UTD Terrain Reflection Model With Application
to ILS Glide Slope

A Dissertation Presented to
The Faculty of the College of Engineering and Technology
Ohio University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
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June, 1981
This Dissertation has been approved for the Department of Electrical Engineering and the College of Engineering and Technology.

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ACKNOWLEDGEMENTS

The author would like to thank Dr. Ray J. Luebbers, his dissertation advisor, for the help and guidance in this investigation.

A special thanks goes to the staff of the Avionics Engineering Center, Ohio University, Mr. Kent A. Chamberlin, and Mr. Larry L. Lamb.
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CHAPTER I
INTRODUCTION

The subject of this dissertation is a computer mathematical model which determines the horizontally polarized electric field reflected by uneven terrain. The model is applied to the Instrument Landing System (ILS), which depends on ground reflections for its operation. The major systems in ILS consist of a glide slope, localizer, marker beacons, and monitors. The principle application of this work is to the glide slope.

Glide slope systems provide vertical guidance information. The operating frequency band is between 329.0 MHz to 335.0 MHz. Image, waveguide, and end-fire glide slope systems are the three types available. Only the image and waveguide systems are addressed in the following; the end-fire system is still under development. The vertical glide path angle is between 2.0 to 3.3 degrees. All of the angles described in this study are measured upward starting from the horizon, unless clearly stated otherwise.

Three types of image glide slope systems, Null Reference, Sideband Reference, and Capture Effect, are available at the present time. All types require the presence of reflecting ground to generate the desired total electric field, which is the superposition of the direct and reflected fields. The direct field propagates in the line-
of-sight from the antennas to the observation point, which is the aircraft location. The reflected field is the field that is reflected off the ground to the airplane. Hence, the vertical glide path angle is a function of the antenna heights above the ground plane.

The Null Reference (NR) system is the most common type. The system operates with two antennas at a 2:1 antenna height ratio. The NR system requires a large amount of flat reflecting ground. However, it is the simplest and easiest to maintain. For a typical three degree glide path angle at 330.0 MHz, the antenna heights are 28.0 and 14.0 feet. The lower antenna radiates CSB (carrier modulated by 90 Hz and 150 Hz sideband frequencies); the upper antenna radiates only sideband frequencies (SBO). The radiated signals combine below three degrees to give a fly-up signal (150 Hz > 90 Hz), and above three degrees to give a fly-down signal (90 Hz > 150 Hz). For every glide slope system operated in the United States, this fly-up or fly-down convention is the same.

The Sideband Reference (SBR) system requires a shorter flat reflecting ground than the NR system. The trade off is the high sensitivity of glide path angle due to an alteration in ground level, viz, snow accumulation. The SBR system needs two antennas with a typical 3:1 antenna height ratio. To produce a three degree glide path at 330.0 MHz, the antenna heights are set to 21.0 and 7.0 feet. The upper antenna radiates SBO similar to the NR upper antenna. The
lower antenna, however, radiates both CSB and SBO signals, with SBO signal being 180 electrical degrees out of phase with respect to CSB signal.

The Capture Effect (CE) system needs three antennas with the antenna height ratio 3:2:1. The CE system is the most complicated of the three described thus far. Only a short flat ground plane is required for operation. The system is designed for operation at facilities where terrain roughness in the approach area precludes the operation of the NR and SBR systems. The typical antenna heights to generate a three degree glide path angle are 42.0, 28.0, and 14.0 feet. For details of the system operation, refer to Reference 1.

A waveguide glide slope system, in contrast with the image glide slope systems, does not require reflecting ground to form the electric field. The electric field is the superposition of radiation from each slot located on the waveguide structure. However, if the terrain is an upslope, the reflected signal can interfere with the direct signal. The adjustment of glide path angle is accomplished by physically tilting the waveguide. Since the waveguide is about 90 feet tall, there are mechanical problems in securing and tilting the structure. Furthermore, this is the most difficult system to operate and maintain.

The end-fire glide slope system consists of two slotted-cable antennas. The antenna system does not require a tower, but is installed on a waist height wooden
structure. Due to its height, the antennas are installed closed to the runway shoulder. The glide path angle is determined by the relative phase of signals radiated from two slotted-cable antennas. As mentioned, this system is still under development.

The localizer provides azimuthal information. The operating frequency is between 108.0 MHz to 112.0 MHz. The carrier is modulated with 90 Hz and 150 Hz signals which are used for designating whether the airplane is on the left or the right of the approach runway centerline. Instead of ground roughness, objects in the vicinity of the localizer, such as hangars, towers, building, and aircraft are the dominant causes of poor localizer performance.

The monitor is designed to detect faults in the system. If a system operates outside the prescribed allowable range, it is shut down.

Marker beacons are used to mark the different ranges along the approach path. The beacons consist of a 75.0 MHz transmitter which is modulated with an audio tone, with each beacon having with a different tone. In this way the pilot is able to determine the distance from the runway by associating different tones with different ranges.

In this work, the mathematical model is applied only to image glide slope systems. Modifications, however, can be made for localizer and monitor analyses, and indeed for many other propagation problems.

The idea of using a model to simulate the effect of the
irregular ground on the glide path performance is not new. The first ILS modeling attempts were made by Ohio University [2]. These efforts were continued and expanded during the following years [3,4]. The basic approach used was a Physical Optics (PO) technique. The PO technique is based on assumed ground currents, which are then integrated to obtain the electric field scattered from the reflecting terrain. The details will be given in Chapter II, section A. One of the drawbacks is the assumption that current on one area has no effect on the neighbouring currents. If this assumption is not made, using a PO technique to calculate these effects is very expensive in terms of computer time since determining the fields incident on each point of the ground requires integrating over all of the intervening ground from the antenna. Because of this difficulty the PO models usually neglect this interaction entirely and allow the electric fields radiated by the ground currents to pass through any subsequent obstructions as if they did not exist. While the above may seem to be a poor approximation to what happens physically, good results can be obtained for many types of terrain. However, running times on the order of hours can be expected.

The fastest running PO model available at the present time is that developed by the Transportation Systems Center (TSC) [5,6]. The TSC model approximates the terrain by using the terrain profile along the line from the glide slope mast to the aircraft. If one makes a linear approximation to
this profile, the terrain model in Figure 1-1 results. This two-dimensional ground model allows one to perform the X-direction radiation integration on the induced ground currents in closed form using asymptotic methods, thus drastically reducing the computation time. A typical site calculation might require one hundred seconds rather than hours of computer time required by PO models previously available.

While much of the previous work in modeling has been done using the PO approach, other techniques have been used. A model developed by Godfrey, et al, [7] was based on the half-plane diffraction solutions of Senior [8], Woods [9], and Bromwich [10]. This isolated half plane also can be handled using PO methods, and is useful in modeling glide slope sites which have a finite length flat reflecting surface in front of the antenna which then drops off sharply to terrain which is either shadowed from the antennas or is so rough that it does not reflect coherently. In addition to treating the problem using diffraction theory rather than the PO approach, the model of Reference 11 also allows for the presence of an infinite plane located below a half plane. This extension is made using image theory. However, this model can handle only limited terrain configuration.

In summary, the previous models all have shortcomings. Hence, a new reflection model which makes use of both the Geometrical Theory of Diffraction (GTD) [12] and the Uniform Theory of Diffraction (UTD) [13] to eliminate the
aforementioned drawbacks has been developed. The GTD and UTD theoretical backgrounds are provided in Chapter II, sections C and D. This new mathematical model is called the UTD model.

The GTD and UTD techniques treat the electric fields as rays. This is possible due to the localized nature of wave interactions at high frequency. This allows inclusion of the interactions omitted from the previous models. Therefore, results obtained from the UTD model which include these interactions should be more accurate or at least as accurate as those without. Also the UTD model consumes less computation time. The UTD model running time is independent of the size of the modeling terrain area, but does depend on the amount of terrain irregularity. The UTD model includes thirteen types of rays in the calculations. Each ray description and a test for its existence is discussed in Chapter III.

A two dimensional (2-D) UTD model was developed first. But later in the validation process, the 2-D UTD model was found to be insufficient to represent the ground terrain in many cases. Therefore, a three dimensional (3-D) UTD model was also developed. To be able to compare 3-D results, a 3-D model based on the TSC work was also developed. For these 3-D models, the profile changes automatically as the observation point moves.

In Chapter IV, one hypothetical and three actual reflecting terrains are used for UTD model validations. The
hypothetical terrain considered is included to demonstrate the inaccuracy of the 2-D TSC results. The first two actual sites are approximated to be two-dimensional. Therefore, the 2-D UTD and 2-D TSC models are utilized. The third site, however, contains noticeable terrain variations transverse to the centerline. Hence, the 3-D UTD and 3-D TSC models are applied at this site.
Figure 1-1. Two-Dimensional Conducting Plate Approximation to Reflecting Terrain.
CHAPTER II
THEORY OF WAVES SCATTERED BY IRREGULAR TERRAIN

For the frequency range and application considered in this dissertation, there are four categories of techniques that have been used to determine the amplitude and phase of a radio wave propagating in the presence of irregular terrain. These categories are: Physical Optics (PO), Geometrical Optics (GO), Geometrical Theory of Diffraction (GTD), and Uniform Theory of Diffraction (UTD). Although the work described here is an extension of the UTD technique, a brief description of the other techniques will be given for comparative purposes.

All of the techniques to be discussed make some simplifying assumptions in characterizing the terrain between the transmitting and receiving antennas. One such assumption is that the terrain is piecewise linear; that is, the terrain is comprised of flat plates whose edges, which are perpendicular to the runway centerline (Y-axis), are extended to infinity. Hence, the terrain model appears to be two-dimensional (see Figure 1-1).

Determination of scattered fields using the PO technique is accomplished by first computing the currents induced by the source on each terrain plate between the transmitting and receiving antennas. These currents are readily determined approximately by an application of
Maxwell's equations and knowledge of the geometries involved. Once the induced current on each plate is known, the resultant scattered field from a plate can be determined by integrating the current over the surface of that plate. The scattered field is the complex sum of the fields generated by all of the plates between the transmitter and receiver. The total field at the receiving antenna is the superposition of the scattered plus the direct field.

The Geometrical-Optics Theory, Geometrical Theory of Diffraction and Uniform Theory of Diffraction do not consider induced currents in determining scattered fields, but rather assume rays emanating from the radiating source. The two types of rays considered by GO theory are the direct and reflected. Extensions of GO theory are made by inclusion of diffracting mechanisms. Thus diffracted rays are considered by both GTD and UTD techniques.

The direct ray propagates in a straight line between the transmitting and receiving antennas. The reflected ray exists for a particular plate when the incident angle from the transmitter to the plate is equal to the reflected angle from the plate to the receiver. The diffracted ray is determined from the knowledge of wave scattering from a specified straight edge. Examples of the direct, reflected and diffracted rays are given in Figure 2-1. As can be seen in Figure 2-1, the composite signal at the observation point may undergo abrupt changes as the observation point moves with respect to the terrain. Such signal strength
Figure 2-1. Exterior Wedge Diffraction Geometry and Coordinates.
discontinuities, which are not real-world phenomena, result when any reflection point reaches an edge, i.e., a cliff dropoff or hill. It is at these boundaries, as shown in Figure 2-1, where the UTD, GTD and GO results differ significantly.

GO and GTD methods do not attempt to eliminate the discontinuities that occur at these boundaries and hence, unrealistic, abrupt changes will appear with these methods in predictions from some terrain profiles.

The abrupt changes in signal amplitude and phase resulting from terrain discontinuities are eliminated with the UTD technique by the use of a blend function which incorporates the Fresnel integral as a weighting function for rays near boundaries. This method is used in the specific technique addressed in this paper. An extension of the UTD method is accomplished by considering not only the direct, reflected, and diffracted rays, but also by considering combinations of those rays (e.g. doubly-reflected, reflected-diffracted-reflected, etc.).

A. Physical Optics Approximation Technique

As mentioned in the Introduction, the PO technique determines the scattered electromagnetic fields by first determining the induced currents on all illuminated scatterers. To illustrate the mathematics and geometries involved, consider the arbitrary scattering element (obstacle) in the presence of a radiator shown in Figure
2-2. The PO method generally assumes that the scatterer is perfectly conducting, which is a good assumption for low incident angle and horizontally polarized fields. Hence, the induced current densities (electric and magnetic) must satisfy boundary conditions; thus,

\[ \vec{J}_s = \hat{U} \times \vec{H}, \]
\[ \vec{M}_s = \vec{E} \times \hat{U}, \]

where

\[ \vec{E} = \vec{E}^i + \vec{E}^s, \]
\[ \vec{H} = \vec{H}^i + \vec{H}^s, \]

and

\[ \vec{E}^i = \text{incident electric field}, \]
\[ \vec{E}^s = \text{scattered electric field}, \]
\[ \vec{H}^i = \text{incident magnetic field}, \]
\[ \vec{H}^s = \text{scattered magnetic field}, \]
\[ \hat{U} = \text{the unit vector pointing perpendicularly outward from the obstacle}, \]
\[ \vec{J}_s = \text{electric current density on the ground (obstacle)}, \]
\[ \vec{M}_s = \text{magnetic current density on the ground (obstacle)}. \]

In making the above calculation, the PO technique assumes that the surface is relatively smooth (within the Rayleigh criterion) and that the dimensions of the surface are much larger than a wavelength. Additionally, incident \( \vec{H} \) is assumed to be zero in shadow regions.

In order to determine the scattered fields generated by
Figure 2-2. Coordinate System for Electromagnetic Reflection.
the induced surface currents, image theory is used to include the presence of the perfect conductor. Hence, the current density value used to determine the scattered field is:

\[ \bar{J}_s = 20 \times \bar{H}^d \quad (2.1) \]

On any illuminated surface, Equation (2.1) is known as the Physical Optics approximation. The surface current which is expressed in Equation (2.1) is a good approximation only in the region which is not near an edge. It should be noted that this calculation is based only upon the geometry of the surface with respect to the radiator and the incident magnetic field.

Given the surface current density determined in Equation (2.1), the scattered magnetic field can be determined directly:

\[ \overline{H}^s(r' - r) = \frac{1}{4\pi} \int_{s'} \bar{J}_s \times \nabla_s(r', r) \, ds' \quad (2.2) \]

where

\[ \nabla_s(r', r) = \frac{e^{-jk\cdot(r' - r)}}{|r' - r|} \left\{ \frac{1}{|r' - r|} - jk \right\} \cdot (r' - r) \quad (2.3) \]

and \( s' \) is the surface area containing the surface current \( \bar{J}_s \). The vectors used in Equations (2.2) and (2.3) are identified in Figure 2-2. Equation (2.3) is recognized as being the gradient of the two-point Green's Function. This Green's Function is often times approximated for large values of \( r' - r \) by setting the first term within the brackets in Equation (2.3) equal to zero.

The incident magnetic field radiated by the source
The antenna is given by:

\[ \mathbf{H}^d(\mathbf{r}) = \frac{1}{4\pi} \int_{v'} \mathbf{J}(\mathbf{r}') \times \nabla \xi(\mathbf{r}, \mathbf{r}') \, dv' \]  

(2.4)

where

- \( v' \) is the volume occupied by the antenna source,
- \( \mathbf{J} \) is the current density on the antenna.

Equations (2.1), (2.2), (2.3), and (2.4) provide all of the information required to compute the scattered field from a conducting element illuminated by a radiator. The PO technique does not assume any interaction between scattering elements; therefore, each scatterer can be treated separately if more than one is present. The total magnetic field at the observation point is determined by summing vectorially the magnetic field from all illuminated scattering surfaces and the direct magnetic field from the antenna.

As stated, the PC method does not assume any interaction between scattering elements. Failure to consider this factor is seen as a significant drawback for certain cases. One attempt has been made to include mutual interaction by considering an edge current [15]. The extended PO technique is known as the Physical Theory of Diffraction (PTD). However, using the PTD to include mutual interactions of several scattering plates does not result in a viable solution [16].

Computer models utilizing the PO technique for predicting scattering from irregular terrain have proven to be satisfactory for some terrain configurations,
unsatisfactory for others. Predictions obtained from PO models will be shown later in this study.

B. Geometrical Optics Technique

As it is named, the Geometrical Optics (GO) technique involves the geometry of the problem as well as the assumption of a localized nature of the wave at very high frequency. The GO technique is considered as the simplest method to calculate the electric field, and it is only applied in the presence of homogeneous media. The technique also assumes that energy must be conserved along the propagation path.

Since the principle of energy conservation is applied, the power flow across areas $d\sigma_{A1}$ and $d\sigma_{A2}$ is identical. Figure 2-3 illustrates the astigmatic tube of rays which forms a wavefront. The locations where wavefronts disappear are called caustics. From Figure 2-3, it can be seen that

$$\frac{d\sigma_{A1}}{d\sigma_{A2}} = \frac{\rho_1 \rho_2}{(\rho_1 + d)(\rho_2 + d)}$$

(2.5)

where $\rho_1$ and $\rho_2$ are the principle radii of wavefront curvatures, and $d$ is the distance between two consecutive wavefronts. It can be shown that the amplitude of the electric field and the areas have the following relation,

$$\left| \frac{E(d)}{E(0)} \right| = \left( \frac{d\sigma_{A1}}{d\sigma_{A2}} \right)^{1/2}$$

(2.6)

Furthermore, if one chooses 0 as a reference wavefront
Figure 2-3. Astigmatic Tube of Rays Illustrating Geometrical Optics Approach to Propagation.
location, the electric field at d can be expressed as:

\[
\bar{E}(d) = \frac{\rho_1 \rho_2}{(\rho_1 + d)(\rho_2 + d)} e^{jkd},
\]

(2.7)

where \(\bar{E}(0)\) is the electric field at the reference point, and \(k\) is the propagation constant. The electric field at d is now expressed in the GO form. This expression is valid everywhere except at caustics.

The ideal ground scattering terrain for the ILS is an infinite, flat, perfect conducting plane. Thus, the total electric field in the upper half space, that is the region which includes a radiation source, is the sum of the direct and reflected fields. Moreover, no electric field can exist below the plane.

The GO technique has been applied in the past to determine the total electric field at the monitor location. A typical monitor location is 250 feet forward of the antenna mast. In the area between the antenna mast and monitor location, the terrain is graded smooth. Thus, no abrupt terrain change is expected. Hence, the total electric field calculation using the GO technique is accurate and comparable with measurements [17].

