQRT((XP*XP)+(YP+H)*(YP+H))

C

R9=WLNURM*SQRT((XS(I))*XS(I)+(YS(I)+H)*(YS(I)+H))

C

PHP=(PI-ATAN2(YS(I),XS(I)-XL))*TTDEG

C

PH1=(PI-ATAN2(YP,XP-XL))*TTDEG

C

PH2=(PI-ATAN2(XP-XL,-H-YP))*TTDEG

C

PH3=270.0-PH1

C

THP=(ATAN2(YS(I),XS(I)))*TTDEG

C

TH1=(PI-ATAN2(YP,-XP))*TTDEG

C

TH2=(PI-ATAN2(-XP,-H-YP))*TTDEG

C

TH3=(30.0-PH1)

C

TH4=ATAN2(-XS(I),YS(I)+H)

C

IF(XS(I).LT.0.0.0.AND.ABS((THI-THS)/TT-180.0).LE.1.3) GO TO 9999

C

IF(XS(I).LE.0.0.0.AND.ABS((THI-THP-180.0).EQ.0.0) GO TO 9999

C

IF(XS(I).GT.0.0.0.AND.ABS((TH2-THP-180.0).EQ.0.0) GO TO 9999

C

IF(ABS(PHI-PHP-180.0).EQ.0.0) GO TO 9999

C

CA=G(R3,R4)

C

CALL DFHC=(DA,1.5,CA,P1-PHP,1.)

C

CALL DFHCF(DA,1.5,CA,P1-PHP,1.)

C

DK1=DH(DA,DB)

C

21400000
CALL DFCF(ZA,1.5,OK,TH2-TH4/TT,1.0)
001557 CALL DFCF(ZB,1.5,OK,TH2+TH4/TT,1.0)
001566 DLL=DL(ZA,ZB)
001575 IF(TYPE.NE.2.0) DLL=DS(ZA,ZB)
001606 DAL[1]=A(I)*F(R9)*DLL*F(R8)
001632 CAL(I)=CAL(I)*FB(TH1-TH4)
001642 GA(I)=A(I)*F(R0(I))
001655 GA(I)=GA(I)*F(R(I))
001665 RA(I)=A(I)*F(R1*R2)
001701 RA(I)=RA(I)*FB(THI-ATAN2(XS(I),ABS(XR-XS(I))))
001717 DAR1(I)=DAR1(I)*FB(0.5*P1-TH1-PHP*TT)
00176 DAR2[1]=A(I)*F(R3)*DR[21]*F(HW)*Q.*DR*22*F(R5)
002014 DAR2[1]=DAR2[1]*FB(0.5*P1-TH1-PHP*TT)
002027 DAL[1]=A(I)*F(R6)*DL[21]*F(R7)
002053 DAL[1]=DAL[1]*FB(0.5*P1+TH1-DHP*TT)
002066 DAL[1]=A(I)*F(R6)*DL[21]*F(HW)*Q.*DL[22]*F(R8)
002124 DAL[1]=DAL[1]*FB(0.5*P1+TH1-DHP*TT)
002137 IF(XS(I).EQ.0.0) DAL[1]=0.5*DAL[1]
002147 YL2=G(R8,R6+H)
002153 XF=2.0*G(R6,H+R8)
002161 CALL CS(R,S;XF)
002163 CALL WANG(TH2,0.0,1.5,YL2,HA,HB)
002167 CALL WANG(270.0,0.0,1.5,YL2,HC,HD)
002173 PLUS=A(I)*F(R6)*FL(XS;CDF)*COT(TP/3.0)*PW(0.125)*F(HW)/3.0/STP
002243 IF(TYPE.NE.2.0) HA=HB
002247 IF(XS(I).EQ.0.0) DAL[1]=DAL[1]+PLUS*HA*F(R8)
002270 IF(XS(I).EQ.0.0) AND TYPE.EQ.1.0) DAL[2]=CMPLX(0.0,0.0)
002306 IF(XS(I).GE.0.0) DAL[1]=CMPLX(0.0,0.0)
002316 C DAL[1]=CMPLX(0.0,0.0)
002325 C DAR3[1]=CMPLX(0.0,0.0)
002333 WX=G(R9,HW)
002335 CALL DFCF(ZX,1.5,WX,0.0-TH4/TT,1.0)
002343 CALL DFCF(ZY,1.5,kx,0.0+TH4/TT,1.0)