There is difficulty in total electric field determination when applying the GO technique to non-flat terrain. As an example, consider terrain represented by an infinite wedge configuration which has a sharp dropoff as shown in Figure 2-4. If the monitor location is the point of interest, then the terrain discontinuity has a minimal
Figure 2-4. Terrain with 90 Degree Dropoff.
effect on the total electric field. Hence, the total field obtained using GO is accurate at the monitor location. If the electric field amplitude is to be determined at the airborne observation point shown in Figure 2-4, then the terrain discontinuity is between the antenna mast and the point of interest. To illustrate the effect of the terrain discontinuity, considered Figure 2-5. In the figure the total electric field pattern is shown at a constant radius of 50,000 feet from the base of the antenna mast and covers from 8.0 to -8.0 degree vertically. Note that two discontinuities exist in the GO calculated antenna pattern at elevations of ±1.6 degrees. At ±1.6 degrees, the abrupt change is due to sudden disappearance of the reflected field caused by the discontinuity in the reflecting surface. This point is located on the reflection boundary (RB). The RB line is shown in Figure 2-4. From angles of ±1.6 to -1.6 degrees, only the direct field exists. The second discontinuity happens when the observation point is no longer in the antenna line-of-sight, which means that the field radiated directly from the antenna to the observation point is blocked by the terrain. This observation point is on the shadow boundary (SB) and the boundary line is shown in Figure 2-4. According to GO, there is no electric field in the shadow region, which is from ±1.6 to -8.0 degrees, as indicated in Figure 2-5. This GO antenna pattern, with discontinuities, is contradictory to the physical requirement that the total field must be continuous. This
Figure 2-5. Antenna Patterns Obtained by Geometrical Optics, Geometrical Theory of Diffraction, and Uniform Theory of Diffraction Techniques.
is evidence that the results obtained from the GO technique are inaccurate in the neighborhood of discontinuities.

To improve the calculation accuracy, the GO technique is extended by adding a diffraction mechanism. One of the methods for calculating the diffracted field is known as the Geometrical Theory of Diffraction (GTD) [12]. The GTD technique will be discussed in the next section. The GTD result is more accurate than the GO result.

The GTD method, however, has its own limitation, that is, the diffracted field becomes infinite at both RB and SB (see Figure 2-4). The antenna pattern obtained using the GTD method is also illustrated in Figure 2-5. Similarly, one observes two discontinuities at the same elevation angle as using the GO technique. However, the GTD method predicts a non-zero field everywhere, which agrees with the physical requirements. Far away from discontinuities, the field amplitudes calculated using GO and GTD techniques are the same. Because of the discontinuities that exist in the antenna pattern, it is necessary for the GTD technique to be further modified. One of the modification versions is known as the Uniform Theory of Diffraction (UTD), which has been developed in the last decade [13]. The UTD calculated antenna pattern is also shown in Figure 2-5. It can be seen that far away from the discontinuities, the field amplitudes obtained from the GO, GTD and UTD techniques are approximately equal, but the UTD result shows no discontinuity. Therefore, the UTD method gives an
acceptable and the most accurate result. Further explanations of the GTD and UTD techniques will be presented in the following sections.

C. Geometrical Theory of Diffraction

The Physical Optics approach to electromagnetic reflection calculations involves integrating over the entire illuminated surface. The larger the surface, the more time required to evaluate the solution. The GTD approach is formulated in terms of reflected and diffracted rays, with the reflected rays coming from the surface of the reflector and the diffracted rays from the edges. The time required for evaluation of the GTD solution does not depend upon the size of the reflecting surface, but rather on how many diffracting edges there are. Also, since the GTD solution is based on rays which can be traced geometrically, the effects of shadowing and blockage can be included easily. The GTD approach has its beginnings in a classical paper by Sommerfeld [18]. But it has been put into an easy-to-use form by J.B. Keller only within the last two decades [12]. The diffracted ray is due to a ray incident on an edge at the diffraction point. Because of the local nature of edge diffraction at high frequency, asymptotic methods may be used to obtain the closed form calculation for the edge diffracted field due to this ray.

From Maxwell's equations in a source-free region occupied by an isotropic and homogeneous medium, the
electric field $\mathbf{E}$ must satisfy the wave equation, which is

$$\nabla^2 \mathbf{E} + k^2 \mathbf{E} = 0,$$

and the condition that

$$\nabla \cdot \mathbf{E} = 0$$

where

$$k = \omega/\sqrt{\mu \varepsilon} \quad \text{the phase constant},$$

$$\omega = \text{the angular frequency},$$

$$\varepsilon = \text{the permittivity of medium},$$

and

$$\mu = \text{the permeability of medium}.$$

Kline [19] has suggested that $\mathbf{E}$ along the ray can be expressed in the form of

$$\mathbf{E} = e^{-jk\psi(x,y,z)} \sum_{m=0}^{\infty} \frac{E_m(x,y,z)}{(j\omega)^m},$$

and the boundary conditions are

$$E_z = 0 \quad \text{(acoustic soft)},$$

$$\frac{\partial E_z}{\partial \mathbf{n}} = 0 \quad \text{(acoustic hard)},$$

where $\frac{\partial}{\partial \mathbf{n}}$ is the derivative along the normal to the boundary surface.

Acoustic soft is equivalent to tangential $\mathbf{E}$ being zero at the perfect conducting surface. For acoustic hard, the derivative of tangential $\mathbf{E}$ is zero.

Considering Equation (2.9) for high frequencies ($\omega \gg 1$), the first term will dominate, and thus can be approximated by:

$$\mathbf{E} \approx e^{-jk\psi(x,y,z)}E_0(x,y,z).$$
The second derivative of Equation (2.10) is
\[ \nabla^2 \vec{E} + (\nabla \psi)^2 k^2 \vec{E} = jk \left[ \vec{E}_o \nabla^2 \psi + 2(\nabla \psi \cdot \nabla) \vec{E}_o \right] + \frac{\nabla^2 \vec{E}_o}{\vec{E}_o} . \]

Since this equation must satisfy the wave equation, which is Equation (2.8), the following coefficient constraints must be met:
\[ (\nabla \psi)^2 = 1 \quad , \quad (2.11) \]
\[ \frac{\nabla^2 \vec{E}_o}{\vec{E}_o} = 0 \quad , \quad (2.12) \]
\[ \vec{E}_o \nabla^2 \psi + 2(\nabla \psi \cdot \nabla) \vec{E}_o = 0 \quad . \quad (2.13) \]

Equation (2.11) is the Eikonal equation of geometrical optics, which states that the propagation direction of the wavefront \( \psi \) is a straight line. Equation (2.12) implies that the amplitude of the electric field to be considered must not vary rapidly with respect to its coordinate. Equation (2.13) is known as the transport equation. The quantity \( (\nabla \psi \cdot \nabla) \vec{E}_o \) can be reduced to \( \frac{d \vec{E}_o}{ds} \) which is the rate of change of \( \vec{E}_o \) along the differential arc length \( ds \) along which energy is propagated. By substituting into Equation (2.13) and rewriting the terms, one obtains:
\[ \frac{d \vec{E}_o}{ds} + \frac{1}{2} (\nabla \psi)^2 \vec{E}_o = 0 \quad , \quad (2.14) \]

which is of the form:
\[ \frac{dy}{dx} + f(x)y = 0 \quad , \quad (2.15) \]

and has the known solution given by:
\[ \ln y(x) - \ln y(x_o) = - \int_{x_o}^{x} f(x') \, dx' . \]
Thus, the solution of Equation (2.14) is:

\[ -1/2 \int v^2 \psi \, ds' \]

\[ \overline{E}_o(s) = \overline{E}_o(s_0) e^{-s/s_0}, \]

and from Equation (2.11), the solution is

\[ \psi = \psi_o + s, \]

and

\[ \nabla \psi = \hat{s}, \]

where

\[ s = \text{the propagation distance}, \]
\[ \hat{s} = \text{a unit vector tangential to the ray}. \]

Let us introduce the Gaussian curvature of the wavefront \( G = \frac{1}{\rho_1 \rho_2} \), where \( \rho_1 \) and \( \rho_2 \) are the principle radii of curvature of the wavefront surface \( \psi \) (see Figure 2-3). For isotropic homogeneous medium,

\[ \nabla(G \cdot \hat{s}) = 0. \]

Using the vector identity and rearrange terms,

\[ \hat{s} \cdot \nabla G = -G \nabla \cdot \hat{s}, \]

but

\[ \hat{s} \cdot \nabla = \frac{d}{ds}, \]

and

\[ \hat{s} = \nabla \psi, \]

\[ \frac{dG}{ds} = -G \nabla^2 \psi, \]

then

\[ \frac{dG}{ds} + (\nabla^2 \psi)G = 0, \]

where it can be seen that the above equation has the same form as Equation (2.15). Therefore, by integrating this equation, one obtains
$$G(s) = \sqrt{G(s_o)} e^{s_0}$$

then

$$\overline{E}_o(s) = \overline{E}_o(s_o) \sqrt{\frac{G(s)}{G(s_o)}}.$$ Substituting $\overline{E}_o$ in the asymptotic high frequency approximation, the electric field is written as

$$E(s) = \overline{E}_o(s_o) \sqrt{\frac{G(s)}{G(s_o)}} e^{-jks}.$$ (2.16)

Referring to Figure 2-3, we assume that the surface area $A_1$ contains energy $(A_1)^2 c^{-1} d\sigma_{A_1}$, where $c$ is the light speed, $A_1$ is the amplitude, and $d\sigma_{A_1}$ is the astigmatic tube of rays surface area. When the energy propagates in space, the energy at a new position $(A_2)$ becomes $(A_2)^2 c^{-1} d\sigma_{A_2}$, where $d\sigma_{A_2}$ is the new cross sectional area, and $A_2$ is the amplitude. Hence, by the principle of conservation of energy,

$$(A_1)^2 d\sigma_{A_1} = (A_2)^2 d\sigma_{A_2},$$

so that

$$A_1 = A_2 \sqrt{\frac{d\sigma_{A_2}}{d\sigma_{A_1}}}.$$

We now can write the ratio of the surface area as:

$$\frac{d\sigma_{A_2}}{d\sigma_{A_1}} = \frac{\rho_1 \rho_2}{(\rho_1 + d)(\rho_2 + d)},$$

where $d$ is the distance measured along the beam from the
reference point 0 (see Figure 2-3). Substituting \( \frac{G(s)}{G(s_0)} \) in Equation (2.16), yields:

\[
\bar{E}(s) = \bar{E}_0(s_0) \sqrt{\frac{\rho_1 \rho_2}{(\rho_1 + d)(\rho_2 + d)}} e^{-jks},
\]

which is the same form as the geometrical optics approximation. Equation (2.17) describes the electric field amplitude and phase in space. Furthermore, at a caustic where \(-d = \rho_1 \) or \( \rho_2 \), Equation (2.17) is undefined.

A rigorous treatment is considered next. Instead of using only the leading term in the expansion of Equation (2.19), the infinite sum is included. Again, the derivations will be similar to when considering the dominant term only. One obtains,

\[
(\nabla \psi)^2 = 1
\]

\[
\bar{E}_n \nabla^2 \psi + 2(\nabla \psi \cdot \nabla) \bar{E}_n = -\nabla^2 \bar{E}_n - 1 \quad n = 0, 1 \ldots \quad (2.18)
\]

It should be noted that the coefficient \( \bar{E}_{-1} \) has been added for completion of the successive recursion, and its value is zero [20]. Thus, the Equation (2.18) is now in the recursive form, in which it has a solution of the form

\[
\bar{E}_n(s) = \bar{E}_n(s_0) e^{-jks} - 1/2 \int_{s_0}^{s} e^{-jks} \nabla^2 \bar{E}_{n-1}(\tau) d\tau ,
\]

\[
= \bar{E}_n(s_0) \sqrt{\frac{G(s)}{G(s_0)}} e^{-jks} - 1/2 \int_{s_0}^{s} \sqrt{\frac{G(s)}{G(s_0)}} \nabla^2 \bar{E}_{n-1}(\tau) d\tau ,
\]

\[
= \bar{E}_n(s_0) \sqrt{\frac{G(s)}{G(s_0)}} e^{-jks} - 1/2 \sqrt{G(s)} \int_{s_0}^{s} \sqrt{G(\tau)}^{-1/2} \nabla^2 \bar{E}_{n-1}(\tau) d\tau ,
\]

(2.19)
In Keller's theory, $\overline{E}_o(s)$ is assumed to have a simple relation with $\overline{E}_o(s_0)$. Thus, Equation (2.19) can be expressed as:

$$\overline{E}_o(s) = \overline{E}_o(s_0) \cdot D \sqrt{\frac{G(s)}{G(s_0)}} e^{-jks} \quad (2.20)$$

The factor of proportionality $D$ is called the dyadic diffraction coefficient. In the case of a perfectly conducting wedge, $D$ is obtained by comparing Equation (2.18) with the exact solution derived by Sommerfeld [18]. Moreover, $\overline{E}_n(s)$, for $n>>1$, is not determined by this theory. The reason for this is the degree of difficulty encountered in determining the solution to satisfy Equation (2.18).

Substituting Equation (2.17) into Equation (2.20), the result is

$$\overline{E}_o(s) = \overline{E}_o(s_0) \cdot D \sqrt{\frac{\rho_1 \rho_2}{(\rho_1 + d)(\rho_2 + d)}} e^{-jks} \quad (2.21)$$

This equation will describe the diffracted field amplitude and phase at the observation point. Without loss of generality, let us choose the reference point from where $d$ is measured at the diffracting point. Hence $\rho_2$ becomes the distance between the source and the diffracting point. Furthermore, in the limit as $\rho_1 \to 0$, Equation (2.21) becomes

$$\overline{E}_o(s) = \overline{E}_o(s_0) \cdot D \sqrt{\frac{\rho_1 \rho_2}{d(\rho_2 + d)}} e^{-jks} \quad (2.22)$$

After moving the reference point from an arbitrary point to the diffraction point located on the diffracting edge,
Equation (2.22) becomes

$$\overline{E_0}(s) = \overline{E_0}(s_0) \cdot \overline{D} \sqrt{\frac{s'}{s(s' + s)}} e^{-jks},$$  \hspace{1cm} (2.23)

where

\( s = \) the distance from the source to the diffraction point,

\( s' = \) the distance from the diffraction point to the observation point (see Figure 2-1).

In this study, only the dyadic diffraction coefficient for a perfectly conducting wedge is considered. While James has developed a diffraction coefficient for an impedance wedge [21], its application is beyond the scope of this research. According to Reference 13, \( \overline{D} \) can be expressed in terms of the soft boundary \( (D_s) \) and hard boundary \( (D_h) \) conditions as:

$$\overline{D} = -\hat{\beta}_o \hat{\beta} D_s - \hat{\phi}' \hat{\phi} D_h$$

where

$$\hat{\beta}_o = \hat{s}' \times \hat{\phi}'$$

$$\hat{\beta} = \hat{s} \times \hat{\phi}$$

and

$$\hat{s}' = \text{the unit vector in the direction from the source to the diffraction point.}$$

$$\hat{s} = \text{the unit vector in the direction from the diffraction point to the observation point.}$$

$$\hat{\phi}' = \text{the unit vector perpendicular to the plane which contains a diffracting edge and } \hat{s}'. \hspace{1cm} \hat{\phi} = \text{the unit vector perpendicular to the plane which}$$
contains a diffracting edge and \( \hat{s} \).

Figures 2-6 and 2-7 illustrate the diffraction geometry. It is appropriate at this point to introduce the ray fixed coordinate systems. The ray fixed coordinates are composed of three orthogonal unit vectors from either the \( \hat{s'}, \hat{\phi'}, \hat{\beta}_0 \) or \( \hat{s}, \hat{\phi}, \hat{\beta} \) groups.

It has been shown in Reference 13 that the diffraction field in ray fixed coordinates can be expressed as

\[
\bar{E}^{d}(s) = \bar{E}^{d}(Q_{E}) \cdot \bar{D}(\hat{s}, \hat{s'}) A(s)e^{-jks},
\]

where

\[
A(s) = \text{the function describing the amplitude variation along the ray and is equal to } \sqrt{\frac{s}{s(s' + s)}}. \\
\bar{D} \text{ is determined by comparing the exact solution of the perfect conducting wedge obtained by Sommerfeld and Equation (2.24). Both solutions are the same in the ray fixed coordinates provided that}
\]

\[
D_S(\phi, \phi', \beta) = \frac{e^{-j\pi/4}}{m^22\pi k \sin \beta_0} \left( \frac{1}{\cos(\pi/m) - \cos(\phi - \phi')} + \frac{1}{\cos(\pi/m) - \cos(\phi + \phi')} \right),
\]

where \( m \) is defined in Figure 2-6.

\( \bar{D} \) represents the modal description of the wave existing in the presence of the wedge structure and excited by a transmitting source. It should be noted that the diffraction coefficients are undefined when the following conditions are satisfied:

\[
\pi = \{ \phi + \phi' \text{ reflection boundary (RB)}, \phi - \phi' \text{ shadow boundary (SB)} \}
\]
Figure 2-6. Illustration of Diffraction Unit Vectors when Antenna Source is Located Exterior to the Wedge.
Figure 2-7. Diffraction Angle $\beta_o$ and Cone of Diffracted Rays.
Hence, the first and second terms in Equation (2.25) become singular at the shadow and reflection boundaries. This is the obvious shortcoming of diffraction coefficients expressed in the form of Equation (2.25). However, the calculated diffracted field far away from either reflection or shadow boundaries is accurate as shown in Figure 2-5.

The diffracted field determined by using Equations (2.24) and (2.25) is a ray field, i.e., the diffracted field can still be expanded in the form of Equation (2.9). Hence, the higher interaction (doubly or higher) diffracted field can be determined by canonical calculation and superposition of rays.

D. Uniform Theory of Diffraction

The shortcoming of the GTD in determining the diffracted field near the reflection and shadow boundaries can be eliminated. Several attempts have been made toward extending the accuracy of the GTD solution at reflection and shadow boundaries where infinite fields are calculated using GTD. As a result, the Uniform Theory of Diffraction (UTD), Modified Slope Diffraction (MSD) and the Uniform Asymptotic Theory (UAT) are among the promising asymptotic techniques that provide a valid result everywhere. The UTD and MSD techniques have been developed by Kouyoumjian and Pathak [13], and Hwang and Kouyoumjian [22], respectively. The UAT technique has been introduced by Ahluwalia, Lewis and Boersma [23].
In the ILS glide slope application, the free space vertical pattern of the practical antenna can be approximated by an isotropic source. Rahmat-Samii and R. Mittra have shown that the UTD, MSD and UAT techniques yield the same field calculation for an isotropic source in the presence of a half-plane [24]. They also pointed out that the UAT technique determines the total electric field at the image location of the source incorrectly. The MSD technique, on the other hand, involves a greater number of calculation steps than the UTD method, and hence requires a larger amount of computation time. Furthermore, the MSD technique is not more accurate than the UTD technique when the field incident at the edge does not vary rapidly, which is the case here. Therefore, only the UTD technique will be used here.