002352 DL8=DH(ZX,ZY)
002361 IF(TYPE.NE.2.0) DL8=DS(ZX,ZY)
DAL(1) = A(1) * F(49) * CY + Z0 * S(HW) * DL3 * F(R7)
DAL(1) = DAL(1) * F31 * TH1 * TH4
IF (X5(1) .GT. 0.0) DAL(1) = CMPLX (0.0, 0.0)
IF (TH1 = .78751 AND TH1 = .360.0) DAL(1) = CMPLX (0.0, 0.0)
H1 = SQRT (XP * XL1 * (XP * XL1) * (YP * H1) * (YP * H1)) / XL4 * YDA
TH15 = (PI - ATAN2 (YP, XP - XL1)) * TTUEG
PA = G (XW1, ZR1)
CALL DFKCF (ZP, 1.5, PA, 270.0, TH3 / TT, 1.0)
CALL DFKCF (ZC, 1.5, PA, 270.0, TH3 / TT, 1.0)
DL1 = DH (ZP, ZQ)
IF (TYPE = NF .EQ. 2.0) DL = CS (ZP, ZQ)
PB = G (XLW, R10)
CALL DFKCF (ZR, 1.5, PB, 0.0, TH5, 1.0)
CALL DFHCF (ZS, 1.5, PB, 0.0, TH5, 1.0)
DLT2 = DH (ZR, ZS)
IF (TYPE = NF .EQ. 2.0) DL = DS (ZR, ZS)
DB2(1) = A(1) * F(H9) * CBL1 * (XW1) + 0.5 * DBL2 * F(R10)
DB2(1) = DB (2.0) * F31 * (TH1 - TH4)
IF (X5(1) .GT. 0.0) DB2(1) = CMPLX (0.0, 0.0)
IF (X5(1) .LT. 0.0) DB2(1) = 0.5 * DB2(1)
IF (TYPE = NE .EQ. 2.0) HC = HD
IF (X5(1) .LT. 0.0) DB2(1) = DB(2.1) - PLUS * HC * (XW1) * DBL2 * F(R10)
IF (TH5 = 3.5 AND .TH5 = .360.0) DB2(1) = CMPLX (0.0, 0.0)
QX = G (XK3, XLW)
CALL DFKCF (ZG, 1.5, PQ, 0.0, PHP, 1.0)
CALL DFKCF (ZH, 1.5, PQ, 0.0, PHP, 1.0)
DLT1 = DH (ZG, ZH)
IF (TYPE = NE .EQ. 2.0) DLT1 = DS (ZG, ZH)
W = G (R7, XLW)
CALL DFHCF (ZM, 1.5, CH, TH1, 1.0)
CALL DFHCF (ZN, 1.5, CW, TH1, 1.0)
DLK2 = DH (ZM, ZN)
IF (TYPE = NF .EQ. 2.0) DLK2 = CS (ZM, ZN)
DLR(1) = A(1) * F(R3) * DLK1 * F(XLW) * 0.5 * DLR2 * F(R7)
DLR(1) = DLR(1) * F8 (0.5, PI - TH1 - PHP * TH)
IF (TH1 = .78751 AND .TH1 = .360.0) DLR(1) = CMPLX (0.0, 0.0)
QZ = G (R6, XLW)
CALL DFKCF (ZC, 1.5, QZ, 0.0, PHP, 1.0)
CALL DFKCF (ZD, 1.5, QZ, 0.0, PHP, 1.0)
DLR(1) = DH (ZC, ZD)
IF (TYPE = NE .EQ. 2.0) DLR1 = CS (ZC, ZD)
QY = G (XH4, R4)
034130  IF (TYPE.EQ.3.0) DAL2(I)=DAL2(I)*COS(0.5*PI+TH1-THP*TT)
034147  IF (TYPE.EQ.3.0) DAL8(I)=DAL8(I)*COS(TH1-TH4)
034163  IF (TYPE.EQ.3.0) DB2(I)=DB2(I)*COS(TH1-TH4)
034177  IF (TYPE.EQ.3.0) DLR(I)=DLR(I)*COS(0.5*PI+TH1-THP*TT)
034216  IF (TYPE.EQ.3.0) DKL(I)=DKL(I)*COS(0.5*PI+TH1-THP*TT)