The approach of the UTD technique is to modify the diffraction coefficients expressed in Equation (2.25). The closed form equation is composed of cotangent and Fresnel functions. This equation can be applied to any type of wedge configuration. The UTD diffraction coefficient is given by [13]:

\[
D_h(\phi, \phi', \beta_o) = \frac{-e^{-j\pi/4}}{2\sqrt{2}\pi k\sin\beta_o} \times \left\{ \cot\left( \frac{\pi + (\phi - \phi')}{2m} \right) F[kLa_+(\phi - \phi')] \\
+ \cot\left( \frac{\pi - (\phi - \phi')}{2m} \right) F[kLa_-(-\phi - \phi')] \\
+ \{ \cot\left( \frac{\pi + (\phi + \phi')}{2m} \right) F[kLa_+(-\phi + \phi')] \\
+ \cot\left( \frac{\pi - (\phi + \phi')}{2m} \right) F[kLa_-(-\phi + \phi')] \} \right\} (2.27a)
\]
where

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

\[ a = 2 \cos^2 \left\{ \frac{2\pi n N^+ - \beta}{2} \right\} \]

\[ N = \text{the integers which most nearly satisfy the following two equations,} \]

\[ 2\pi m N^+ - \beta^+ = \pi \]

\[ 2\pi m N^- - \beta^- = -\pi \]

\[ \beta = \phi \pm \phi' \]

and

\[ \phi \text{ and } \phi' \text{ are shown in Figure 2-6.} \]

The distance parameter \( L \) is given by:

\[ L = \frac{ss'}{s + s'} \sin^2 \beta_0 \quad (2.28) \]

for spherical wave incidence. The angle of diffraction \( \beta_0 \) is shown in Figure 2-7. At reflection and shadow boundaries, one of the cotangent functions in equation (2.27a) becomes singular. But, the product of this cotangent function and the Fresnel function is still finite and it can be approximated by the expression:

\[ \cot \left( \frac{\pi + \beta}{2m} \right) F \left[ kL \left( \frac{\pi}{2m} \right) \right] \approx m(\sqrt{2\pi kL} \ \text{sgn} \delta - \{ 2kL \delta e^{j\pi/4} \}) e^{j\pi/4} \quad (2.29) \]

with \( \delta \) determined by:
\[ \beta - 2\pi m n = \mp (\pi - \delta) \]  \hspace{1cm} (2.30)

and \( \delta \ll 1 \). The minus sign and positive sign in Equation (2.27a) correspond to \( D_s \) and \( D_h \), respectively. Furthermore, the first two terms and the last two terms in the bracket in Equation (2.27a) compensate the discontinuities at shadow and reflection boundaries. These terms are sometimes referred to as the transition function.

When the observation point moves away from both reflection and shadow boundaries until all of the arguments of the transition functions are large (\( \gg 10 \)) the amplitude of the transition function can be approximated as 1; Equation (2.27a) is then reduced to Equation (2.25). If this condition happens, the observation point is said to be outside transition regions.

Thus, the transition regions here are defined as being where at least one argument in the transition function in equation (2.27a) is smaller than a certain number. In the following discussion this number is selected to be 2. Reference 26 shows that a transition region is a hyperbola which makes an angle \( \Omega \) (see Figure 2-8), where

\[ \Omega = 2 \sin^{-1} \frac{M}{\sqrt{2kb}} \]  \hspace{1cm} (2.31)

\( M \) is equal to 2, \( b \) is the source-edge separation, and \( k \) is defined previously. The transition region always exists around a reflection or shadow boundary, and is referred to in the literature as a reflection transition (Tr), or shadow
Figure 2-8. Two Transition Regions about the Reflection and Shadow Boundaries Where Fields are Rapidly Varying. In shaded regions, only the UTD technique is valid, but outside the shaded areas, both the GTD and UTD techniques are valid.
transition (Ts) region.

It is well known that, in the transition regions, the diffracted field calculated using the UTD method is not a ray field and can not expanded in the form of Equation (2.9). The ray field property must be preserved in order to use the canonical determination of the intersection diffraction mechanisms, viz, double-diffraction. This is considered as an extension of the UTD.

A simple way to preserve the ray field property is to require that the second edge must not be located in any of the transition regions of the first edge. This is done in this ILS application. If, however, the second edge is located in a transition region, a more rigorous treatment is required [25,27]. One of the methods is to modify term by term in Equation (2.27a). This is beyond the scope of this study. Therefore, the ordinary UTD technique is used in all of the discussions to follow.
CHAPTER III
RAY TYPES AND EXISTENCE

In this chapter, the description of rays and the algorithms to test their existence are described. Thirteen types of rays will be included in the UTD model. These rays are separated into three different groups which are designated as the zero-order, first-order and second-order groups.

The zero-order group consists of three different types of rays, the direct, reflected, and singly-diffracted rays. This group of rays will be discussed in detail in section A. The zero-order group rays are the most important due to their high amplitude.

The first-order group of rays is made up of combinations of reflected and diffracted rays. Therefore, the group consists of the doubly-reflected, reflected-diffracted, diffracted-reflected, and doubly-diffracted rays. These rays will be discussed in detail in section B.

The last group of rays considered, the second-order group, is made up of eight rays which are combinations of the first-order group rays and a reflected or diffracted ray. This group of rays consists of triply-reflected, reflected-reflected-diffracted, reflected-diffracted-reflected, reflected-diffracted-diffracted, diffracted-reflected-reflected, diffracted-reflected-diffracted,
diffracted-diffrated-reflected, and triply-diffracted rays. But in the ILS application a typical triple diffrated ray contribution is small when compared with the zero-order ray contributions. Therefore, only the first seven types of second order rays are included and will be discussed in section C.

In order to investigate all possible combinations of each ray described thus far, a large amount of computation time is required. This is undesirable, and can be reduced by making assumption that all of the existing rays do not contribute significantly to the total field at the observation point. Thus, certain low amplitude rays may be ignored to reduce the computation time. An example of a low amplitude ray to which the above assumption may be applied is the doubly-diffracted ray. To illustrate this type of situation refer to Figure 3.1a. This ray, impinging on the edge f, and diffracted from the edge f to the edge e has a small amplitude when compared with the ray amplitude that is diffracted from the edge e to the edge f as shown in Figure 3.1b. The choice of rays to be included is discussed more fully in later sections of this chapter.

A. Zero-Order Group

The zero-order group of rays is composed of three strong rays which make up the cornerstone of diffraction theory. These rays are the direct, singly reflected, and singly diffracted rays. We now proceed to discuss the zero-
Figure 3-1a. The Doubly-Diffracted Ray Situation Which Is Excluded from the UTD Model Calculation.

Figure 3-1b. The Doubly-Diffracted Ray Is Considered in the Calculation.
order group rays as well as to give some logical tests for their existence.

A.1 Direct Ray

The direct ray is the ray which contributes the most significant contribution if it exists, and is defined as the ray which travels directly from the original source (transmitting antenna) to the observation point (field point). This ray can exist only if there is no terrain high enough to block its path of travel. There are different methods that can be used to test for the existence of this ray. In this study, one of these will be discussed. Figure 3-2 shows the direct ray. Since the actual terrain is approximated by many finite flat plates, the computer program must logically test the ray for blockage by any of these plates. If the ray is not blocked, then its associated field is calculated, and it becomes the first field contribution included in the total field.

A.2 Singly-Reflected Ray

A singly-Reflected (B) ray is defined as a ray reflected once from a plate, where the incident angle of the ray with respect to the plate is equal to the reflected angle. An example of such a ray is given in Figure 3-3.

To test for the existence of the ray, the first step is to find the image source location. This image source is uniquely determined by the original source and the unit
Figure 3-2. The Direct Ray Which Propagates Directly from the Source Antenna to the Observation Point.
normal of plate. After the image source is found, the ray is assumed to radiate from this source to the observation point with a 180 degree phase delay with respect to the original source. The second step is to determine whether or not the ray has an interception point within the physical boundaries of the plate. For example, with reference to Figure 3-3, the singly reflected ray from plate L cannot exist if it does not intercept plate L. The interception point (CL) is sometimes called the specular point. Not only must the ray intercept the plate, but also the ray must not be blocked by the other plates. If CL exists, then a blockage test for the existence of the ray in the scattered direction must be performed. Once this ray passes all of the tests, its electromagnetic field is calculated and vectorially added to previous contributions. This computer algorithm is again performed on the next plate until all of the plates have been included. The final result is the total singly reflected field \( \overrightarrow{E}^R \) given by

\[
\overrightarrow{E}^R = \sum_{L=1}^{N} \overrightarrow{E}^R_L
\]

where

- \( N \) = the number of modeling plates,
- \( L \) = the plate index,
- \( \overrightarrow{E}^R_L \) = the singly-reflected field from plate L.

### A.3 Singly Diffracted Ray

The last ray of the zero-order group to be discussed is the singly diffracted ray. Diffraction is the phenomenon
Figure 3-3. The Singly-Reflected Ray Reflected from Plate L to the Observation Point.
which occurs when the electromagnetic wave is incident on any discontinuity in the geometry of an object; i.e., a sharp corner or an edge. This phenomenon has been known for more than a century. One classical example is the two-dimensional, perfectly conducting wedge in the presence of a plane wave (see Figure 2-1). Figure 2-1 also shows the reflection and the shadow boundaries. These boundaries, in Figure 2-1, are defined with respect to a corner of the illuminated face and they extend outward into space. Space is divided by the shadow boundary into two regions which are called the illuminated region and the shadow region. In the illuminated region, the direct ray exists everywhere, but in the shadow region, the direct ray ceases to exist. According to the GO approximation, there is no electromagnetic field in the shadow region when the wedge is large in term of the wavelength. This means that there is a field discontinuity as the point of observation moves across the shadow boundary. This is, of course, not true in the physical world. If the diffracted fields are calculated accurately, the total electromagnetic field will be continuous throughout the space exterior to the wedge. This is evidence that if one combines the GO field and the diffracted field, the resulted field will be more accurate than the GO field alone, especially in the neighbourhood of shadow and reflection boundaries.

The computation required to find the diffracted ray is much more complicated than for finding the direct or the
singly reflected ray. The diffracted field pattern from the wedge is quite peculiar since there are discontinuities in amplitude and phase at both of the boundaries. These discontinuities will compensate for the disappearance of the direct and singly reflected rays, which will occur at the shadow and reflection boundaries, respectively. The abrupt amplitude and phase changes in the field at the discontinuities are on the order of 3 Db and 180 electrical degrees, respectively. In this study, the diffraction field is calculated using results obtained by Kouyoumjian [13], which are an approximate high frequency closed form solution.

One of the important points in the process of finding the diffracted field is to locate the diffraction point (Qe). Qe is the point where the angle between the plane containing the line from the source to Qe and the diffracting edge is equal to the angle between the plane containing the diffracting edge and the line from Qe to the observation point (see Figure 2-7). In other words, Qe is the point that satisfies the Law of Edge Diffraction (Fermat's Principle). In most of the UTD computer programs written by other investigators an iterative technique has been used to locate Qe, but this is inefficient. An algorithm for the two-dimensional problem of locating Qe has been developed for this model, and the algorithm is described in Appendix A. Thus, the problem of finding Qe is simplified, and requires little computation time.
Once Qe is found, the logical test for ray existence is performed. Let plate L and plate L+1 form a wedge as shown in Figure 3-4. The edge e of this wedge is under test for the existence of a diffraction point. The computer program separates the entire modeling terrain into two regions. The first region includes the first plate to plate L-1, the second region is from plate L+2 to the last plate. In the first region, the computer program tests for blockage using the antenna location and Qe as the two end points of a ray. In the second region, Qe and the observation point are the two end points and similar blockage tests are performed. If the ray passes these blockage tests the diffracted ray is evaluated and the contribution is vectorially added to the total. If the ray was blocked, the next edge, which is formed by plates L+1 and L+2, is considered. The program repeats the procedure until all of the edges have been tested for possible diffracted rays. The final result is the total singly diffracted field (\( \vec{E}^D \)), which is given by

\[
\vec{E}^D = \sum_{e}^{T} \vec{E}_e^D
\]

where

- \( T \) = the number of edges,
- \( e \) = the edge index,
- \( \vec{E}_e^D \) = the singly diffracted field from the edge \( e \) evaluated at the observation point.

B. First-Order Group

The first-order group is composed of combinations of
Figure 3-4. The Singly-Diffracted Ray Diffracted from Edge e to the Observation Point.
reflected and diffracted rays which are; the doubly-reflected, the reflected-diffracted, the diffracted-reflected, and the doubly-diffracted rays. The ray descriptions and blockage tests are presented in the following sections.

B.1 Doubly-Reflected Ray

The doubly-reflected (RR) ray is one that is reflected from two different modeling plates. An example of this ray is shown in Figure 3-5, where the ray is reflected from plate L to plate M, and reflected off plate M to the observation point.

The existence determination algorithm starts with the location of the doubly imaged source. This can be accomplished by first determining the image of the original source with respect to plate L, and then treating this image source as if it were the actual source and determining its image with respect to plate M. The RR ray is assumed to radiate from this doubly imaged source to the observation point, and in phase with respect to the original source. Once the doubly imaged source is found, and using the location of the observation point, the reflection point (CM) with respect to plate M is determined. If CM is located outside the physical boundaries of plate M, the RR ray does not exist. But if CM lies within the boundaries, the location of the reflection point on plate L (CL) must be determined. This is done by the use of the first imaged
Figure 3-5. The Doubly-Reflected Ray Reflected from Plate L to Plate M, and Reflected from Plate M to the Observation Point.
source and CM as the two points of a ray. Once again the reflection point CL must lie on the plate L. If CL and CM are found to exist, the blockage tests are performed. In summary, for the RR ray to exist, interception points CL and CM must be located on both plates, and the line of sight from the original source to CL, from CL to CM, and from CM to the observation point must not be blocked. If these conditions are met, the RR ray electric field amplitude and phase are calculated and added to the previous contributions.

This process is repeated until all of the plate combinations possible have been tested. The final result is the total Doubly-Reflected field (\( \mathbf{E}^{RR} \)), which is given by

\[
\mathbf{E}^{RR} = \sum_{L} \sum_{M} \mathbf{E}_{L,M}^{RR},
\]

where

\[ N = \text{the number of modeling plates}, \]
\[ L, M = \text{the plate indexes}, \]
\[ \mathbf{E}_{L,M}^{RR} = \text{the doubly-reflected field for plate L and plate M}. \]

B.2 Reflected-Diffracted Ray

The reflected-diffracted (RD) ray is the ray that is reflected once from a plate K and then diffracted once by an edge e. An example of such a ray is given in Figure 3-6.

The existence of the reflection point (CK) and the diffraction point (Qe) is the first requirement for a RD ray.
Figure 3-6. The Reflected-Diffracted Ray Reflected from Plate K to Edge e (Diffraction Point $Q_e$) and Diffracted from Edge e to the Observation Point.
to exist. There are at least two possible methods to determine the existence of these two points.

The first method involves creating images of the edge under test and the observation point with respect to an extension of the reflecting plane under test (K in this case); the geometries involved in the first method are shown in Figure 3-7a. With the antenna location, image edge, and image observation point, the location of the diffraction point on the (image) edge is calculated. Finally, if a line between the source and the image of Qe intersects the plane K, CK exists, and the ray is tested for blockage.

The second method is to image the source rather than the diffraction point (see Figure 3-7b). For this method, a line between the source image and Qe intersecting plane K determines the existence of Qe and CK. Due to computational considerations, the latter method is considered desirable and is used in this study, although they give identical results.

If CK and Qe are determined to exist, the blockage algorithm is performed. If the ray is not blocked, RD ray electric field amplitude and phase are calculated and added to the previous contributions. It should be noted that the phase of the RD image source is delayed 180 electrical degrees with respect to the original source for horizontal polarization.

This process is repeated until all plate and edge combinations for the RD ray have been tested. The final
Figure 3-7a. Depiction of First Method for Determining the Existence of a Diffraction Point \( Q_e \) for a Possible Reflected-Diffracted Ray Reflected from Plate K and Diffracted at Edge \( e \).

Figure 3-7b. Depiction of Second Method for Determining the Existence of a Diffraction Point \( Q_e \) for a Possible Reflected-Diffracted Ray Reflected from Plate K and Diffracted at Edge \( e \).
result is the total Reflected-Diffracted field \( \mathbf{E}^{\text{RD}} \), which is given by

\[
\mathbf{E}^{\text{RD}} = \sum_{K=1}^{N} \sum_{e=1}^{T} \mathbf{E}_{K,e}^{\text{RD}},
\]

where

- \( N \) = the number of modeling plates,
- \( K \) = the plate index,
- \( T \) = the number of edges,
- \( e \) = the edge index,
- \( \mathbf{E}_{K,e}^{\text{RD}} \) = the Reflected-Diffracted field for plate \( K \) and edge \( e \).

3.3 Diffracted-Reflected Ray

The diffracted-reflected (DR) ray is the ray that is diffracted from an edge and reflected off a plate, which is not part of the same edge, to the observation point. The ray geometry is illustrated in Figure 3-8.

The first requirement for a DR ray to exist is that the diffraction point and reflection point must exist. There are two possible methods to determine the existences of these two points.

The first method involves imaging the antenna source and the edge \( e \) in this case) with respect to an extension of the plate under test \( L \) in this case). Figure 3-9a depicts the geometry involved in this method. With an image source location, image edge \( e \) and the observation point, the image of the diffraction point is determined. Using the image of the diffraction point and the observation point as
Figure 3-8. The Diffractions-Reflected Ray diffracted from Edge e (Diffraction Point $Q_e$) to Plate L and reflected from Plate L to the Observation Point.
two end points together with a plane which contains plate L, reflection point (CL) is calculated. Finally, Qe is determined by re-imagining the image of the diffraction point with respect to plate L.

The second method is to image the observation point with respect to the plane containing plate L (see Figure 3-9b). With the antenna location, the edge and the image of the observation point, Qe is determined using the same logic as for the singly diffracted ray. CL is found by using Qe and the image of the observation point as two end points of a line that intercepts an extension of plate L.

Comparing these two methods indicated that the latter method required fewer computation steps, hence less computation time. Therefore, the latter method is used.

After Qe and CL are determined to exist, the second requirement is the line of sight from the antenna location to Qe, from Qe to CL, and from CL to the observation point must not be blocked. If the line of sight is not blocked, the DR ray electric field amplitude and phase are calculated and added to the previous contributions. The phase of the DR ray is also delayed by 180 electrical degrees due to the reflection.

This process is repeated until all edge and plate combinations for the DR ray have been tested. The final result is the total Diffracted-Reflected field (E^{DR}), which is given by
Figure 3-9a. The First Method for Determining the Diffracted-Reflected Ray Path.