034235  IF (YP.GT.0.0) GO TO 3333
044240  KAI(I)=Cmplx(0.0,0.0)
044261  IF (XS(I).GE.0.0 AND PHI1-PHI.EQ.180.0 OR TH1-THP.EQ.180.)
044264  1 GO TO 9999

044312  IF (XS(I).LT.0.0 AND PHI1-PHI.EQ.180.0 AND TH1-THP.EQ.180.)
044313  1 GA(I)=Cmplx(0.0,0.0)
044356  IF (PHI1.GT.270.0 AND PHI1.LT.360.0) CAR1(I)=Cmplx(0.0,0.0)
044375  IF (TH1.GT.270.0 AND TH1.LT.360.0) DAL1(I)=Cmplx(0.0,0.0)
044414  IF (PH2.GE.270.0 AND PHI2.LT.360.0) CAR2(I)=Cmplx(0.0,0.0)
044433  IF (TH2.GE.270.0 AND TH2.LT.360.0) DAL2(I)=Cmplx(0.0,0.0)
044532  IF (TH3.LT.0.0) DAL3(I)=Cmplx(0.0,0.0)
044669  IF (PHI3.LT.0.0) CAR3(I)=Cmplx(0.0,0.0)
044743  IF (TH2.GE.270.0 AND TH2.LT.360.0) DAL(I)=Cmplx(0.0,0.0)
044513  IF (XS(I).LT.0.0 AND XP.LT.0.0) KA(I)=AT(I)*R*(SQRT((XS(I)+XP)*
044550  (XS(I)+XP)+(YS(I)-YP)*(YS(I)-YP))/Xlamda)
045557  YK=YF-XP*(YP-YS(I))/XP*XS(I))
044566  IF (YP.EQ.-H.*R.Y.R.*C.0.0) GO TO 9999
046124  1RA(I)=RA(I)+RA(I)*ATAN2(-XS(I),YS(I)-YR-TH1)
044612  IF (XS(I).LT.0.0 AND XPLT.0.0 AND TYPE.EQ.3.0)
044645  1RA(I)=RA(I)*COS(TH1-ATAN2(-XS(I),YS(I)-YR))
044645  IF (YK.LE.-H.0.R.Y.GE.0.0) RA(I)=Cmplx(0.0,0.0)
044664  T(I)=GA(I)+KA(I)+CAR(I)+DKL(I)+DKL(I)+DAL2(I)+DAL3(I)
044723  1+DAL(I)
044723  T(I)=T(I)+DLR(I)+DLR(I)
044734  T(I)=T(I)+DB2(I)
044742  T(I)=T(I)+DALH(I)
\begin{lstlisting}[language=FORTRAN]
005626   M=1+1
005533   RO(M)=SQRT((XP-XS(M))*(XP-XS(M))+(YP-YS(M))*(YP-YS(M)))/XLAMDA
005644   UB(M) = FA(U(I))*FLOAT(1), RO(1)*XLAMDA, RO(M)*XLAMDA)+UB(1)
005655   IF (1.GT.NN) OI(M)=O(I)-FA(FLOAT(I-NN)*D(I),RO(1)*XLAMDA,
           1*K00(M)*XLAMDA)
005672   IF (O(I).GT.PI02) OI(M)=O(I)-FA(FLOAT(I-NN)*D(I),RO(1)*XLAMDA,
           1*K00(M)*XLAMDA)
005707   IF (CH(I).GT.PI02 .AND. 1.GT.NN)
           1*HH(M)=UB(I)+FA(FLOAT(I-NN)*D(I),RO(1)*XLAMDA,RO(M)*XLAMDA)
005714   IF (1.GT.NNN) GO TO 11
005740   I=I+1
005741   GO TO 20
005741   11 CONTINUE
005741   SATAL=COMPLX(0.0,0.0)
005744   RATAL=COMPLX(0.0,0.0)
005746   TCNTL=COMPLX(0.0,0.0)
005751   UO 3 K=1,N
005752   RATAL=RATAL+GGA(K)
005759   SATAL=SATAL+SAS(K)
005766   3 TOTAL=TOTAL+TA(K)
005776   ATAL=CAHS(TOTAL)
006000   DTAI=20.0*ALOG10(ATAL)
006033   GAI=CAHS(RATAL)
006055   DBGA=20.0*ALOG10(GAI)
006010   SASM=CAHS(SATAL)
006012   DBSAS=20.0*ALOG10(SASM)
006015   WR=REAL(TOTAL)
006017   WI=AIMAG(TOTAL)
006020   PHASE=ATAN2(WI,WR)
006023   THS = THS+TTOEG
006025   PHASE=PHASE+TTOEG
006027   WRITE (6,4) THS,ATAL,DTAL,UBGA,USBAS,PHASE
006346   4 FORMAT (5X,*THS=*,F7.2,5X,*ATAL=*,E12.4,5X,*DBTAL=*,E12.4,5X,*DUBGA=*,E12.4,5X,*USBAS=*,E12.4,5X,*PHASE=*,E12.4)
  *
C L-1 Stokes the computed points in reverse order in the array, that is,
C        THS FROM -179 TC +179 DEG FOR CARTESIAN PLOTTING
C *
006346   5 L=L-1
006050   THSTFD(L)=THS
006052   AMPTFD(L)=ATAL
\end{lstlisting}
Q06053  DBTFD(L)=DTAL
Q06055  PHTFD(L)=PHASE
Q06056  GO TO 9958

* 006057  1 CONTINUE
C FIND MAX AMPTFD
Q06057  AMAX=AMPTFD(J)
Q06064  IF (AMPTFD(J)<EQ.0.) AMPTFD(J)=(AMPTFD(J-1)+AMPTFD(J+1))/2.
Q06070  IF (AMPTFD(J).LE.AMAX) GO TO 6956
Q06073  AMAX=AMPTFD(J)
Q06074  TMAX=THSTFD(J)
Q06076  6956 CONTINUE

* C NORMALIZE AMPTFD
Q06100  DG 6957 J=1,180
Q06102  AMPTFD(J)=AMPTFD(J)/AMAX
Q06104  6957 CONTINUE
Q06106  PRINT 5553,AMAX,TMAX
Q06115  5553 FORMAT(//' MAX AMPTFD=*F9.5* FOR THSTFD=9F3* DEG*)

* Q06115  PRINT 29,(THSTFD(J),AMPTFD(J),DBTFD(J),PHTFD(J),J=1,180)
Q06135  29 FORMAT(//'2X*THS*5X*AMPTFDNCR*7X*DBT*8X*PHASE*1(F5.3,14XF9.5))

* Q06135  THSTFD(181)=-180.
Q06136  THSTFD(182)=30.
Q06140  AMPTFD(181)=0.
Q06140  AMPTFD(182)=-1.
Q06142  PHTFD(181)=-180.
Q06142  PHTFD(182)=30.
Q06144  CALL PLTFDP(THSTFD,PHTFD,180)
Q06146  CALL PLTTFD(THSTFD,AMPTFD,180)

* C REORDER THSTFD VS DBTFD IN THE ARRAY, FROM 1 TO 359 DEG, FOR PULAR PLOT

* Q06151  KK=90
Q06152  GO 1113 J=1,90
Q06154  KK=KK+1
Q06156  TEMP=THSTFD(KK)
Q06157  THSTFD(KK)=THSTFD(J)+360
006162    THSTFD(J)=TEMP
006164    TEMP=DBTFO(KK)
006165    DBTFO(KK)=DBTFO(J)
006167    DBTFO(J)=TEMP
006170    1113 CONTINUE
**  IN LCSBOX
      **
006172    FIELD=5HTOTAL
006173    DMAX=DBTFO(1)
006174    IMAX=IHSTFD(1)
006176    DO 6958 J=2,180
006200    IF (DBTFO(J).EQ.0.) DBTFO(J)=(DBTFO(J-1)+DBTFO(J+1))/2.
006204    IF (DBTFO(J).LE.DMAX) GO TO 6958
006207    DMAX=DBTFO(J)
006210    TMAX=THSTFD(J)
006212    6958 CONTINUE
      **
C  NORMALIZE DBTFO
006214    DO 6959 J=1,180
006216    DBTFO(J)=DBTFO(J)-DMAX
006220    IF (DBTFO(J).LT.-40.) DBTFO(J)=-40.
006224    6959 CONTINUE
006226    PRINT 5554,DMAX,TMAX
006236    5554 FORMAT(/// MAX DBTFO=*F9.5* FOR THSTFD=*F3* DEG*)
006236    PRINT 5555,(THSTFD(J),DBTFO(J),J=1,180)
006252    5555 FORMAT(/// THSTFD*7X*DBTFO NORM*/(2XF3,8X,F10.5))
      *
006252    CALL POOLPLI(THSTFD,DBTFO,180,7.5,8,1,N,TY,AL,XLAMDA,X,HL,R1,RS
1,THI,DMAX,FIELD,SOURCE)
006275    PRINT 8888
C06301    8888 FORMAT(///)
      *
006301    CALL TSTI(N,AL,R1,RS+RI,A,TY,SOURCE)
006337    GO TO 6789
C06310    1112 CONTINUE
006310    CALL CALPLT(J,0.,599)
006313    STOP
006315    END
SUBROUTINE DFRCP(D,XA,Y,B,XLMCA)

THIS ROUTINE IS TO COMPUTE THE DIFFRACTION COEFFICIENT

COMPLEX F1J,F2J,G,R,T1,D1,T2,D0,F1,F2,S

COMMON/PICCNST/PI,2WP2,STP,SQRTP1,TT,TD0EG,PI02,PI14

00C010

* BR=B*TT
00C011 ARK1=(PI+BR)/(2.0*XN)
00C015 ARG2=(PI-BR)/(2.0*XN)
00C020 CX=2=COS(ARG1)
00C022 CXX=2=COS(ARG2)
00C024 SXX=2=SIN(ARG1)
00C026 SXX2=SIN(ARG2)
00C030 X1=(BR+PI)/(2.0*XN*PI)
00C037 N1=X1
00C041 E1=X1-N1
00C043 IF(E1.GT.0.5) N1=N1+1
00C050 IF(E1.LT.-0.5) N1=N1-1
00C054 FN1=FLOAT(N1)
00C055 A2=(BR-PI)/(2.0*XN*PI)
00C061 N2=X2
00C063 E2=X2-N2
00C065 IF(E2.GT.0.5) N2=N2+1
00C072 IF(E2.LT.-0.5) N2=N2-1
00C076 FN2=FLOAT(N2)
00C077 A1=1.0+COS(-BR+2.0*XN*PI*FN1)
00C080 A2=1.0+COS(-BR+2.0*XN*PI*FN2)
00C087 SAI=SQR(A1)
00C091 SAI2=SQR(A2)
00C093 XX=(SQR(TWOPI*Y))*SAI
00C096 YY=(SQR(TWOPI*Y))*SAI2
00C096 XXS=XX*XX
00C096 YYS=YY*YY
00C100 PC=SQR(PI02)
00C104 CALL CS(C1,S1,XXS)
00C106 CC1=0.5-C1
00C107 SS1=0.5-S1
00C107 F1J=PC*CMPX(SS1,CC1)
00C109 CALL CS(C2,S2,YYS)
00C109 CC2=0.5-C2