Figure 3-9b. The Second Method for Determining the Diffracted-Reflected Ray Path.
where \[ E_{e,L}^{DR} = T \sum_{e} N \sum_{L} E_{e,L}^{DR}, \]

- \( N \) = the number of modeling plates,
- \( T \) = the number of edges,
- \( e \) = the edge index,
- \( L \) = the plate index,
- \( E_{e,L}^{DR} \) = the Diffracted-Reflected field for edge \( e \) and plate \( L \).

### B.4 Doubly-Diffracted Ray

The doubly-diffracted (DD) ray is diffracted by two different edges. An example of this ray is illustrated in Figure 3-10, where the first edge is formed by connected plates \( K \) and \( K-1 \), and the second edge is formed by plate \( L \) and plate \( L-1 \). It should be noted that the edges are not part of the same plate. There always exists a doubly-diffracted ray where both edges are part of the same plate. This type of ray is sometimes referred to as the surface wave in the sense that the ray after the first diffraction propagates along the plate surface. However, the ray amplitude of the surface wave is attenuated quickly. Furthermore, the typical plate width used is more than 100 wavelengths. Hence, this type of Doubly-diffracted ray is ignored in these calculations.

Before starting the blockage test, the two diffraction points \( DK \) and \( DL \) have to be determined. If both \( DK \) and \( DL \) exist, testing for blockage of the line of sight from the source to \( DK \), \( DK \) to \( DL \), and \( DL \) to the observation point is
Figure 3-10. The Doubly-Diffracted Ray Diffracted from Edge e (Diffraction Point Q_e) to Edge e' (Diffraction Point Q_e'), and Diffracted from Edge e' to the Observation Point.
performed. If there is no line of sight blockage, the DD ray exists and its associated electric field components are calculated. It should be noted that if the edges are infinitely long (2-dimensional), both diffraction points always exist.

The process is repeated until all of the edges have been tested. The final result is the total doubly diffracted field \( E_{DD} \), which is given by

\[
E_{DD} = \sum_{e} \sum_{e'} T_{e,e'} E_{e,e'}^{DD}
\]

where

- \( T \) = the number of edges,
- \( e, e' \) = the edge indexes,
- \( E_{e,e'}^{DD} \) = the Doubly-Diffracted field for edges \( e \) and \( e' \).

C. Second-Order Group

The second-order group is composed of eight rays which are: the triply-reflected, reflected-reflected-diffracted, reflected-diffracted-reflected, reflected-diffracted-diffracted, diffracted-reflected-reflected, diffracted-reflected-diffracted, diffracted-diffracted-reflected, and triple-diffracted. Only the first seven rays are discussed. There are several different algorithms which can be used to test for the existence of a particular ray. For example, refer to Figures 3-7a and 3-6b for the Reflected-Diffracted ray. However, using any algorithm the same result is obtained. The algorithms used in these sections are chosen so that the required computation steps are minimum.
There are three required major steps in testing for ray existence: the setup procedure, calculating the reflection and/or diffraction point(s), and the line-of-sight blockage test. If the ray passes these, it exists. The last step is then the electric field amplitude and phase calculation. Similar tests as are applied to the previous ray group are also used for the second-order group rays. For example, the diffracted-diffracted-reflected ray is simply the doubly-diffracted ray diffracted toward the image of the observation point instead of diffracted toward the real observation point. Therefore, the tests to determine the reflection of diffraction points for the second-order rays are not discussed in these sections. It should be mentioned again that the UTD model includes rays which propagate in the forward direction only. We now proceed to describe the included rays in detail.

C.1 Triply-Reflected Ray

The Triply-Reflected (RRB) ray is defined as any ray reflected from plates three times, with the incident and reflected angles on each plate equal. An example of such a ray is given in Figure 3-11.

To test for the existence of the ray, the first step is to find the image source location of the antenna source with respect to the first reflecting plate (K in this case). The method of determining the image source location is explained in section A.2. Once the image location is found, using it
Figure 3-11. The Triply-Reflected Ray Reflected from Plate K to Plate L, Reflected from Plate L to Plate M, and Reflected from Plate M to the Observation Point.
as a source a second image with respect to plate L is calculated. Then using the second image as if it were the source, a third image point with respect to plate M is calculated.

The second step is to determine whether or not reflection points exist within the physical boundaries of plate K, L, and M. This can be ascertained by using the third image and the observation points as two points on a line. This line must intercept plate M; the interception point (RM) and the second image location are then used as two points on a line that must intercept plate L. Again, by using the interception point on plate L (RL) and the first image location as two end points on a line, the third interception point (RK) is found and must be located on plate K. If any one of the three reflection points, RK, RL, and RM is not located within the appropriate plate boundary, the RRR ray does not exist and the next reflecting plate (M+1) is considered.

If three reflection points exist, the third step is to determine whether or not the ray which travels from the antenna source to RK, RK to RL, RL to RM, and RM to the observation point is blocked by the other plates. If the RRR ray passes all blockage tests, its electric field amplitude and phase are calculated and added to the previous contributions. This algorithm is performed on all forward ray combinations of plates. The final result is the total triply-reflected field \( E^{RRR} \), which is given by
where

\[ E^{RRR}_{K,L,M} = \sum_{N} \sum_{L} \sum_{M} E^{RRR}_{K,L,M} \]

\[ N \]
\[ = \] the number of modeling plates,
\[ K, L, M \]
\[ = \] the plate indexes,
\[ E^{RRR}_{K,L,M} \]
\[ = \] the triple-reflected field.

C.2 Reflected-Reflected-Diffracted Ray

The Reflected-Reflected-Diffracted (RRD) ray is defined as a ray reflected by two different plates, then diffracted from an edge to the observation point. Moreover, the edge must not be part of the two reflecting plates. An example of this ray is given in Figure 3-12.

The first step to test for the existence of the ray is to find the image source position with respect to plate \( K \). The method of determining the image location is explained in section A.2. Once the first image point is found, the second image point must be calculated using the first image location and plate \( L \). Using the second image location and an edge (edge \( e \) in this case) the diffraction point is determined by using the method described in section A.3.

The second step is to determine whether or not there are reflection points existing within plates \( K \) and \( L \), and a diffraction point (Qe) on edge \( e \). With the exception of the case of an edge and a line which contains the second image point and the observation point being parallel, the diffraction point always exists in the two-dimensional case. Qe and the second image location are used as two points on a line. The reflection point (RL) where this line intercepts
The Reflected-Reflected-Diffracted Ray Reflected from Plate K to Plate L, Reflected from Plate L to Edge e (Diffraction Point $Q_e$), and Diffracted from Edge e to the Observation Point.
plate L is determined. Then using RL and the first image location as two points on a line, the reflecting point RK, which is the interception point on plate K, is calculated. If either RL, RK, or Qe do not exist the RRD ray will not exist.

The third step is to test whether or not the ray from the antenna source to RK, RK to RL, RL to Qe, and Qe to the observation point is blocked by the other plates.

If an RRD ray passes the existence tests, its electric field amplitude and phase are calculated and added to the previous contributions. This algorithm is performed on all forward traveling ray combinations of plates and edges. The final result becomes the total Reflected-Reflected-Diffracted field \( \overline{E}_{RRD} \), which is given by

\[
\overline{E}_{RRD} = \sum_{K,L,e}^{N,N,N} \overline{E}_{K,L,e}^{RRD},
\]

where

- \( N \) = the number of modeling plates,
- \( T \) = the number of edges,
- \( K, L \) = the plate indices,
- \( e \) = the edge index,
- \( \overline{E}_{K,L,e}^{RRD} \) = the RRD field.

### C.3 Reflected-Diffracted-Reflected Ray

The Reflected-Diffracted-Reflected (RDR) ray is reflected once from a plate, diffracted by an edge which is not part of the plate, and reflected once more from another plate. Figure 3-13 depicts an RDR ray.
Figure 3-13. The Reflected-Diffracted-Reflected Ray Reflected from Plate K to Edge e (Diffraction Point $Q_e$), Diffracted from Edge e to Plate M, and Reflected from Plate M to the Observation Point.
The first step in the ray existence tests is to determine that the edge (edge e in this case) is located above both reflecting plates (plates K and M are considered). If this condition is met, the source and observation point are imaged with respect to plate K and plate M, respectively; also, an image of edge e with respect to plate K is calculated. By using an image of edge e, the image source, and the image of the observation point the image diffraction point (Qei) is determined. The method in determining the diffraction point is explained in section A.3. Qei is then reimaged with respect to plate K to a point on edge e, and is the diffraction point (Qe).

The second step is to test for the existence of the reflection points on plates K and M. The reflection point on plate K (RK) is determined by generating a line which contains Qe and the image source, intercepting plate K; similarly, the reflection point on plate M (RM) is where a line which contains Qe and the image of the observation point intersects plate M.

Once RK and RM are determined to exist on plates K and M, the last step required is the blockage test. The line-of-sight from the antenna to RK, RK to Qe, Qe to RM, and RM to the observer must not be blocked by the other plates.

If the ray passes the existence test, its electric field amplitude and phase are calculated and added to the total. This process is repeated until all forward traveling ray combinations of plates and edges are examined. The
The reflected-diffracted-diffracted (ROD) ray is defined as a ray reflected from a plate and diffracted from two different edges, where the diffraction edges are not part of the plate. An example of this ray geometry is given in Figure 3-14.

The first step to test for ray existence is to locate the image source with respect to plate K. Once this image point is found, the diffraction points on edges e and e' are determined. The algorithm to find the diffraction points for parallel edges is discussed in detail in Appendix A. It should be noted that if the edges are oriented arbitrarily, determining both diffraction points is much more difficult. This is also true for the doubly-diffracted ray.

The second step is to determine the existence of the reflection point (K in this case). This is done by generating a line which contains the image source and the
Figure 3-14. The reflected-diffracted-diffracted ray reflected from Plate K to Edge e (Diffraction Point Q_{e}) and diffracted from Edge e to the Observation Point.
diffraction point (e in this case) and testing whether it intercepts plate K.

The third step is the blockage test. A line which originates from the source to RK, RK to Qe, Qe to Qe', and Qe' to the observation point must not be blocked by the other plates.

Once the ray passes the existence tests, its electric field amplitude and phase are calculated and added to the previous contributions. This algorithm is performed on all forward traveling ray combinations of existing plates and edges. The final result becomes the total Reflected-Diffracted-Diffracted field \( E^{RDD} \), which is given by

\[
E^{RDD} = \sum_{K} \sum_{e} \sum_{e'} E_{K,e,e'}^{RDD},
\]

where

- \( N \) = the number of modeling plates,
- \( T \) = the number of edges,
- \( K \) = the plate number,
- \( e, e' \) = the edge indexes,
- \( E_{K,e,e'}^{RDD} \) = the RDD field.

C.5 Diffracted-Reflected-Reflected-Ray

The Diffracted-Reflected-Reflected (DRR) ray is diffracted once from an edge and reflected from two different plates. Furthermore, the diffracting edge must not be part of a reflecting plate. The ray geometry is illustrated in Figure 3-15.

The first step in the ray existence test is to
Figure 3-15. The Diffracted-Reflected-Reflected Ray Diffracted from Edge e (Diffraction Point Q_e) to Plate L, Reflected from Plate L to Plate M, and Reflected from Plate M to the Observation Point.
determine that the diffraction point and both reflection points exist. This is done by imaging the observer location with respect to plate M, and using this image location, further image with respect to plate L to form the secondary-image point. By using the secondary-image observer point, the source, and the edge e, the location of the diffraction point (Qe) is calculated. The method of obtaining Qe is discussed in section E.3. Once Qe is found, the determination of both reflection points is performed. By using Qe and the secondary-image observer location as two points on a line, the intersection point (RL) on the extension of plate L is calculated; similarly, by using RL and the first image observation point as two points on another line, the intersection point (RM) on the extension of plate M is determined. Both RL and RM must be located on plates L and M for the DRR ray to exist.

The last step is the blockage test. A line from the source to Qe, Qe to RL, RL to RM, and RM to the observation point must not be blocked by the other plates. If the line is not blocked, the DRR ray electric field amplitude and phase are calculated and added to the previous contributions.

The process is repeated until all edge and plates in forward direction combinations for the DRR ray have been examined. The final result is the total Diffracted-Reflected-Reflected field ($E_{\text{DRR}}$), which is given by

$$E_{\text{DRR}} = \sum \sum \sum E_{e,L,M}^{\text{DRR}}$$
where

\[ N = \text{the number of modeling plates}, \]
\[ T = \text{the number of edges}, \]
\[ L, M = \text{the plate indexes}, \]
\[ e = \text{the edge index}, \]
\[ E^{\text{DRR}}_{e,L,M} = \text{the DRR field}. \]

C.6 Diffracted-Reflected-Diffracted Ray

The Diffracted-Reflected-Diffracted (DRD) ray is one that is diffracted from an edge, reflected from a plate which is not part of the same edge, and diffracted once more from another edge which is part of the reflecting plate. An example of this ray geometry is illustrated in Figure 3-16.

The first condition to test whether or not the DRD ray is possible is that the diffraction points on both edges (edges \( e \) and \( e' \) in this case) and the reflection point on a plate (plate \( L \) for example) must exist. One method to determine this is to image both edge \( e' \) and the observation point with respect to plate \( L \). Then, using the source, edge \( e \), image of edge \( e' \), and image of the observation point, the diffraction points are determined as for the DD ray.

The second step is to test whether or not the reflection point is on plate \( L \). The reflection point is obtained by generating a line which contains both diffraction points, and intersects plate \( L \) at \( R_L \). For the DRD ray to exist, \( R_L \) must be within the boundaries of plate \( L \). It should be noted that one diffraction point is on the
Figure 3-16. The Diffracted-Reflected-Diffracted Ray diffracted from Edge e (Diffraction Point $Q_e$) to Plate L, reflected from Plate L to Edge $e'$ (Diffraction Point $Q_{e'}$), and diffracted from Edge $e'$ to the Observation Point.
image of edge e'. Therefore, before starting blockage tests, the actual diffraction point is needed. The resultant point (Qe') is thus located on edge e'.

The final condition for the ray to exist is no blockage. The line of sight from the source to Qe, Qe to RL, RL to Qe', and Qe' to the observation point must not be blocked by the other plates. If the line is not blocked, the ray electric field amplitude and phase are calculated and added to the previous contributions.

The process is repeated until all edges and plates in forward direction combinations for the DRD ray have been tested. The final result is the total Diffracted-Reflected-Diffracted field (\( E_{\text{DRD}} \)), which is given by

\[
E_{\text{DRD}} = \sum_{e}^{N} \sum_{L}^{T} \sum_{e'}^{T} E_{e,L,e'}^{\text{DRD}}
\]

where

- \( N \) = the number of modeling plates,
- \( T \) = the number of edges,
- \( L \) = the plate index,
- \( e, e' \) = the edge indexes,
- \( E_{e,L,e'}^{\text{DRD}} \) = the DRD field.

C.7 Diffracted-Diffracted-Reflected Ray

The Diffracted-Diffracted-Reflected (DDR) ray is defined as a ray diffracted from two different edges, and reflected once from a plate which does not touch those diffracting edges. An example of this ray geometry is illustrated in Figure 3-17.
Figure 3-17. The Diffracted-Diffracted-Reflected Ray Diffracted from Edge e (Diffraction Point $Q_e$) to Edge $e'$ (Diffraction Point $Q_{e'}$), Diffracted from Edge $e'$ to Plate $M$, and Reflected from Plate $M$ to the Observation Point.
The first step is to calculate an image of the observation point with respect to the reflecting plate (plate M in this case). The image location must lie below the plane which contains reflecting plate M. If this condition is met the next step is performed.

This is to determine the diffraction points on both edges (edge e and e') and the reflection point. The method is very similar to the one used for the doubly-diffracted ray. The only difference is that instead of using the real observation point, the image observation point is utilized. Therefore, by using the image observation point, source location, and edges e and e' the diffraction points Qe and Qe' are determined. Once Qe and Qe' are found, the reflection point on plate M is calculated. This is done by using Qe' and the image observation point as two points on a line that intercepts the plane which contains plate M. If the reflection point (RM) is found to exist within plate M, the blockage test is performed.

The blockage test is the last step in the ray existence algorithm. The line-of-sight propagation path from the antenna source to Qe, Qe to Qe', Qe' to RM, and RM to the observation point must not be blocked by the other plates.

If the DDR ray passes all three steps, it exists and the electric field amplitude and phase are calculated and added to the previous contributions. This algorithm is repeated on all-forward direction combinations of plates and edges. The final result becomes the total Diffracted-
Diffracted-Reflected field \( \vec{E}^{DDR} \), which is given by

\[
\vec{E}^{DDR} = \sum_{e}^T \sum_{e'}^T \sum_{M}^N \vec{E}_{e,e',M}^{DDR},
\]

where

\( T \) = the number of edges,

\( N \) = the number of modeling plates,

\( e, e' \) = the edge indices,

\( M \) = the plate index,

\( L \) = the plate which includes edge \( e' \),

\( \vec{E}_{e,e',M}^{DDR} \) = the DDR ray.
CHAPTER IV
APPLICATIONS AT TEST SITES

Results of the UTD reflection model as applied to the ILS glide slope are presented. Four different terrain configurations are selected to demonstrate the accuracy of the UTD results. This is done by comparing the UTD results against PO (Physical Optics) [5,6] results and flight measurements. A 2-D (2-Dimensional) hypothetical drop-off and up-slope terrain configuration is considered first. Since no measurements are available, ideal (flat) terrain is used for reference. The 2-D UTD results are compared with 2-D PO and GO (Geometrical Optics) results. In addition, the PO shadowing treatment is described.

For the second site, the ground terrain in the approach path is a drop-off followed by level ground. For the third site, the ground terrain is generally an up-slope. The 2-D UTD and 2-D PO models were again used for the second and third case calculations. The calculated results are then compared against airborne measurements.

The last site is a mild up-slope with large lateral terrain variations in the direction perpendicular to the runway centerline (X-direction). Special treatment of the terrain inputs to both the 2-D UTD and 2-D PO models is required to account for this terrain variation, and the method used is described. By using the three-dimensional
terrain input together with the 2-D UTD and 2-D PO models, the resulting models are referred to as the 3-D UTD and 3-D PO models.

The relative total electric field for the first case is computed at a 50,000 foot constant radius and covers a sector from 1.0 to 4.5 degrees elevation. For the second, third, and fourth sites, different types of measurement pattern cuts are calculated such that direct comparisons with flight measurements can be made. The special flight maneuvering procedures for ILS measurements according to the Federal Aviation Administration (FAA) standards are low-approach, level, perpendicular to runway, and orbital. The level and low-approach flight runs are most commonly performed during flight measurements. It should be noted that the flight measurement result shows the relation between the course deviation indication (CDI) in microamperes vs. the distance from the reference point. A CDI is obtained from calculating a ratio of the sideband and carrier complex amplitudes and multiplying with a constant. The resultant real part is the CDI. In Appendix B more detail is provided.

The level flight measurement is made at a constant 1000 foot altitude (typical), and is flown inbound from 54,000 to 18,200 feet from the antenna mast. The result is generally used to provide the value of the path angle (angle at which the receiver CDI current is zero) and the width angle (difference in the elevation angles at which the CDI current
is ±15 microamperes). This is considered as a far-field measurement. The low-approach flight is made along the extended runway centerline (localizer on-course) and on the glide path from an altitude of 1500 feet to an altitude over the runway of 20 feet. The purpose of this measurement is to determine the glide path structure characteristic along the glide path angle.

A. Hypothetical Site

A.1 Introduction

To demonstrate the UTD calculation shadowing accuracy as compared to the improper shadowing of the PO model, a simple but realistic 2-D terrain with a drop-off and up-slope configuration is used. The terrain profile is illustrated in Figure 4-1. Letters are assigned to reflecting sections and numbers are given to edges for use in following discussions.

Two grade values are chosen for the up-slope section. With a mild up-slope of 3.5 percent grade, the drop-off at the far-end of the up-slope portion is 7.5 feet. For the moderate up-slope of 11.0 percent grade, the highest elevation at the far end of an up-slope is 45 feet. When viewed from the base of the antenna mast (reference point) toward the highest point, the elevation angles for the mild and moderate up-slope cases are 2.0 and 6.3 degrees, respectively. These types of upslopes are frequently encountered at existing airports. The antenna height is
Figure 4-1. Two-Dimensional Hypothetical Terrain Profile Used in Calculating the Results in Figures 4-2 and 4-3. (Not to Scale)
28.26 feet, which is the typical height used in practice, and the simulation frequency is 330.0 MHz.

A.2 Model Comparison

For the hypothetical profile of Figure 4-1, the 2-D UTD results are compared against the 2-D PO calculations. For the GO calculations a profile consisting of a level reflecting plane is assumed. The antenna patterns obtained from the 2-D UTD, 2-D PO, and GO methods are superimposed with one another. The GO result is used as a reference for each comparison. To allow the reader to understand how the PO and UTD methods differ in handling the shadowing, a brief discussion is given below.

With reference to Figure 4-1, for a mild up-slope case, the PO calculation starts with the ground current determination in the illuminated portions. It can be seen that the illuminated portions of the terrain consist of section a, and portions of sections c and e. In the PO approximation, there are no ground currents on sections b and d, since they are shadowed by sections a and c, respectively. The lit-portion determination is performed by generating two straight lines, which originate from the antenna and impinge on the two edges of the section under test. If there is no line-of-sight obstruction, the entire section is illuminated. However, if either one or both lines are blocked, the angle between the two lines is reduced until both lines are not blocked by any intervening
sections. As an example, it can be seen in Figure 4-1 that a portion of section c is illuminated. This algorithm is repeated for all sections. The PO model calculates the electric field radiated from each lit portion and, by superposition, the electric fields are added to the direct field for determining the total electric fields.

The UTD technique treats wave propagation using rays. The algorithms for testing their existence are explained in Appendix A. In the range from 1.0 to 4.5 degrees, and for this hypothetical case, the existing rays are the direct, reflected (Ra, Rc, Re), diffracted (D2, D4), diffracted-reflected (D2Rc, D4Re), doubly-diffracted (D2D4), and diffracted-diffracted-reflected (D2D4Re). One might guess that the doubly-reflected ray would exist. This is not the case due to the small amount of up-slope. It should be pointed out that edges 1 and 6 are assumed to extend to infinity. Hence, they are ignored in the diffraction calculations. Furthermore, the UTD calculations involve only rays that are propagated in a forward direction; for example, D4D2, the backward traveling doubly-diffracted ray is not considered.

The relative electric field amplitude obtained from the 2-D UTD, 2-D PO, and GO methods are illustrated in Figure 4-2. These curves have an amplitude null at 3.0 degrees. The 2-D UTD and 2-D PO curves show a slight amount of deviation from the GO curve. This is due to the effect of the terrain. Furthermore, the 2-D UTD and 2-D PO curves agree
Figure 4-2. Calculated Normalized Antenna Patterns Vs. Elevation Angle Above Horizontal for Two-Dimensional Hypothetical Terrain of Figure 4-1 with 2-Degree Upslope Grade.
well from 1.0 to 4.0 degrees. This is not surprising since the up-slope section is only a 3.5 percent grade, and does not strongly affect the ground current induced by the antenna source. Also, the up-slope does not block the electric field reradiated from ground currents on section a, in the range considered.

The moderate up-slope case is considered next. The upslope grade is increased from 3.5 to 11.0 percent, with the far-end of the upslope 45 feet above the base of the mast. For this case, section c blocks the ground current radiation entirely when the observation point is below 1.7 degrees. Hence, in the far field, the relative amplitude must be reduced significantly. Figure 4-3 depicts the 2-D UTD, 2-D PO, and GO curves. The 2-D PO model still predicts a strong field amplitude in the region below 1.7 degrees, whereas the 2-D UTD curve indicates a much lower amplitude as expected. Furthermore, the 2-D PO pattern null location does not change significantly from the mild up-slope case. This inaccuracy is due to the assumptions made in the 2-D PO model. If the terrain has a moderate up-slope similar to this hypothetical case, one must be aware of the errors in the 2-D PO result at low angle calculations.

B. Kodiak Alaska

B.1 Introduction

Kodiak Alaska, Runway 25 is the first ILS site selected to validate the 2-D UTD model. The terrain has only small
Figure 4-3. Calculated Normalized Antenna Patterns Vs. Elevation Angle Above Horizontal for Two-Dimensional Hypothetical Terrain of Figure 4-1 with 6.3 Degree Upslope Grade.
lateral terrain variations (in the direction perpendicular to the runway centerline) on the order of 1.0 foot. A significant portion of the reflecting surface in front of the glide slope antenna is ocean. The ocean has tidal variations on the order of 12.0 feet from low to high tide. The design glide path angle is 2.0 degrees and the operating frequency is 330.8 MHz. Figure 4-4 shows the linearized terrain profile parallel to the runway centerline taken directly in front of the base of the antenna mast, which is located 322.0 feet from the runway centerline.

The NR, SBR, and CE glide slope systems were set up for experimental tests at this site. For the purpose of validation only the results obtained for NR system, during high and low tides, and level and low-approach flight measurements are discussed.

Five conducting plates are used to approximate the terrain out to 5000 feet from the antenna mast. The results, which include tidal effects on the electric fields, are calculated and converted into the course deviation indication (CDI), as is described in Appendix B, and compared against the results obtained from the 2-D PO model and flight measurements.

B.2 Model Validation

Comparisons between 2-D UTD and 2-D PO results and flight measurements are made for both level and low-approach (simulated) measurements. These two basic flight runs are
Figure 4-4. Profile of Terrain in the Reflecting Zone for Kodiak, Alaska.
commonly employed during site inspections under FAA Orders for measuring vertical and structure characteristics of the glide slope.

The level flight measurements are considered in tabulated form in Table 1. The agreement between both calculated and measured path angle is quite good, with both 2-D UTD and 2-D PO results being within 0.08 degrees of the measured value. The greatest discrepancy occurs for the 2-D PO calculation of the low tide path width.

During high tide, the drop-off from land to ocean is 14.0 feet. Thus, almost all of the ocean surface is illuminated by the antennas and the results determined from 2-D UTD and 2-D PO are very similar. Figure 4-5 depicts the calculated and measured curves of CDI vs. elevation angle for level flight measurement. It can be seen that both calculations provided an accurate prediction below 2.0 degrees elevation.

For low tide, where the drop-off is 26.0 feet, Figure 4-6 shows a bend in the vertical structure as determined by the 2-D PO model at about 1.5 degrees elevation. This is the angle where the dominant reflecting surface is changing from ocean to land. This is evidence that the 2-D UTD result is more accurate than the one obtained from the 2-D PO model, at least for this case involving a severe terrain discontinuity.

Next, the low-approach results determined from both 2-D UTD and 2-D PO are compared with flight measurements in
Table 1. Comparison of Measured and Calculated Results for Kodiak Null Reference Glide Slope System.

<table>
<thead>
<tr>
<th>Null Reference</th>
<th>Measurement</th>
<th>Calculated UTD</th>
<th>Calculated PO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\alpha_p$</td>
<td>$\alpha_w$</td>
<td>$s$</td>
</tr>
<tr>
<td>High Tide</td>
<td>1.99</td>
<td>.54</td>
<td>.59</td>
</tr>
<tr>
<td>Low Tide</td>
<td>2.29</td>
<td>.68</td>
<td>.28</td>
</tr>
</tbody>
</table>

All Angles in Degrees

$\alpha_p$ = path angle; i.e., angle at which 0.0 $\mu$A CDI occurs

$\alpha_w$ = total width; i.e., angle between $\pm$75.0 CDI points

$\alpha_u$ = angle at which $+75$ $\mu$A occurs

$s$ = symmetry factor $= \frac{\alpha_u - \alpha_p}{\alpha_w}$
Figure 4-5. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Null Reference System at High Tide at Kodiak.
Figure 4-6. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000’ High Level Run Flight Measurement Along the Runway Centerline for the Null Reference System at Low Tide at Kodiak.
Figure 4-7. During high tide, both calculated results indicate similar monotonic changes in CDI up to 1000 feet from the antenna mast. When comparing both results against flight measurements, the trends are similar but with an offset in the measured values. The offset could be from the time of the measurement which may not have been exactly at high tide.

The last structure comparison, shown in Figure 4-8, is for low tide. In contrast with the high tide (see Figure 4-7), the trends are reversed. The CDI's determined from 2-D UTD, 2-D PO and flight measurement at 30,000 feet are 30, 40, and 29 microamperes, respectively. The 2-D UTD and 2-D PO results are highly correlated with the flight measurement as shown in Figure 4-8.

C. Carswell Air Force Base

C.1 Introduction

Carswell Air Force Base, Runway 35, is the second site for the 2-D UTD model validation. The ground terrain in front of the transmitting antenna is generally a mild upslope with minimal lateral terrain variation. The elevation angle when viewed from the base of the antenna mast to the highest point is 0.49 degrees. Figure 4-9 illustrates the terrain profile used for the 2-D UTD calculations. The effect of the up-slope on the glide path is expected to be different from the previous sites. Furthermore, the accuracy of the 2-D PO results is expected to diminish because of
Figure 4-7. Measured and Calculated Curves of CDI Vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Null Reference System at High Tide at Kodiak.
Figure 4-8. Measured and Calculated Curves of CDI Vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Null Reference System at Low Tide at Kodiak.
Figure 4-9. Profile of Terrain in the Reflecting Zone for Carswell AFB, Texas.
neglecting the mutual interactions and the improper shadowing approximations. The glide path angle is 2.8 degrees and the operating frequency is 332.0 MHz.

Since this terrain is rougher than the Kodiak site, more modeling plates are required. Seven conducting plates are used to represent the ground reflecting terrain out to 3500 feet from the mast. Beyond this distance the ground is a down-slope and it stays in the shadow of the up-slope section to about 7000 feet. At this distance one would expect negligible ground current amplitudes.

The NR and CE systems were set-up and measured at this site. The antenna heights for the NR were 34.29 and 17.14 feet. For the CE systems, the antenna heights were 51.42, 34.29, and 17.14 feet. Two each of 1000-foot level and 2.8 degree low-approach flight measurements are selected for the 2-D UTD model validation. Results obtained from the 2-D UTD model are also compared against the 2-D PO determination.

B.2 Model Validation

The results of calculated and measured level runs are plotted in Figures 4-10 through 4-13. The path angles and width angles, both calculated and measured, are summarized in Table 2. Referring to the table, it is seen that for both NR and CE, the angles measured and calculated are in agreement to well within 0.1 degrees.

Figures 4-10 and 4-11 are obtained from the NR level flight measurements; calculations are from the 2-D UTD and
<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Calculated UTD</th>
<th>Calculated PO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\alpha_p$</td>
<td>$\alpha_w$</td>
<td>$s$</td>
</tr>
<tr>
<td>Null Reference</td>
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<td>0.72</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>2.86</td>
<td>0.73</td>
<td>0.42</td>
</tr>
<tr>
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<td>2.86</td>
<td>0.73</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>2.87</td>
<td>0.75</td>
<td>0.47</td>
</tr>
</tbody>
</table>

All Angles in Degrees

$\alpha_p =$ path angle; i.e., angle at which 0.0 \( \mu \)A CDI occurs

$\alpha_w =$ width angle; i.e., angle between \( \pm 75.0 \) \( \mu \)A CDI points

$\alpha_u =$ angle at which \( +75 \) \( \mu \)A occurs

$s =$ symmetry factor = $\frac{\alpha_u - \alpha_p}{\alpha_w}$

Table 2. Tabulated Results for Carswell Level Flight Measurements and 2-D UTD and 2-D PO Calculations.
Figure 4-10. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Null Reference System at Carswell AFB, Texas.
Figure 4-11. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000 ft High Level Run Flight Measurement Along the Runway Centerline for the Null Reference System at Carswell AFB, Texas.
Figure 4-12. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Capture Effect System at Carswell AFB, Texas.
Figure 4-13. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Capture Effect System at Carswell AFB, Texas.
2-D PO models. The measured curves exhibit more roughness than the calculated. This is because the terrain is not modeled in all its detail but rather by a piecewise-linear approximation as discussed in Chapter I.

The curves obtained from the CE level flight measurements, 2-D UTD and 2-D PO calculations are shown in Figures 4-12 and 4-13. All curves agree well with each other at high angles. However, at angles below 1.5 degrees the calculated results differ appreciably; the 2-D PO calculated curve indicates a second glide path angle (zero microamperes) at 1.25 degrees, whereas the 2-D UTD curve predicts 200.0 microamperes at this angle.

Figures 4-14 through 4-17 are the calculated and measured results for the low-approach runs of the NR and CE systems. There is a slight bias indicated in the measured curves when compared with calculations. From Figures 4-16 and 4-17, when the CDI offsets are removed, the CE calculated curves show excellent agreement with the measurements, with the 2-D UTD calculation being in slightly better agreement than the 2-D PO results.

This offset is most likely due to a small error in determining antenna heights. It should be pointed out that the modeling sections used to model the actual terrain are representative of the average terrain elevation. The first section, for example, is intended to represent the average ground elevation around the antenna mast. Hence, the antenna heights used in the models are measured with respect
Figure 4-14. Measured and Calculated Curves of CDI vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Null Reference System at Carswell AFB, Texas.
Figure 4-15. Measured and Calculated Curves of CDI Vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Null Reference System at Carswell AFB, Texas.
Figure 4-16. Measured and Calculated Curves of CDI Vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Capture Effect System at Carswell AFB, Texas.
Figure 4-17. Measured and Calculated Curves of CDI vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Capture Effect System at Carswell AFB, Texas.
to this average elevation. But in practice, the antenna heights are measured vertically with respect to the concrete top of the base of the mast. If the concrete top is located on the average elevation, the calculated and measured glide path angles will agree. This problem can be eliminated by accurate surveying.

D. Springfield, Ohio Municipal Airport

D.1 Introduction

The location used most recently for 2-D UTD model validation measurements is the proposed glide slope on Runway 24 at Springfield, Ohio Municipal Airport. It was found that there is a 11.5 foot elevation difference between the base of the antenna mast and the runway surface directly across from the antenna. Thus the lateral terrain variation is significant. The terrain in front of the mast also possesses a down-slope parallel to the runway to about 1500 feet. Furthermore, the terrain portion that covers the distance from 1500 to 4000 feet is uneven, with drainage ditches and humps. For this terrain, the 2-D UTD and 2-D PO models, which can not include three-dimensional variations, are not expected to produce accurate results.

The 3-D (3-Dimensional) models are obviously a logical approach to this problem. However, the solution complexity will increase many fold. As mentioned in Chapter I, the 3-D PO model requires an hour or more of computer time, and therefore becomes less attractive for practical use. For the
3-D UTD model, several additional ray mechanisms, viz, the diffraction off the corner of the plate, must be included in the model. With the additional rays, the 3-D UTD model will also require large amount of computer time. Therefore, development of the rigorous 3-D UTD model has not been pursued.

A less elegant, but nonetheless effective approach was suggested by Mr. L. H. Mitchell for use in taking lateral terrain variations into account. The PO theory suggests that the largest contribution to the total reflected signal from the ground is that which is reflected from the area of the first Fresnel zone. Although the dimension of the first Fresnel zone may be up to 4000 feet in the direction parallel to the runway, the width of the first Fresnel zone is less than 150 feet [28]. The most important ground to be considered is, therefore, the first 75 feet on either side of a line from the antenna to the aircraft. A first approximation in considering the lateral terrain variation can be made by making a piecewise linear approximation to the ground profile along the line from the antenna to the aircraft, and setting up plates in the 2-D UTD model to have the same profile. Figure 4-18 is a sketch of the topography of the terrain survey data provided by the Air Force. Figure 4-19 shows two-dimensional plate sections having the same profile as on the line from the antenna to the aircraft in Figure 4-18. As the aircraft changes position, the profile changes and the plate model in Figure 4-19 will
Figure 4-18. The Springfield Site Topography.
Figure 4-18. (Continued).

Projection of an Aircraft on the Runway Center-Line Extended

Profile Line from Antenna to Projected Aircraft

Distance in Feet from the Reference Point

2000

2500

3000

3500

4000

Aircraft
Figure 4-19. Terrain Profile Along a Line from the Antenna Mast to the Point Below an Aircraft Located As Shown in Figure 4-18b at Springfield, Ohio Municipal Airport.
change. The changing profile is automatically calculated by the computer. It can be seen that the number of modeling plates is kept constant at nine.

If the terrain is so uneven that strong reflections occur from areas other than along the line from the antenna to the aircraft, the accuracy of this approach will be diminished. This might occur in the case of hills to the side causing the terrain to have a bowl shape. Fortunately, this is not the case at Springfield airport. Even though the computer models must calculate the terrain profile for each aircraft position, less than 2 seconds of additional running-time is required than for the 2-D model versions. In the remaining discussion, this approach using 2-D UTD and 2-D PO models when applied to the 3-D terrain data is called the 3-D UTD and 3-D PO models.

Two image glide slope systems, NR and CE, were set up for experiments at this airport. The designed glide path angle is 2.8 degrees, with an operating frequency of 332.2 MHz. The base of the antenna mast (reference elevation point) is 450.0 feet to the side of the runway centerline as indicated in Figure 4-18. The antenna heights for the NR are 28.0 and 14.0 feet. For the CE system, the antenna heights are 42.9, 28.6 and 14.3 feet [29].