54
SUBROUTINE CD(D,XN, XL, BETA, XLMCA, T1, T2)
C T1 - BETP OR BEM 1 OR -1
C T2 - C/D(PHIS) OR C/D(PHIO) 1 OR 0
000012 INTEGER T1, T2
000012 COMPLEX D, CP, CM, D, DMV, P, CCP, CCM, C, F1, F2
000012 PI(X) = CEXP(CMPLX(0, X))
000012 C
000030 COMMON/PICONST/PI, TWCPI, STP, SQRTPI, TT, TTDEG, PIO2, PIO4
*
000030 XK = TOWPI / XLMUA
000031 CP = P(-PI04) / 4.* (XN**2) * SQRT(TWQPI * XK)
000053 BR = BETA * TT
000054 TP = (PI + BR) / (2.*XN)
000060 ATP = ABS(TP)
000062 IF(ATP .LT. 0.01) GO TO 10
000065 XNP = (BR + PI) / (2.*XN*PI)
000070 NP = XNP
000072 E1 = VXNP-PI
000074 IF(E1 .GT. 0.5) NP = NP + 1
000074 IF(E1 .LT. -0.5) NP = NP - 1
000080 AP = 1.* COS(-BR + 2.*XN*NP*PI)
000120 XKAP = XK*XL*AP
000122 CP = CEXP(CMPLX(0, PI04)) / 4.* (XN**2) * SQRT(TWQPI * XK) * (SIN((PI + BR)/
1(2.*XN)) * XN**2))
000155 CCP = CP * V(XKAP)
000175 GO TO 11
000201 10 A1 = 2.*XXX * XL * (XN**2) * (ATP**2)
000207 CALL CS(C1, S1, A1)
000211 F1 = CMPLX(C, 4.*XXX * XL * (XN**2)) + 2.* SQRTPI * P(A1) * (2.*XXX * XL * (XN**2)
1) * 1.5) * ATP * P(-PI04) - SQRT(2.) * CMPLX(C1, -S1))
000273 CCP = C * F1
000301 11 XM = (PI - BR) / (2.*XN)
000304 ATM = ABS(TM)
000306 IF(ATM .LT. 0.01) GO TO 20
000311 XNM = (BR + PI) / (2.*XN*PI)
000314 NM = XNM
000316 E2 = XNM - NM
000320 IF(E2 .GT. 0.5) NM = NM + 1
000324 IF(E2 .LT. -0.5) NM = NM - 1
000330 AM = 1.* COS(-BR + 2.*XN*NM*PI)
000344 XKAM = XK*XL*AM
000346 CM = CEXP(CMPLX(0, -PI04)) / 4.* (XN**2) * SQRT(TWQPI * XK) * (SIN((PI - BR)/
1(2.*XN)) * XN**2))
CCM=CS*(X,KAM)

GO TO 21

AL=2.*XX*X+X*(XX**2)*(ATP**2)

CALL CS(C1,S1,A1)

F2=CMPLX(*J,4.*XX*X+X*(XX**2)) + 2.*SQRTP1 **(A1)*((12.*XX*X+X*(XX**2))

1)*(-L5)*ATM*(P+PI04)-SQR(2.*CMPLX(C1,-S1))

CCM=C*F2

IF(T1.*EQ. 1 ) GO TO 1

DP=CCP

DM=-CCM

IF(T2.*EQ. 1 )DP=-CCP

IF(T2.*EQ. 1 )DM=CCM

GO TO 2

DM=CCM

U=OP+OM

RETURN

END

CCMPLX FUNCTION V(X)

TRANSITION FUNCTION FOR THE INTEGRAL WITH THE INTEGRAND HAVING THE

POLAR OF ORDER TWO CLOSE TO THE SADDLE

X = K*A(RETA)

P(X)=CEXP(CMPLX(*O,X))
SUBROUTINE WANG(N, M, T, X, D1, D2)
C
COMPLEX D1, D2, DA, CB, CH, DS, U, V
000011 DHI(U, V) = SQRT(T - 6.23815301796 * (U + V)
C
000036 DSI(U, V) = SQRT(T - 6.23815301796 * (U - V)
C
000062 CALL DHCF(DA, XN, XL, PH-PHP, 1, 0)
C
000087 CALL DHRCF(CB, XN, XL, PH-PHP, 1, 0)
C
000077 D1 = UH(DA, DR)
C
000111 D2 = DS(CA, DB)
C
000120 RETURN
C
END

SUBROUTINE CS(C, S, X)
C
COMPUTES THE FRESNEL INTEGRALS
C
DESCRIPTION OF PARAMETERS
C
C THE RESULTANT VALUE C(X)
C S THE RESULTANT VALUE S(X)
C X THE ARGUMENT OF FRESNEL INTEGRALS
C IF X IS NEGATIVE, THE ABSOLUTE VALUE IS USED
C
C THE ARGUMENT VALUE X REMAINS UNCHANGED
C
C C(X) = INTEGRAL(COS(T)/SQRT(T) SUMMED OVER T FROM 0 TO T) X
C S(X) = INTEGRAL(SIN(T)/SQRT(T) SUMMED OVER T FROM 0 TO T)
C
C EVALUATION
C USING DIFFERENT APPROXIMATIONS FOR X LT. 4 AND X GT. 4
C
C REFERENCE
C COMPUTATION OF FRESNEL INTEGRALS BY H. GERSMA,
C MATHEMATICAL TABLES AND OTHER AIDS TO COMPUTATION, VOL. 14,
C 1960, NO. 72, P. 380
C
3.06 Z = ABS(X)
3.07 IF(Z-4.1, 1, 2
3.12 C = SQRT(Z)
3.16 S = Z*C
3.20 Z = (4.2-Z) * (4.2-Z)
3.24 C = C*(((1144-107785E-11*Z+5.234297E-9)*Z+5.451182E-7)*Z
1+3.27330*Z+1.20418*Z+1.202544*Z+1.840965E-1)
3.28 S = S*(((6.67768E-10*Z+5.883158E-8)*Z+5.051131E-6)*Z
1+2.441816E-4)*Z+6.121320E-3)*Z+8.026490E-2)