The 3-D UTD results are compared against the 3-D PO results and flight measurements for both glide slope systems. Two level-flight and two low-approach flight measurements of both systems are used in this validation.
D.2 Model Validation

The level-flight comparisons are in Figures 4-20 and 4-21 for the NR system. It can be seen that trends of all curves agree well for the most part, except for the 3-D PO curve which indicates a discrepancy at about 3.2 degrees. The 3-D UTD curve, however, still agrees with both measured curves. This PO disagreement is due to the up-slope section in the area at 3000 feet. Both measurements show the glide path to be about 2.84 degrees whereas the 3-D UTD and 3-D PO predict the angle to be at 2.73 and 2.70 degrees, respectively. Again the error is probably due to the antenna height determination as discussed in the previous section.

Two NR low-approach flight measurements are used for the validation. Figures 4-22 and 4-23 illustrate the calculated 3-D UTD and 3-D PO results and the measured curves. The trends of all curves are noticeably bent and agree well.

Figures 4-24 through 4-27 illustrate two level-flight and two low-approach measurements for the CE experiments. Figures 4-24 and 4-25 show the level-flight results which are obtained from the 3-D UTD and 3-D PO models and measurements. Once again, there is a discrepancy on the glide path angle determination. The calculated angles are identical at 2.8 degrees and the measured angle is higher at about 2.92 degrees. This higher actual glide path angle shows the same trend as for the NR setup. Otherwise, both
Figure 4-20. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Null Reference System at Springfield, Ohio.
Figure 4-21. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Null Reference System at Springfield, Ohio.
Figure 4-22. Measured and Calculated Curves of CDI Vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Null Reference System at Springfield, Ohio.
Figure 4-23. Measured and Calculated Curves of CDI vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Null Reference System at Springfield, Ohio.
Figure 4-24. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Capture Effect System at Springfield, Ohio.
Figure 4-25. Measured and Calculated Curves of CDI Vs. Elevation Angle for a 1000' High Level Run Flight Measurement Along the Runway Centerline for the Capture Effect System at Springfield, Ohio.
the 3-D UTD and 3-D PO results agree well with one another and are in excellent correlation with the measurements.

Figures 4-26 and 4-27 contain the CE low-approach calculations and measurements. It can be seen that the 3-D UTD and 3-D PO results are in excellent agreement with the measurements except for the path angle offset. Also, the upslope effect is much less noticeable than for the NR results. This is due to the CE system, which is designed to minimize the upslope effect.

The computer running-times required to calculate the CDI at the 81 observation points for a NR level-flight trace when using the 3-D UTD and 3-D PO models are 380.0 and 80.0 seconds, respectively. For the NR low-approach curve, the 3-D UTD and 3-D PO models require 360.0 and 112.0 seconds. When using the CE system, longer computations are expected for the same number of observation points. This is due to the additional antenna, the upper antenna in the CE system. For a level-flight track and 81 calculation points, the 3-D UTD and 3-D PO models consume 570.0 and 120.0 seconds; for a low-approach curve, the 3-D UTD and 3-D PO models require 540.0 and 168.0 seconds. It can be seen that the 3-D PO model consumes less computer running-time than the 3-D UTD model for this example. The reason is that the 3-D UTD model has to test for each ray blockage for every observation position before it calculates the field contributions due to the rays. Whereas, the 3-D PO model does the calculation immediately since the method assumes
Figure 4-26. Measured and Calculated Curves of CDI Vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Capture Effect System at Springfield, Ohio.
Figure 4-27. Measured and Calculated Curves of CDI vs. Distance for a Low-Approach Flight Along the Runway Centerline for the Capture Effect System at Springfield, Ohio.
there is no interaction between plates.
A computer model for calculating the electric field reflected from irregular ground has been developed, and applied to ILS glide path simulation. The model is based on the Uniform Theory of Diffraction (UTD). The results when compared to measurements indicate that this UTD model can accurately predict ILS flight path effects due to ground irregularity. Furthermore, the results obtained from this new UTD model are compared against the predictions of a previously developed Physical Optics (PO) model. UTD and PO predictions in most cases agree with one another, but better results are obtained from the UTD model for truncated or severely upsloping terrain.

For a typical 5000-foot reflecting zone, the UTD model requires less computation time than the PO model if fewer than six modeling plates are used to represent terrain roughness. Table 3 shows the computation times required for each model when 1000' high level flight calculation for 81 observation points are made. For a small number of plates, the UTD model is faster than the PO model, but as the number of plates increases, the UTD model becomes slower as many more possible interaction effects must be examined. The PO model running time depends primarily on the length of the ground plane, not terrain irregularity.
The UTD model can be extended for use in many radio communication problems that involve ground reflections. The theory used in the development is applicable to frequencies above 100 MHz [30]. If one wants to include effects of finite ground conductivity, an extended UTD theory is available [21], and can be used to modify the existing UTD model. However, for the horizontally polarized electric fields and low grazing incidence angles (less than 4 degrees from horizon) considered throughout this study, the effect of an impedance surface has been shown to be minimal [31].
Table 3. Comparisons of CPU Running Time Between the Physical Optics (PO) Approximation and the High Frequency Theory of Diffraction Approximation (UTD).

<table>
<thead>
<tr>
<th>Number of Modeling Plates</th>
<th>Distance of Modeling Terrain (Feet)</th>
<th>Total CPU in Seconds for 81 Calculation Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>3</td>
<td>5000</td>
<td>79.2</td>
</tr>
<tr>
<td>4</td>
<td>5000</td>
<td>81.9</td>
</tr>
<tr>
<td>5</td>
<td>5000</td>
<td>80.0</td>
</tr>
<tr>
<td>6</td>
<td>5000</td>
<td>80.0</td>
</tr>
<tr>
<td>6</td>
<td>56000</td>
<td>3120.0</td>
</tr>
<tr>
<td>7</td>
<td>5000</td>
<td>78.6</td>
</tr>
</tbody>
</table>
REFERENCES


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[31] Breien, T., 'Multipath Analysis of ILS Glide Path,'
ELAB, The Norwegian Institute of Technology, N-7034, 1979, Norway.

In this appendix, the purpose of and the algorithms used in each FORTRAN subroutine required for the Uniform Theory of Diffraction (UTD) terrain reflection calculations are explained. The UTD model consists of 21 subroutines and 4 function subroutines. Flow diagrams are shown only for two major subroutines, VENGO and VETDIF.

Recently, the UTD model input format has been modified in such a way that it can be used as for Physical Optics (PO) and Geometrical Optics (GO) calculations with minimum changes in data. Moreover, the output format from each model is identical for ease of comparison. This force one to introduce a new main program which is named OUGS [32]. The former UTD main program becomes one of the subroutines in OUGS. As a result of this arrangement, only one subroutine is required for the GO calculation; two essential subroutines obtained from the TSC model [5,6] are needed for a PO calculation. The block diagram of OUGS is shown in Figure A-1. The description of both the OUGS program and PO subroutines will not be addressed here. We now proceed to explain the UTD model subroutines in detail.

Subroutine VOUILS

The purpose of this subroutine is to calculate the
Figure A-1. Block Diagram of Hybrid OUGS Program for Calculating Glide Slope Performance over Irregular Terrain.
total electric field, using the GO technique, of a point source over a ground plane. The routine is called from the main program only when the GO option for a flat reflecting surface is utilized. The slope of the 2-dimensional reflecting surface is included in the calculation.

Inputs to this subroutine are the antenna location \((X_P, Y_P, Z_P)\), observation point \((X, Y, Z)\) and plate corner (edge) locations \((X_O, Y_O, Z_O)\). The slope is calculated from the first two corner input. The field determination in the presence of the perfect reflecting plane is very simple, thus few computer instructions are required. The total field obtained from this subroutine is affected by the slope of flat reflecting surface. The output from this subroutine is the total electric field \((CET)\), which is returned to the main program.

Subroutine VECTOR

Subroutine VECTOR can perform six vector operations which are;

1) Cross product,
2) Normalized cross product,
3) Unit vector defined by two position vectors,
4) Dot product,
5) Projection of two directional vectors,
6) Vector difference between two position vectors.

In the case of an invalid vector operation, an error message is printed out. The above vector operations can be
written in mathematical form as:

1) \( \overline{C} = \overline{A} \times \overline{B} \)

2) \( \overline{C} = \frac{\overline{A} \times \overline{B}}{|\overline{A} \times \overline{B}|} \)

3) \( \overline{C} = \frac{(\overline{B} - \overline{A})}{|\overline{B} - \overline{A}|} \)

4) \( C(1) = \overline{A} \cdot \overline{B} \)

5) \( C(1) = \frac{\overline{A} \cdot \overline{B}}{|\overline{A} \cdot \overline{B}|} \)

6) \( \overline{C} = \overline{B} - \overline{A} \)

Subroutine VGROUN

The functions of this subroutine are to initialize all of the values that are required for the UTD electric field calculations, and to act as a buffer between the OUGS program and the peripheral subroutines.

The observation point and antenna locations, which are supplied by the main program, are reformatted for more efficient manipulation. Also, VGROUN extends the X-component of the plates to 50,000 feet. Then, each plate is checked to insure that its four corners are coplanar (for future 3-dimensional development) and the normal vector of that plate is then determined. The normal vector is calculated in such a way that the Z-component is negative. The wedge angle which is formed by two connected plates is calculated by using their normal vectors and vector cross product operation. The angle is measured below the terrain profile.

Two different dipole antenna orientations are possible. The variable NOANT=1 for an antenna which is oriented in Y-
direction, and NOANT=2 for an antenna with X-direction orientation.

To reduce the calculation time, the lengths in feet are converted to wavelength. After conversion, subroutines VENGO and VETDIF are called for the electric field determinations. The phi components obtained from both subroutines (VENGO, VETDIF) are stored in EPGON and EPDT. The resultant field (CET) is the sum of EPGON and EPDT, and is returned to the OUGS program. It should be pointed out that not only are the phi components calculated, but also the theta components, which are stored in ETGON and ETDT. The total theta component is the sum of ETGON and ETDT.

Function ATGN2(X,Y)

Function ATGN2 is set to zero when both arguments X and Y equal to zero, otherwise it becomes equal to the CSQR of Y/X.

Complex Function CSQR(X)

Function CSQR determines the phase of its complex argument (X). The value of this function is limited to $\pm \pi$ rather than zero to $2\pi$ range provided by the arc-tangent library function.

Function COT(X)

This function calculates the value of cotangent for a given value of argument X. The default value is set to
10E+30 when the argument approaches the poles of the cotangent.

Function SGN(X)

This function sets the value of SGN to +1 or -1 according to the sign of the argument X, and to zero if the argument is zero.

Subroutine TRANS

The function of subroutine TRANS is to transform input vector components from one coordinate system to another (Cartesian to Spherical coordinates or vice versa). With IOP=1, the input requirements are two vectors, A and B, which are used as two end points to determine radian (RAD), theta (TH), and phi (PH) components with respect to vector A. If IOP=2, the inputs required are vector A and three spherical components, RAD, TH, and PH. After the transformation from Cartesian to Spherical coordinates, the resultant vector B is the output and is measured with respect to vector A.

Subroutine VENGO

This subroutine calculates the sum of the electric field amplitude and phase, which result from the direct, reflected, doubly-reflected, reflected-diffracted, reflected-reflected-diffracted, reflected-diffracted-reflected, and triple-reflected fields. The subroutine
considers the direct field first. The direct ray originates from the transmitting antenna (ANT) to the observation point (FPTS). Then subroutine VLOGI1 is called to determine any possible blockage. If there is no blockage, the electric field components are calculated by subroutine SOURCE. If the direct ray is blocked the direct field contribution is zero.

There are cases when the direct ray contribution is undesired. For example, one might be interested in only the total ground-scattered field. An option is provided to eliminate the direct field contribution. Coding parameter JDIR to one enforces zero direct field contribution, with JDIR set equal to zero otherwise.

The reflected rays are considered next. All of the possible singly reflected rays from every plate are examined within the DO statement 301, where LP is a plate index. When plate LP is under tested, subroutine VEXIST is called to determine the image source (SI) and reflection point OQ on plate LP. If OQ does exist, the blockage algorithms are started by checking for the blockage from ANT to OQ, and OQ to FPTS. If no blockage occurs (the reflected ray exists), subroutine SOURCE is called to compute the reflected field components \( \text{ETR, EPR} \) from plate LP. The \( \text{ETR} \) and \( \text{EPR} \) contributions are then added to \( \text{ETGON} \) and \( \text{EPGON} \), respectively.

After the reflected ray from plate LP is evaluated, the doubly-reflect ray is considered. The DO statement 414
which is looped inside DO statement 301 will examine all of
the plates LN that can possibly interact with plate LP to
contribute a doubly-reflected ray. If LN is equal to LP, no
calculation is performed. Referring to the discussion made
in Chapter III, plate LN is always located further away from
the source than plate LP. Therefore, only the RR ray
datailng in the forward direction are included. The
process stops after the last plate (NPLATE) is considered.

Subroutine IMAGE is called to determine a secondary
image location (SII) of the image source (SI) with respect
to plate LN. By utilizing pairs SII, FPTS and SI, ANT, two
reflection points (OQ, RP) are determined by calling VEXIST
twice. OQ and RP must both be located on plate LN and LP,
respectively. If they are not, the doubly-reflected ray
contribution is zero. Also, the line from ANT to BP, BP to
OQ, and OQ to FPTS must not be blocked. If no blockage
occurs, routine SOURCE is called, the doubly-reflected ray
components (ETRR, EPRR) from plate LP to plate LN are
determined, and then added to ETGON and EPGON, respectively.

During the doubly reflected ray determination, several
required parameters for the reflected-reflected-diffracted
(RRD) ray calculation are calculated. Hence, to save
computer time, subroutine VRRD is immediately called for RRD
evaluations. The outputs from subroutine VRRD, ETRRD and
EPRRD, are added to the total field components ETGON and
EPGON, respectively. JRRD is an option parameter; the RRD
field is calculated only when JRRD is equal to zero.
Reflected-diffracted (RD) ray contributions are considered next. All possible RD ray contributions from edges are evaluated within DO statement 426. All edges past the edge where plates LP+1 and LP+2 are connected are considered. The RD ray is reflected from plate LP to the edge, and diffracted from the edge to the observation point (FPTS). It should be noted that DO statement 426 is nested within DO statement 301.

The reflection point (RF1) on plate LP and the possible diffraction point (RP) on edge LM are calculated first. If both RF1 and RP exist, the blockage algorithms are performed for the blockage from ANT to RF1, RF1 to RP, and RP to FPTS. If there is no blockage, routine VEMDIF is called for evaluation of RD ray amplitude determination. ETRD and EPRD are the electric field components determined by routine VEMDIF, and they are added to the total field components ETGON and EPGON, respectively. JRD is the encoded parameter; it is set to zero if the RD components are desired and to one otherwise.

The last ray considered by subroutine VENGO is the reflected-diffracted-reflected (RDR) ray. The electric field amplitudes of the RDR ray, ETRDR and EPRDR, are the outputs of subroutine VRDR. JRD is the coding parameter. It is set equal to zero if RDR contributions are desired, and to one otherwise. It should be pointed out that if the RD ray does not exist (for a two-dimensional problem), the RDR ray will not exist either. The RDR components (ETRDR, EPRDR) are
added to the ETGON and EPGON components. These components are the outputs of subroutine VENGO, and are returned to the subroutine VGROUN for further calculation.

Since subroutine VENGO involves several ray evaluations, the block diagram of Figure A-2 is also provided as additional informations.

Subroutine VRDR

This subroutine computes the reflected-diffracted-reflected (RDR) ray contributions. It is called from subroutine VENGO after the completion of the reflected-diffracted (RD) ray determination. It is important to note that when there are no lateral terrain variations in the terrain being considered (2-Dimensional), results obtained from blockage tests for the RD ray can be reused in RDR testing, at least from the antenna to the first reflection point on plate LP, and from the first reflection point to the diffraction point (DP). Therefore, only the additional blockage tests between DE and the second reflection point (RF1), and from RF1 to the observation point (FPTS) are required.

The ray determination process starts with the computation of an image of FPTS with respect to the second reflected plate (LM). By using this image location (FPTI), FPTS, and four corners of the plate LM, routine VEXIST is called to determine RF1. If RF1 does not exist, the next possible plate (LM+1) is considered. If RF1 exists,
Figure A-2. Subroutine VENGO Flow Diagram.
Figure A-2. (Continued).
Figure A-2. (Continued).
blockage tests begin in two zones. The first zone is from DP to RF1; the second zone is from RF1 to FPTS. Subroutine VLOGII is called twice for the blockage tests. If there is no blockage, the RDR ray exists and subroutine VEMDIP is called for the field components (ETRDR, EPRDR) computation. Both components are then accumulated in ETSUM and EPSUM, which will be the total RDR ray contributions and are the outputs of this subroutine VRDR.

Subroutine VRRD

The purpose of this subroutine is to perform tests for existence of the reflected-reflected-diffracted (RRD) rays and calculate their electric field components. It is called from subroutine VENGO during a doubly-reflected ray existence test. The two reflecting plates LP, LN are the inputs. In this subroutine only the combination of edges with fixed reflecting plates are considered. The ray is assumed to reflect from plate LP to plate LN where plate LN is situated further away from the transmitting antenna than plate LP. The statement, DO 100 LA=NEXT,NPLATE will consider all combinations of edges existing in between NEXT, which is equal to LN+2, to NPLATE (last plate). It should be noted that the first edge is part of plate LN+2 and therefore it must be located further out from the antenna than plate LN.

Subroutine VRRD begins by setting ray contributions ETSUM, EPSUM to zero. Next, the diffraction point (RP) on
the edge defined by an index in DO statement 100 is calculated. This is done by using the inputs SII (doubly-image source location) and FPTS (observation point) and subroutine VBETA. The other output besides RP returned from subroutine VBETA is BETAO, which is the diffraction angle of incident on the edge. Once RP is found, it must lie above the plane which contains plate LN. By calling subroutine VEXIST twice, the reflection points which are located on plate LP (OQ1) and plate LN (OQ2), are determined. It is essential that both OQ1 and OQ2 must exist simultaneously. The last requirement for the ray to exist is passing the blockage test. Subroutine VLOGI1 is called four times to achieve the test. If there is no line-of-sight blockage from ANT to OQ1, OQ1 to OQ2, OQ2 to RP, and RP to FPTS, subroutine VEMDIF is called for the RRD electric field components ETRRD, EPRRD determination. ETRRD and EPRRD are then accumulated in ETSUM and EPSUM, respectively. After all of the edges are tested, the total RRD ray components (ETSUM, EPSUM), are the outputs from this subroutine.

Subroutine VDRR

This subroutine computes the diffracted-reflected-reflected (DRR) ray. This is the ray that is diffracted from an edge (formed by plate IP-1 and LP) to plate LJ, reflected from plate LJ to plate LT, and finally reflected from plate LT to the observation point (FPTS). The plate index is the control parameter in DO statement 55. LP and LJ are the
inputs of this subroutine which is called from subroutine VETDIF.

An image of the observation point FI is determined first with respect to an extension of plate LT; for the DRR ray to exist, this image must be located below plate LT. Secondly, the observation point image FI is again imaged, this time with respect to an extension of plate LJ. This second-image observation point is FII. Given the transmitting antenna location, the diffracting edge, and FII, the diffraction point DPT is determined by calling subroutine VBETA. If DPT exists, using DPT and FII as two end points, the intersection point RLJ on plate LJ is determined by using subroutine VEXIST. Finally, using RLJ and FI as two end points, the intersection point RLT on plate LT is determined. DPT, RLJ, and RLT must exist simultaneously. If one of them does not exist, the next plate (LJ+1) is considered for a possible DRR ray.

The blockage algorithm starts by testing the line of sight from the antenna location to DPT, DPT to RLJ, RLJ to RLT, and RLT to the observation point (FPTS). If there is no blockage, the DRR ray exists and the ray contributions to the total field are calculated, and then added to ETSUM and EPSUM for theta and phi components, respectively. The existence and blockage algorithms are repeated until all possible plates are accounted for. ETSUM and EPSUM are the total contributions from DRR rays that occur from DPT, LJ, and LT. ETSUM and EPSUM are the outputs and are transferred
to the subroutine VENGO.

Subroutine VMERGH

This subroutine is called in the case of testing for ray blockage when the end points are situated on two consecutive plates, K and L. It is assumed that plate L is located further away from the antenna than plate K. Furthermore, the edge formed by the plates K and L lies along the X-axis (2-Dimensional case). Figures A-3a and A-3b show two possible cases. The vector cross product \( \hat{\mathbf{c}} \) between the two unit normal vectors associated with plates K and L is performed by,

\[
\hat{\mathbf{c}} = \hat{\mathbf{u}}_K \times \hat{\mathbf{u}}_L
\]

The first component in resulting vector \( \mathbf{c} \) determines if the ray exists. The logic is coded in the first component of vector \( \hat{\mathbf{c}} \) as follows,

\[
C(1) = \begin{cases} 
eg \text{negative value} : \text{ray is blocked}, \\ \text{positive value} : \text{ray is not blocked}. 
\end{cases}
\]

Subroutine VETDIF

Subroutine VETDIF calculates six types of rays: singly-diffracted, diffracted-reflected (DR), doubly-diffracted (DD), diffracted-reflected-diffracted (DRD), diffracted-diffracted-reflected (DDR), and diffracted-reflected-reflected (DRR). It is called only from subroutine VGROUN.

Subroutine VETDIF begins by setting all of the ray contributions to zero and then transferring the antenna
Figure A-3a. Ray Is Not Blocked from Plates K and L.

Figure A-3b. Ray Is Blocked from Plates K and L.
(two-end points) locations to RS1 and RS2.

After this initialization, the edge which is formed by two connected plates (LP, LP-1) is considered. With three inputs, the antenna location, the edge, and the observation point, subroutine VBETA is called for determining the diffraction point (DPT) on the edge. Then using ANT, DPT, and FPTS subroutine VEMDIF is called. After VEMDIF is called, ETDT and EPDT are resulting complex theta and phi components of the singly-diffracted ray. The components are then added to the previous contributions (SUMT, SUMP).

The diffracted-reflected (DR) ray is considered next. This ray is diffracted by the edge that was considered previously and reflected off plate LJ, which is not part of the edge. The image location (UR) of the observation point (FPTS) is imaged with respect to the planar extension of plate LJ. UR must be located below the plane LJ. Next, using the inputs, ANT, the edge, and UR, the diffraction point DPT for the DR ray is determined. This is accomplished by calling subroutine VBETA.

The reflection point C is calculated next and it must be located on plate LJ. C is determined by calling subroutine VEXIST. If either DPT or C do not exist, the DR ray contributions are set to zero and plate LJ+1 is considered. Otherwise, the blockage algorithm begins by testing the line from ANT to DPT, DPT to C, and C to FPTS. If there is no blockage, the DR ray exists and subroutine VEMDIF is called for the ray component determinations.
Theta and phi components are added to SUMT and SUMP.

Following DR ray calculations, DRR rays are examined. This is done by simply calling subroutine VDRR. The complex amplitudes and phases of DRR rays are added to the total.

The next ray to be considered is the DRD ray. This ray can occur only when a DR ray exists. If a DR ray exists, the edge which is formed by the connected plates LR and LR-1, where plate LR is different from plates LP and LJ, is considered. It should be noted that LR-1 is always greater than LJ here. The edge formed by plates LR and LR-1 and FPTS are imaged with respect to extension of plate LJ. Using the antenna location, the edge (formed by plates LP and LP-1), the image of the edge (formed by plates LR and LR-1), and the image of FPTS, the diffraction points DP1 and DP2 are calculated by calling subroutine V2dif. If DP1 and DP2 exist, subroutine VEEXIST is called, and the result of this calculation is the reflection point location DPT on plate LJ. If DPT does not lie on plate LJ, the next edge is considered. Otherwise, the blocking algorithm starts by testing the blocking of the line from ANT to DP1, DP1 to DPT, DPT to DP2, and DP2 to FPTS. If there is no blocking, subroutine V2DIF is called twice for DRD ray calculations. The ray contributions EDTDRD and EPDDR are added to the total.

The next ray considered in subroutine V2DIF is the DD ray. This ray is diffracted by two edges in which are not part of the same plate. The first edge is formed by plates
LP and LP-1, whereas the second edge is formed by plates LM and LM-1. Subroutine V2DIF is called for two diffraction point determinations (DP1, DP2). The blockage algorithm begins by testing the line from ANT to DP1, DP1 to DP2, and DP2 to PPTS. If there is no blockage, subroutine VEMDIF is called twice for DD ray amplitude and phase determinations. ETDD and EPDD are the theta and phi components of the DD ray and they are added to the total.

The last ray considered is the DDR ray. It can occur only when a DD ray exists. The reflecting plate is LS. The process begins as PPTS is imaged with respect to plate LS. It is necessary that the image must be located above the plane of plate LS. Subroutine VEXIST is called to calculate the reflection point C on plate LS. If C does not exist, the next plate LS+1 is considered. Otherwise, the blockage test starts by checking for blockage on the lines from ANT to DP1, DP1 to DP2, DP2 to C, and C to PPTS. If the lines are not blocked, subroutine VEMDIF is called twice for DDR ray amplitude and phase calculations. ETDDR and EPDDR are added to the corresponding total field components.

The algorithms and calculations are repeated until all of the possible rays combinations are tested and determined. SUMT and SUMPT are the total theta and phi components, and they are the outputs from subroutine VETDIF. The block diagram is shown in Figure A-4.

Subroutine CSX
Figure A-4. Subroutine VETDIF Flow Diagram.
Figure A-4. (Continued).
Figure A-4. (Continued).
This subroutine computes the values of Fresnel's integral. Coding for subroutine CSX was taken from the IBM scientific subroutine package.

Subroutine INTESC

This subroutine determines an intersection $OQ$ between a line, defined by the directional vector $\hat{U}$ and a point $OP$ on the line, and a plane defined by its unit normal vector $\hat{UN}$ and a point $OM$ on the plane. Thus, the essential inputs are $\hat{U}$, $OP$, $\hat{UN}$, and $OM$ (refer to Figure A-5).

The following closed form equation for the determination of the intersection point $OQ$ is used.

$$OQ = OP - \left\{ \frac{\hat{UN} \cdot (OP - OM)}{\hat{UN} \cdot \hat{U}} \right\}$$  \hspace{1cm} (B-1)

In the event that the line and the plane are parallel, no interception point is possible. Hence, it is necessary to have a warning code (IERR) for such a case. The value of IERR will be one when the intersection point is not possible, and zero otherwise. After the calculation is completed, $OQ$ and IERR are the outputs and are returned to the calling subroutine.

Subroutine VEXIST

The main function of the subroutine is to determine whether a ray exists. This subroutine requires the following subroutines: IMAGE, VECTOR, TRIPLE, and INTRSC. A ray exists if and only if there is no blockage between the two points.
Figure A-5. The Geometry of the Vectors Used in Finding the Intersection Point of a Line with a Plane.
of the ray.

There are three options (IO) provided. IO is one for an intersection between a line, which is defined by vector \( U \) and a point \( OS \), and plate \( N \); IO is two for an intersection of a line (defined by two points \( OS \) and image of \( FPTS \) with respect to plate \( N \)) and the plate \( N \). For the last IO option, the interception point \( OQ \) on an extension of plate \( N \) is calculated. \( OQ \) is an output for this option even if located outside the plate \( N \).

The algorithm used to test for ray blockage is based on a vector analysis technique. Given the end points of the ray under test, a point \( TEMP1 \) on the plane which includes the plate under blockage test, and its unit normal vector \( U \), the intersection point where the ray from the source to the observation point intersects the plane can be found by subroutine \( INTRSC \). However, the point and the vector \( U \) of the plane do not completely specify the plate but rather the entire plane, so it is possible that the intersection point is located outside the physical boundaries of the plate. Therefore, further testing is required to determine whether the intersection point lies on the plate. This test can be done with the aid of the scalar triple product by calling subroutine \( TRIPLE \), and supplying it with the locations of the four corners and the normal vector of the plate. This triple product represents the volume of the parallelepiped having three vectors \( U \), \( A \), and \( B \) as its edges. Figure A-6 depicts the geometry of the vectors that form the volume.
Figure A-6. The Scalar Triple Product $D = (\mathbf{A} \times \mathbf{B} \cdot \mathbf{U})$. 
The sign from the triple product $D$ will determine whether the intersection point lies on or outside the plate. A minus sign indicates that the intersection point lies outside the plate, with the constraint that the vector $U$ contains a positive $Z$-component. The computer program has to perform the scalar triple product four different times as shown in Figure A-7. If all of the signs are positive, the intersection point $OQ$ lies on the plate. On the contrary, if one of the four signs is negative, the intersection point $OQ$ lies outside the plate. As a special case, if the scalar triple product gives zero value, the ray is parallel to the plate.

An additional test of whether the intersection point $OQ$ lies between the source and field points is required when the intersection point $OQ$ exists on the plate. The computer program calculates two additional vectors from the source to the intersection point $OQ$ and from field to $OQ$. Then the product of these vectors is performed. If the product gives a positive value, the intersection point $OQ$ lies away from source and observation points and the plate does not block the ray. But if the product gives a negative value, the intersection point $OQ$ exists in between two end points and consequently the plate blocks the ray.

The output parameters are $IC$ and $OQ$. $IC$ is coded as follow:

$IC = 1$, ray is not blocked,

$IC = -1$, ray is blocked.
Figure A-7. The Triple Product $D = (\mathbf{A} \times \mathbf{B} \cdot \mathbf{U})$ Algorithm to Determine Whether the Intersection Point $OQ$ Lies On or Outside the Plate.
Only when IC=1 will CQ contain the intersection point.

Subroutine VAMPHA

The purpose of this subroutine is to convert real and imaginary components of two complex fields (theta and phi contributions) into amplitudes and phases. It is called when the print option parameter (ICON) value is greater zero. If ICON is set greater than zero, amplitude and phase values are written on an output file. For ease of reference, these values are written after the ray name. Throughout the computer program, the theta contribution is printed first followed by the phi contribution.

Subroutine VLOGI1

This subroutine determines whether the line of sight which is defined by two end points SPT and EPT is blocked by any of the plates under test. The inputs are SPT, EPT, starting plate LSTART, final plate LSTOP, and the array which contains the corners of these plates. First, if LSTART is greater than the total number of plates (NPLATE), an error message is printed and the calculation is terminated. The unit directional vector DIRECT is found by:

\[
\text{DIRECT} = \frac{(\text{EPT} - \text{SPT})}{|\text{EPT} - \text{SPT}|}
\]

The DO statement 300 is set by the limits LSTART and LSTOP to check for blockage by calling subroutine VEXIST for each plate. If there is no intersection point (DUM) located in a
plate, and therefore no blockage, the next plate is considered. If, however, DUM exists, a further test is required to determine whether the intersection point lies in between the two end points using the following equations:

\[ \hat{C} = \frac{(SPT-DUM)}{|SPT-DUM|} \]

\[ \bar{C}_I = \frac{(EPT-DUM)}{|SPT-DUM|} \]

\[ C_I(1) = \bar{C}_I \cdot \hat{C} \]

If \( C_I(1) \) is a positive value, the plate blocks the line-of-sight and the blockage test is completed. Only the sign of \( C_I(1) \) is utilized to designate blockage. The result is in LCHECK, with

\[ \text{LCHECK} = \begin{cases} 
1 & \text{blocked} \\
-1 & \text{not blocked} 
\end{cases} \]

Subroutine VBETA

This subroutine is the most important in the diffraction point calculation. It determines the diffraction point such that the angle of edge incidence is equal to the angle of edge diffraction (see Figure 2-7). The diffraction point in several other computer models has been found by either an iteration (trial-error) method or by assuming that the diffracted ray is parallel to the direct ray (far-field case). In contrast, the following algorithm will provide an exact location of the diffraction point by utilizing a cylindrical to rectangular coordinate transformation. Only the two-dimensional case is considered and explained in detail, but the method does work in three dimensions.
Let us assume that the edge under test lies along the X-axis. The required inputs are antenna location (A), edge end points (E1, E2) where E2(1) > E1(1), and observation location (F). From Figure 2-7, the diffracted ray, for a given diffraction point, will contribute to any observation point on the rim of a cone whose axis lies along the edge and hence on the X-axis.

The algorithm starts with a comparison of X-components of both edge end points E1 and E2. Two reference points O and P on the edge are determined in such a way that the angles between vector OA to the edge, and vector OP to the edge are right angles.

Next we define a plane AO which includes the antenna location (A) and the edge. One of the possible plane orientations is shown in Figure A-8a.

Referring to Figure 2-7, the diffracted rays form a cone with the edge as its axis and the angle between the axis and the rays is equal to the incidence angle (BETA). Assuming that the actual observation point is situated on the rim of such a cone, we define a plane FP which includes the observation point and the edge. One can see that the two planes, AO and FP, have the edge as their intersection line. Hence, if one views along the edge, one can see that the two planes make an angle. The basic approach is to determine the virtual observation point (TEM) located on plane AO but still on the same cone described previously. One way is to rotate the plane FP with respect to the edge.
Figure A-8a. Side View of Diffraction Point Determination.

Figure A-8b. Top View of Diffraction Point Determination.
until it coincides with the plane AO. In the subroutine, cylindrical coordinates are defined with the axis aligned with the edge. Once the two planes coincide, the diffraction point (DP) is determined to be the intersection point between a line which includes points A and TEM and the edge (see Figure A-8b). Then the incident angle (BETA), which is equal to the diffraction angle, is easily determined. It should be noted that the plane FP must rotate in such a way that the angle between the virtual observation point and the antenna location (A) when measured at the edge is pi and not zero. The outputs from this subroutine are DP and BETA.

Subroutine VEMDIF

The purposes of the subroutine are to calculate the singly and doubly diffracted ray contributions. Since this subroutine had been originally intended only for singly diffracted (D) ray calculation, only the blockage algorithm for D rays is contained within it. For the other ray types the blockage test is performed before this subroutine is called. Hence, the subroutine serves primarily for ray amplitude calculations. IM is designated as an indication of the type of ray being considered. Further, IM is used as either input or output. The edge convention for this subroutine is that the edge which is located farthest away from the antenna on a plate under test is considered to be the diffracting edge.
The subroutine starts with the field component (ETSUM, EPSUM) initializations. When IM is an input, as mentioned previously, it contains the type-of-ray information. For example, if IM is equal to 1, the singly diffracted ray is under consideration and its components are determined; but if IM is other than 1, the ray contributions involve double diffraction and are calculated without a blockage test.

The blockage algorithm for a D ray begins with tests of line-of-sight blockage from antenna location (ANT) to the diffracted point (RD), and from RD to the observation point (FPT).

Once the singly diffracted ray passes the blockage test its electric field components are determined. First the incident field impinging on RD is obtained. These field components (ETH, EPHI) are calculated by subroutine SOURCE. Then subroutine CONVRT is called to convert ETH and EPHI into ray fixed components (ETER, EPER) (see Chapter II section D). Following subroutine CONVRT, the angles phi, phi', and S (see Chapter II section D) are calculated. Finally, subroutine CONVRT is called once more to convert the diffracted ray components in the ray fixed-coordinate system back to the spherical components (ETDM, EPDM), and IM is set to 1. ETDM, EPDM, and IM are the outputs returned to the calling routine. It should be noted that IM is set to 1 at the end of this subroutine to indicate that the ray under consider exists and has a non-zero contribution.

The blockage test can be speeded up if one realizes
that the result obtained from ANT to RD does not depend on FPT. Therefore, the result from the test in this portion is coded and stored in JREDI array. For the next observation point, coding in JREDI is recalled to determine blockage from ANT to RD.

For the case where IM has value 2, which indicates a ray involving double diffraction SP is the distance from ANT to the first diffraction point (RFPT), and the ray then travels from RFPT to DP. ETDM and EPDM now become the incident field components at the second diffracting edge. Therefore, subroutine SOURCE is not required. All of the calculation steps after calling subroutine SOURCE except for the blockage tests are still needed.

Subroutine TRIPLE

The function of this subroutine is to compute the scalar triple product of vectors \( \vec{A}, \vec{B}, \) and \( \vec{C} \). This subroutine is called only from routine VEXIST. The result of the scalar triple product, \( \vec{A} \cdot \vec{B} \cdot \vec{C} \), is stored in the first component in D.

Subroutine CONVERT

The subroutine converts ray fixed components to spherical components or vice versa. It is called only from subroutine VEMDIP. With an option IO=1, two inputs E1 and E2, which are the theta and phi spherical components, are converted into a perpendicular ET1 and parallel ET2
components in ray fixed coordinates. ET1 and ET2 are the outputs of this subroutine. But if I0=-1, E1 and E2 must be the perpendicular and parallel components, respectively, in the ray fixed coordinates and will be converted to theta and phi spherical components, and both components are stored in ET1 and ET2, respectively.

Subroutine VGTD

The functions of this subroutine are to determine the amplitude AS of the field along a diffracted ray, and the soft (GS) and hard (GH) diffraction coefficients. The subroutine is called from subroutine VEMDIF only when a ray involving diffraction is determined to exist.