74300000
74400000
74500000
74600000
74700000
74800000
74900000
75000000
75100000
75200000
75300000
75400000
75500000
75600000
75700000
75800000
75900000
76000000
76100000
76200000
76300000
76400000
76500000
76600000
76700000
76800000
76900000
77000000
77100000
77200000
77300000
77400000
77500000
77600000
77700000
77800000
77900000
78000000
78100000
78200000
78300000
78400000
J050  RETURN
C051    Z = COS(Z)
J053    S = SIN(Z)
C061    Z = 4 * Z
C113    Z = SGN(Z)
000115   C = 0.5 * Z * (D * A + S * B)
000125   S = 0.5 * Z * (S * A - D * B)
000132   RETURN
000133   END
SUBROUTINE TEST(N, AL, XS, A, TYPE)
C THIS SUBROUTINE PROGRAM COMPUTES THE RADIATION FIELD OF HORN ANTENNA
C
C DIMENSION X(180), AM(180), AP(180), DG(180), AI(180), ANG(180)
C DIMENSION THFD(185), AMFD(185), DBFD(185)
C COMPLEX F, A, DG, CDG, TAL
C COMMON XLAMDA, XPIN, XHL, RI, RS, THI, DMAX, FIELD, SOURCE
C COMMON PI, PIConst, PI, TP, STP, SQRTPI, TT, TTSQRT, TIO2, TID4
C
C XPIN IS POINT OF INCIDENCE WHICH IS X IN MAIN PROGRAM
C
C F(Z) = EXP(COMPLEX(0., -6.2831853071796*Z))/SQRT(6.2831853071796*Z)
C FA(SA, SB, SC) = ACOS((SB*S1B*SC*SC-SA*SA)/(2.*SB*SC))
C FC(AA, SH, SC) = SQRT((SB*SB*SC*SC-2.0*SB*SC*SC-COS(AA))
C FB(SX) = ABS(COS(X/SX)*2.0)*2.0
C
C FB(SX) IS THE OBLIQUITY FACTOR. TO IGNORE IT, SET FB(SX)=1.
C
C NN=(N+1)/2
C L=0
C D=0.0
C IF(N GT 1) D=AL/FLWAT(N-1)
C TH=0.0
C CONTINUE
C
C IF(TH.EQ.90.0) GO TO 15
C TTH=TH+IT
C ANG(1)=THR
C X(1)=XS
C D(1)=A(I)*F(XS)*FA(THR)
C IF(TYPE.EQ.3.0 AND THR.LT.PI/2) D(1)=D(1)*COS(THR)
C IF(TYPE.EQ.3.0 AND THR.GT.PI/2) D(1)=D(1)*COS(PI-THR)
C IF(N.EQ.1) GO TO 11
C I=2
C CONTINUE
C
C X(1)=FC(PI+0.5+THR, FLOAT(I-1)*D, XS)
C IF(1.GT.NN) X(I)=FC(P12, THR, FLOAT(I-NN)*D, XS)
C IF(TH.GT.90.0) X(I)=FC(1.5*PI-THR, FLOAT(I-1)*D, XS)
C IF(TH.GT.90.0 AND I.GT.NN) X(I)=FC(THR-PI/2, FLOAT(I-NN)*D, XS)
C ANG(I)=THR-FA(FLD(I-1)*D, XS, X(I))
C ANG(I)=THR-FA(FLD(I-NN)*D, XS, X(I))
C ANG(I)=THR-FA(FLD(I-1)*D, XS, X(I))
C ANG(I)=THR-FA(FLD(I-NN)*D, XS, X(I))
000376 UG(I)=A(I)*F(X(I))*FB(ANG(I))
000416 IF(TYPE.EQ.3)*AND.ANG(I).LT.PI/2) UG(I)=UG(I)*COS(ANG(I))
000442 IF(TYPE.EQ.3)&AND.ANG(I).GT.PI/2) UG(I)=UG(I)*COS(PI-ANG(I))
000470 IF(I.EQ.N) GO TO 11
000471 I=1+1
000473 GO TO 3
000474 11 CONTINUE
000475 TAL=CMPLX(C,0,0.0)
000477 DO 33 K=1,N
000500 CGS=UG(K)
000503 ANG=ANG(K)*TTDEG
000505 ADG=ABS(CGS)
000507 TAL=TAL+UG(K)
000516 33 CONTINUE
000523 ATAL=CAH(S(TAL))
000524 IF(TH.EQ.0.0) NCM=ATAL
000532 DBTAL=20.0*ALOG10(ATAL)
000560 WRITE(6,4) TH,ATAL,EBTAL
000547 4 FORMAT(5X*TH=*(F10.4,5X,MAGNITUDE= *,E15.4,5X,DBHA= *,E15.4)
000547 L=L+1
000551 THIFO(L)=TH
000553 AMPIFO(L)=ATAL
000554 DBIFO(L)=EBTAL
000556 15 CONTINUE
000556 TH=TH+2.0
000560 IF(THLE.360.0) GO TO 2
000566 PRINT 39,(THIFO(J),AMPIFO(J),DBIFO(J), J=1,L)
000534 39 FORMAT(//2X* TH=7X*MAGNITUDE=7X DBHA=/(F5.2,(5XF10.5)))
000604 C FIND MAX AMPIFO
000606 AMAX=AMPIFO(I)
000607 Tmax=THIFO(I)
000607 DO 6556 J=2,L
000616 IF(AMPIFO(J).LE.AMAX) GO TO 6596
000617 AMAX=AMPIFO(J)
000620 Tmax=THIFO(J)
000621 6556 CONTINUE
000621 C NORMALIZE AMPIFO
000624 DO 6597 J=1,L
000625 AMPIFO(J)=AMPIFO(J)/AMAX
000627 6597 CONTINUE
000631 C PRINT 5555
000631 5555 FORMAT(//* MAX AMPIFO=*(F9.5, F THIFO=*(F3.0 DEG*))
000641
** IN TEST **

0061 FIELD=5HINCID
0062 DMAX=CBIFD(J)
0064 TMAX=THIFD(J)
0066 DO 6598 J=2,L
0062 IF(DBIFD(J).LE.DMAX) GO TO 6598
0065 DMAX=DBIFD(J)
0066 TMAX=THIFD(J)
C CONTINUE

6598 CONTINUE

C NORMALIZE DBFA WHICH IS DBIFD
0062 DC 6579 J=1,L
0063 DBIFD(J)=DBIFD(J)-DMAX
0065 IF(CBIFD(J).LT.-40.) DBIFD(J)=-40.
0067 CONTINUE

6599 CONTINUE

0067 PRINT 5556,DMAX,TMAX
0073 FORMAT(/* MAX DBIFD=**9.5* FOR THIFD=**F3* DEG*)
0073 PRINT 40, (THIFD(J), AMPIFD(J), DBIFD(J), J=1,L)
0074 CALL PLOT(THIFD, CBIFD, 180, 7.5, 8, 1, N, TYPE, AL, XLAMDA, XPIN, XL, H, RI
0075 1, RS, THI, DMAX, FIELD, SOURCE)

******

0071 THIFD(L+1)=0.
0073 THIFD(L+2)=30.
0074 AMPIFD(L+1)=0.
0075 AMPIFD(L+2)=.1
0077 CALL PLTFD(THIFD, AMPIFD, 180)
0071 RETURN
C CONTINUE

END

SUBROUTINE PLTFD(THSTFD, AMPTFD, NPTS)

0001 DIMENSION THSTFD(1), AMPTFD(1)
0003 TMAJ=1.
0004 TMIN=3.
0001 CALL ADMI1(0., 0., 0., 2., 28., 11H TOTAL FIELD, 0., 11)
0003 CALL CALPLT(3., 1., 0., -3.)
0001 CALL CALLAXIS(0., 1., .90., 10., .0., 1., 4., 5., 9H AMPLITUDE, 28, 9)
0003 CALL CALLAX(3., 1., 0., -180., 30., TMAJ, TMN, 10H THSTFD), DEG, 28, -10)
0003 CALL CALLAX(3., 1., 0., 12., 0., 30., TMAJ, TMN, 1H , J+1)
0001 CALL CALLAX(12., 1., 0., 9., 10., .0., 0., 1., 4., 5., 9H , 0., -1)
0003 CALL CALL Lim(THSTFD, AMPTFD, NPTS, 1, 0, 0, 0.

0003 CALL FREE

C CONTINUE

0004 RETURN

0004 END

91300000
91400000
91500000
91600000
91700000
91800000
91900000
92000000
92100000
92200000
92300000
92400000
92500000
92600000
SUBROUTINE PLTTFD( THSTFD, PHTFD, NPTS )
DIMENSION THSTFD(1), PHTFD(1)
TMJ=1.
TMIN=3.
CALL NCTATE( 0., 0., 1., 2., 28., 11., TOTAL, FIELD, 0., 11 )
CALL CAL3LT( 0., 1., 0., 3 )
CALL AXES( 0., 0., 90., 12., -180., 30., 1., 3., 9., PJASE, DEG., +28, 9 )
CALL AXES( 0., C, 0., 12., -180., 30., TMJ, TMIN, 10., THSTFD, DEG., +28, -10 )
CALL AXES( 0., 12., 0., 12., -180., 30., TMJ, TMIN, 1H, 3., 1 )
CALL AXES( 12., 0., 90., 12., -180., 30., 1., 3., 14., 0., -1 )
CALL LINE( THSTFD, PHTFD, NPTS, 1., 0., 0., )
CALL NFRAME
RETURN
END
SUBROUTINE PULPLT(EGS,DSI,DAM,NGCIR,NPLOTS,N,TYPE,AL,
1XLAMDA,X,XL,H,RI,RS,THI,DMAX,FIELD,SOURCE)

* DIMENSION DEGS(1),CRS(1),CHTAB(16)
C026 DIMENSION ANUM(11),FIELD(2)
0026 DIMENSION CC(400),RHOX(400),RHOY(400),PHI(400)

* RAD = DIAM/2.0
C027 HGT = .21

* CHTAB(1) = 1H
0031 CHTAB(2) = 1H5
0034 CHTAB(3) = 2H10
0035 CHTAB(4) = 2H15
0037 CHTAB(5) = 2H20
0040 CHTAB(6) = 2H25
0042 CHTAB(7) = 2H30
0043 CHTAB(8) = 2H35

* CALL NOTATE (0.0,0.0,HGT,3,0.,-1)
0045 RADF = RAD
0051 DELTK = RAD/NGCIR
0052 CX = 10.
0060 PX = 10.
0062 AY = 5.0
0063 PY = 5.
0064 K = 1
0065 HGT = .14

C067 CONTINUE
0067 DO 5 I = 1,NGCIR
0071 RADF = RAD
0073 CALL CIRCLE(CX,AY,0.0,360.,RADF,RADF,3)
101 I.F(I.EQ.3)K = 2
1010 CALL NOTATE (CX,AY,HGT,CHTAB(1),270.0,K)
1016 RADF = RAD - DELTK
1020 CX = CX - DELTR
1021 CONTINUE

*** COORDINATES FOR CENTER OF CIRCLE ****
0127 CNTX = PX - RAD
0130 CNTY = PY
CALL NOTATE (10.5G, 9.0, 21, 11HBOX, HEIGHT=270, 11)
CALL NUMBER (10.50, 6.9, 21, ANUM(7), 270, -1)
CALL NOTATE (10.50, 4.3, 21, 12HNUM, D3=270.12)
CALL NUMBER (10.50, 2.0, 21, ANUM(11), 270, 3)
CALL NOTATE (1.70, 4.3, 21, 15HLINE SOURCES, N=270.15)
CALL NUMBER (1.70, 1.6, 21, ANUM(1), 270, 1)
CALL NOTATE (1.40, 4.8, 21, 20H CURNT TYPE=270, 20)
CALL NUMBER (1.40, 1.2, 21, ANUM(2), 270, 1)
CALL NOTATE (1.40, 4.8, 21, SOURCE, 270, 9)
CALL NOTATE (1.10, 9.0, 21, 11H FIELD, 270, 11)
CALL NOTATE (1.10, 9.0, 21, FIELD, 270, 5)
CALL NOTATE (1.10, 4.0, 21, 12HAPERT WIDTH=270, 12)
CALL NUMBER (1.10, 1.75, 21, ANUM(3), 270, 3)

*** DRAW X AXIS
AX=PX-DIAM-.5
CALL CALPLT (AX, AY, 3)
AX=PX+.5
CALL CALPLT (AX, AY, 2)

*** DRAW ZERO DEGREES AFTER HORIZONTAL
HG T=.21
AX=PX
AY=AY-.05
CALL NOTATE (AX, AY, HG T, 1H0, 270, 1)
AX=AX+.21
AY=AY-.12

*** DEGREE SYMBOL
CALL NOTATE (AX, AY-.07, 1H0, 270, 1)

*** DRAW Y AXIS
AY=5.0
AX=PX-RAD
AY=AY-RAD-.5
CALL CALPLT (AX, AY, 3)
AY=AY+DIAM+.1
CALL CALPLT (AX, AY, 2)

*** DRAW 90 DEGREES
AY=AY-.1
CALL NOTATE (AX, AY, HG T, 2H90, 270, 2)
AX=AX+HG T
AY=AY-.32
CALL NOTATE (AX, AY-.07, 1H0, 270, 1)

*** DRAW 180 DEGREES
AX=PX-CIAM-.3
AY=5.0
CALL NCTATE (AX,AY,HT,07,270...) 106900000
AX=AX+.21 107000000
AY=AY-.5 107100000
CALL NCTATE (AX,AY,07,012,270...) 107200000

***DRAW 270 DEGS
AX=PX+RAD 107300000
AY=5.0-RAD-.05 107400000
CALL NCTATE (AX,AY,HT,07,270...) 107500000
AX=AX+HT 107600000
AY=AY-.5 107700000
CALL NCTATE (AX,AY,07,012,270...) 107800000

151 CONTINUE 107900000

*** PLOT POLAR CURVES ***

*** SCALE DECIBELS AND CONVERT POLAR COORDINATES TO CART. COORDS.
DC 500 JJ=1,NPTS 108000000
PHI= DEG(JJ)*.0174532925 108100000
CWB(JJ)=DAS(JJ)*40. 108200000
CDB(JJ)=.025*RAD+CDB(JJ) 108300000
RHOX(JJ)=CWB(JJ)*COS(PHI 108400000
PHI 108500000
RHOY(JJ)=CDB(JJ)*SIN(PHI 108600000
PHI 108700000
500 CONTINUE 108800000
LIM=NPTS-1 108900000

***BEGIN PLOTTING WITH PEN UP***
IPEA=3 109000000
DO I=1,LIM 109100000
J=1+1 109200000
CALL CIRCLE(RHOX(I),RHOY(I),DEGS(I),DEGS(J),CDB(I),CDB(J),IPEA) 109300000
IF(I.GT.1)GO TO 110 109400000
IPEA=2 109500000
110 CONTINUE 109600000
100 CONTINUE 109700000

CALL NFRAME 109800000
RETURN 109900000
END 110000000
SUBROUTINE PLTIFU(THIFD, AMPIFD, NPTS)

DIMENSION THIFD(1), AMPIFD(1)

IMAJ = 1

CALL CALPTI(0., 1., 0., -3)

CALL AXLS(0., 0., 90., 0., 0., 0., 1., 1., 1., 5., 9, 9, AMPLITUDE, 28., 9)

CALL AXLS(0., 0., 12., 0., 30., IMAJ, IMIN, YTHIFD, DEG, 28., -9)

CALL AXLS(0., 1.), -12., -180., 30., IMAJ, IMIN, ITH , 0., 1)

CALL AXLS(12., 0., 90., 10., 0., 0., 1., 1., 5., ITH, 0., -1)

CALL LINT(THIFD, AMPIFD, 180., 1., 0., 0., 0.)

CALL NFRAME

RETURN

END
REFERENCES


"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—National Aeronautics and Space Act of 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546