There are two built-in functions, H and Q, which are frequently used. The proper values for calculations are then initialized. When grazing incidence is considered, it is necessary to set GD=0.0 and GH=0.5. Therefore, a test for this special case is required. Following this test, BETAP, BETAN, distance parameter L, AS, arguments for cotangent functions and arguments for the transition function are determined.

Equations (25) and (27a) in Chapter II are used to determine GS and GH. One is simpler than the other. The choice depends on the arguments of the transition function (ARG1, ARG2, ARG3, and ARG4). If all of the arguments are large, as mentioned in Chapter II section C, equation (25) which involves only the cosine term is used. This is the
situation where the observation point is located well outside transition regions. However, if just one of the arguments of the transition function is small (less than 10), equation (29a) is used instead. After GS and GH are calculated, the values are returned to subroutine VEMDIF.

Subroutine V2DIF

The purpose of this subroutine are to determine two diffraction points (DP1, DP2) which exist on two different edges. This subroutine is called from two subroutines VENGO and VETDIF during DD, RDD, DRD, and DDR ray determinations. A two-dimensional algorithm is used but it can be extended to three dimensions.

The algorithm begins with the test of edge end points. Here E1 and E2 (edge e), and E3 and E4 (edge e') are the pairs of points which define two edges. E2(1) and E4(1) must be greater than E1(1) and E3(1), respectively (X-components). Points O and P are located on edge e and e'. Similar to subroutine VBETA, points O and P must make a right angle with respect to the antenna location (A) and observation point (F), respectively. Since a two-dimensional algorithm is being considered, edge e and e' are parallel. We introduce a plane PL which includes these diffracting edges.

In general A and F are not on this plane. Both A and F are either above or below the plane PL. The basic idea is to rotate both A with respect to edge e and F with respect
Figure A-9a. Side View of Double Diffraction Points Determination.

Figure A-9b. Top View of Double Diffraction Points Determination.
to edge e' onto the plane PL. Figures A-9a and A-9b depict the side and top views of the edge geometry as well as the rotational direction of A and P. By using A and P and rotating them, A1 and P1 are now on the plane PL. Since A1 and P1 and edge e and edge e' are located on the plane PL, the diffraction angle (BETA) and two diffraction points can be determined by using simple trigonometry. Referring to Figure B-9b, DP1 and DP2 are two diffraction points located where a line which contains A1 and P1 intersects edge e and e', respectively. It should be noted that the line direction must include the following points in sequence: A1, DP1, DP2, and P1. The outputs are DP1, DP2, and BETA.
APPENDIX B
COURSE DEVIATION INDICATION DETERMINATION

In Chapter II, the high frequency techniques to obtain a relative field at the observation point are discussed. The Course Deviation Indication (CDI) current is directly related to these relative fields.

The carrier sideband and sideband only signals are the composite signals from the antennas. The carrier sideband signal (Ecs) is defined as the complex sum of the products between the carrier sideband current amplitude and the relative field associated with each antenna. The sideband only signal (Ess) is defined as the complex sum of the products of the sideband only currents and the relative field associated with each antenna. The nominal relative carrier sideband and sideband only currents for the Null Reference, Sideband Reference, and Capture Effect systems are tabulated in Table 4.

As mentioned in Chapter I, the radiated signals are modulated with 90 Hz and 150 Hz audio signal components. The 90 Hz and 150 Hz signals can be determined in terms of Ecs and Ess as:

\[ E_{150} = E_{cs} + E_{ss} \]

and

\[ E_{90} = E_{cs} - E_{ss} \]

The Difference in Depth of Modulation (DDM) is defined by:

\[ DDM = 10 \times \frac{(E_{150} - E_{90})}{E_{cs}} \]
where $m_0$ is the modulation index, and is 0.4 when applied to a typical glide-slope.

Finally, the CDI current in microamperes is obtained by,

$$\text{CDI} = 2.0 \times p \times DDM,$$

where $p$ is 857.14 for the typical glide slope. The aforementioned discussion can also be utilized for localizer CDI determination. The only differences are the $m_0$ and $p$ parameters. For localizer application, $m_0$ and $p$ are 0.2 and 967.74. It should be noted that, in general, the Capture Effect system has an extra current injected onto the lower and upper antennas, and this current is known as the clearance current. With this current, a receiver in the space below the designed glide path angle will receive a strong fly-up audio tone (150 Hz). However, none of the Capture Effect systems considered in Chapter IV were radiating with the clearance current. Therefore, the information needed to model the effect of the clearance current is not provided here, but is clearly described in Reference 32.
<table>
<thead>
<tr>
<th>Antenna</th>
<th>$I_{ss}$</th>
<th>$I_{cs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Null Reference</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Upper</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Sideband Reference</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>-1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Upper</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Capture Effect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>-0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Middle</td>
<td>1.0</td>
<td>-0.5</td>
</tr>
<tr>
<td>Upper</td>
<td>-0.5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 4. The Nominal Relative Sideband Only ($I_{ss}$) and Carrier Sideband ($I_{cs}$) Currents Used in the Glide Slope Systems.
APPENDIX C

COMPUTER PROGRAM LISTINGS
C FUNCTION STATEMENTS AND INITIALIZATIONS
C
0021 CALL(D,PI)=COSC(P*PI/180),SIN(P*PI/180)
0022 ALOF=(f,0,E)=-(E)*((A-))*((A-))/((A-))
0023 UPER(A,N,E)=-(E)*((A-)*(AP7))/((A-))
0024 CNNS(A,*,E)=-(E)*((A-))/((A-))
0025 PHASE(C)=0ATIN2(FIGA(C),REAL(C))/PI/180
C
C INITIALIZATIONS
C
0026 PI=4.0*COFAV(1.0)
0027 D=2.0*PI
0028 R=PI/180.00
0029 NPRE=0
0030 PSI=0.00
C
C START THE LOOP FOR NEXT SIMULATION.
C
0031 1000CEPSI2=(0.0)
0032 SIGMA=3.00
C
C CLEAR STORAGE WHICH CONTAINS THE BLOCKAGE FROM ANTENNA TO EDGE
C INFORMATION OF THE DIFFRACTED, DIFFRACTED-REFLECTED RAYS.
C
0033 DO 1002 J=1,3
0034 DO 1003 J=1,50
0035 JREO(J2,11)=
0036 JREO(J2,11)=
0037 JREO(J2,11)=
0038 CONTINUE
C
C READ HEADER CARD FOR EACH SIMULATION
C
0039 READ(5,1001)JREP, JHEAD
0040 1001 FORMAT(11,1344)
0041 WRITE(10,1001)JREP, JHEAD
C
C INITIALIZATIONS FOR THE SIMULATION.
C
0042 NREP=0
0043 NANT=0
0044 PATH=0.00
0045 WIDTH=0.00
0046 WDL0=0.00
0047 WHD=0.00
0048 NGET=0
0049 NGET=0
0050 DDM=0.00
0051 ALDL=0.00
0052 DDL=0.00
0053 S=00.00
0054 S=00.00
0055 JNL=0.00
0056 J30=0
C
C READ INPUT DATA SECTIONS
C
0060
0057    1 READ(5,2)NPRIOD, LABEL, DATTEN, PATTERN
0058    ATTENU=DATTEN                           V01011700
0059    C                                              V01011900
0060    IF(NPRIOD.NE.NPRIOD) GO TO 800    V01012000
0061    2 FORMAT((13,1X,1,2F10.4))           V01012100
0062    C                                              V01011900
0063    IF(ATTENU.EQ.0.0) WRITE(10,2)NPRIOD, LABEL    V01012200
0064    GOTO(10,20,47,50), LABEL    V01012300
0065    C                                              V01011900
0066    C PLATE DATA                                V01013100
0067    C 10 READS, IFINE, XRAY, ICON, CEPSI?, SIGMA    V01013200
0068    C IF NE IS LESS THAN OR EQUAL TO 1, PSEUDO 3-D TERRAIN INPUT    V01013300
0069    C IS REQUIRED.                              V01013400
0070    C                                              V01011900
0071    IF(NE.LE.1) J30=1                           V01013500
0072    IF(NE.EQ.0) GO TO 1                           V01013600
0073    11 FORMAT((1X,15,5X,3F10.4))               V01014000
0074    C                                              V01011900
0075    WRITE(10,11)NE,XRAY,ICON                    V01014100
0076    READ(5,12)X(0),Y(0),Z(0)                    V01014200
0077    12 FORMAT((1X,3F10.3))                      V01014300
0078    WRITE(10,12)X(J),Y(J),Z(J)                   V01014400
0079    GOTO 1                                       V01014500
0080                                                                                   V01014600
0081    C THEODOLITE POSITION DATA, PATH REFERENCE, AND WIDTH REFERENCE.                V01014700
0082    C                                              V01011900
0083    20 READ(5,21)XFILE, XT, YT, ZT, PREF, WREF                                        V01014900
0084    21 FORMAT((1X,15,9X,5F10.3))               V01015000
0085    GOTO 1                                       V01015100
0086                                                                                   V01015200
0087                                                                                   V01015300
0088                                                                                   V01015400
0089                                                                                   V01015500
0090    30 READ(5,31)XA,FREQ,YA,MC150,NOANT       V01015600
0091    ZC=0.35712DP                                V01015700
0092                                                                                   V01015800
0093                                                                                   V01015900
0094                                                                                   V01016000
0095                                                                                   V01016100
0096                                                                                   V01016200
0097                                                                                   V01016300
0098                                                                                   V01016400
0099                                                                                   V01016500
0100                                                                                   V01016600
0101                                                                                   V01016700
0102                                                                                   V01016800
0103                                                                                   V01016900
0104                                                                                   V01017000
0105                                                                                   V01017100
0106                                                                                   V01017200
0107                                                                                   V01017300
0108                                                                                   V01017400
0109                                                                                   V01017500
0110                                                                                   V01017600
0111                                                                                   V01017700
0112                                                                                   V01017800
0113                                                                                   V01017900
PATTERN DATA
C
0093  40 READ(5,41)NCUT,NP,NCALC,XOBSI,YOBSI,ZOBSI  VDIO1940
0094  41 IF(NCALC.EQ.1)WRITE(10,41)NCUT,NP,NCALC,XOBSI,YOBSI,ZOBSI  VDIO1940
0095  42 WRITE(10,42)NCUT,NCALC,XOBSI,YOBSI,ZOBSI  VDIO1940
GO TO 1  VDIO1940
0100  43 IF(NCALC.GE.2)WRITE(10,43)NCUT,NP,NCALC,XOBSI,YOBSI,ZOBSI  VDIO1940
0101  44 WRITE(10,44)NCUT,NCALC,XOBSI,YOBSI,ZOBSI  VDIO1940
GO TO 1  VDIO1940
C
C OUTPUT CONTROL PARAMETERS.
C
0107  50 READ(5,51)JPAR,IX,IXM,N,XMN,JOFF,JRR,JRD,JDQ,JDRO,JDQR,JDQRS  VDIO1940
0108  51 IF(JPAR.EQ.0)GO TO 45  VDIO1940
0109  52 WRITE(6,211)JPAR,JRR,JRD,JDQ,JDRO,JDQR,JDQRS  VDIO1940
GO TO 1  VDIO1940
C
C START TO PRINT OUT ALL INPUT DATA FOR SIMULATION
C
0110  60 WRITE(6,211)JPAR,JRR,JRD,JDQ,JDRO,JDQR,JDQRS  VDIO1940
0111  61 IF(JPAR.EQ.0)GO TO 45  VDIO2000
0112  62 IF(JPAR.GE.1)WRITE(6,360)  VDIO2000
0113  63 IF(JPAR.GE.2)WRITE(6,361)  VDIO2000
0114  64 IF(JPAR.GE.3)WRITE(6,362)  VDIO2000
0115  65 IF(JPAR.GE.4)WRITE(6,363)  VDIO2000
0116  66 IF(JPAR.GE.5)WRITE(6,364)  VDIO2000
0117  67 IF(JPAR.GE.6)WRITE(6,365)  VDIO2000
0118  68 IF(JPAR.GE.7)WRITE(6,366)  VDIO2000
0119  69 IF(JPAR.GE.8)WRITE(6,367)  VDIO2000
0120  70 IF(JPAR.GE.9)WRITE(6,368)  VDIO2000
0121  71 IF(JPAR.GE.10)WRITE(6,369) VDIO2000
0122  72 IF(JPAR.GE.11)WRITE(6,370) VDIO2000
0123  73 IF(JPAR.GE.12)WRITE(6,371) VDIO2000
0124  74 JJ=JPAR+JRR+JRD+JDQ+JDRO+JDQR+JDQRS  VDIO2000
0125  75 IF(JPAR.EQ.0)WRITE(6,372)  VDIO2000
0126  76 IF(JPAR.GE.1)WRITE(6,373)  VDIO2000
0127  77 IF(JPAR.GE.2)WRITE(6,374)  VDIO2000
0128  78 IF(JPAR.GE.3)WRITE(6,375)  VDIO2000
0129  79 IF(JPAR.GE.4)WRITE(6,376)  VDIO2000
0130  80 IF(JPAR.GE.5)WRITE(6,377)  VDIO2000
0131  81 IF(JPAR.GE.6)WRITE(6,378)  VDIO2000
0132  82 IF(JPAR.GE.7)WRITE(6,379)  VDIO2000
0133  83 IF(JPAR.GE.8)WRITE(6,380)  VDIO2000
0134  84 IF(JPAR.GE.9)WRITE(6,381)  VDIO2000
0135  85 IF(JPAR.GE.10)WRITE(6,382) VDIO2000
0136  86 IF(JPAR.GE.11)WRITE(6,383) VDIO2000
0137  87 IF(JPAR.GE.12)WRITE(6,384) VDIO2000
0138  88 IF(JPAR.GE.13)WRITE(6,385) VDIO2000
0139  89 IF(JPAR.GE.14)WRITE(6,386) VDIO2000
0140  90 WRITE(6,387)JJ  VDIO2000
FORTRAN IV G LEVEL 21

```
C COMMON CAR, PWR (WAFFTS), 4X, COMMON CLR. PWR (WAFFTS)*)
0101 219 FORMAT(1H1,1X,11X,31,11X,15X,31,10X,15X,31)
0112 217 FORMAT(1H1,1X,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY,yy,YY, yy
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C SELECTED TYPE OF PATTERN CUT.
C
0216 GO TO I,70,75,75,75,75,NCUT
C
C CONSTANT RADIUS PATTERN CUT
C
0217 71
0218 70 X=XYRSI+GO CONS-FYRSI)/(NP-1)
0219 PHIR=PHRSI+(Z0RSF-ZYRSI)/(NP-1)
0220 PHIR=PHIR*PI/180
0221 Y=(XYRSI*CONS(RAD))*CONS(PHI)
0222 Y=(XYRSI*CONS(RAD))
0223 Z=ZERSI*CONS(RAD)
0224 RAN=DATAN((I-ZT),OSORT(X-XT)**2+(Y-YT)**2)
0225 ALPHA=RAD714/PI190
0226 GO TO 90
C
C LINEAR CUT
C
0227 70 X=XYRSI+(J-1.)*Z0RSF-XYRSI)/(NP-1)
0228 Y=XYRSI+(J-1.)*Z0RSF-XYRSI)/(NP-1)
0229 Z=ZERSI+(J-1.)*Z0RSF-ZYRSI)/(NP-1)
0230 RAD=DATAN((I-ZT),OSORT(X-XT)**2+(Y-YT)**2)
0231 ALPHA=RAD714/PI190
0232 GO TO 90
C
C HYPERBOLIC CUT WITH CONSTANT OBSERVED SPACING.
C
0233 75 ALPHA=YRSI
0234 AP=ALPHA*PI/180
0235 X=XYRSI+(J-1.)*Z0RSF-XYRSI)/(NP-1)
0236 Y=XYRSI+(J-1.)*Z0RSF-XYRSI)/(NP-1)
0237 IF(NCUT,NE,4) GO TO 4111
0238 IF(J,GE,NP/4) GO TO 4112
0239 FYRSI=XYRSI
0240 FYRSI=FYRSI
0241 FYRSF=10000.
0242 FYRSF=XYRSF*(XYRSF-XYRSI)*(YJ5SI-10000.)/(YJ5SI-YJ5SF)
0243 NP=NP/4
0244 NJ=J
0245 GO TO 4113
C
C HYPERBOLIC CUT WITH CONCENTRATION CALCULATION
C
0246 POINT FROM 1000 FEET TO 1000 FEET. THE NUMBER OF CALCULATION
C POINTS ARE FIXED TO 84.
C
0247 4112 CONTINUE
0248 FYRSI=XYRSI+(J-1.)*FXRSF-XYRSI)/(NP-1)
0249 FYRSF=10000.
0250 FYRSF=XYRSF
0251 NP=3*NP/4
0252 NJ=J-NP/4
0253 4113 CONTINUE
0254 X=FXRSI+(J-1.)*FXRSF-FXRSI)/(NP-1)
0255 Y=FYRSI+(J-1.)*FYRSF-FYRSI)/(NP-1)
0256 4111 CONTINUE
0257 Z=OSORT((X-XT)**2+(Y-YT)**2)*DATAN(AP)+ZT
GO TO 30
C
C LEVEL RUN WITH CONSTANT INCREASING ELEVATED ANGLE W.R.T.
C THE UNLIFT POSITION.
C
0259 IF(J.EQ.1) GO TO 78
0260 ALPHA=0.0*PI100
0261 ALPHA=4.5*PI100
0262 IF (INCUT.NE.5) GO TO 987
0263 ALPHA=1.0*PI100
0264 ALPHA=4.5*PI100
0265 CONTINUE
0266 ALPHA=ALPHA/PI100
0267 ALPHA=ALPHA/PI100
0268 WRITE(*,650) ZOBST,ALPHA,ALPHAF
0269 IF(ALPHA.GT.1.79) INCRE=.02
0270 IF(ALPHA.LE.1.79) INCRE=.02
0271 WRITE(6,303)
0272 INCRE=(ALPHAF-ALPHA)/NP-1.1
0273 INCRE=(ALPHAF-ALPHA)/NP-1.1
0274 INCRE=(ALPHAF-ALPHA)/NP-1.1
0275 X=0.70
0276 Z=Z055E
0277 CONTINUE
0278 IF(J3.EQ.5) GO TO 79
0279 IF(J1.GT.1) GO TO 97
0280 ALPHA=ALPHA/PI100
0281 GO TO 93
0282 CONTINUE
0283 IF(J1.EQ.1) GO TO 79
0284 IF(J1.EQ.2) GO TO 79
0285 IF(J1.EQ.3) GO TO 79
0286 ALPHA=ALPHA/INCREE
0287 GO TO 93
0288 CONTINUE
0289 ALPHA=ALPHA+(J-1)*INCREE
0290 CONTINUE
0291 CONTINUE
C
C CENTERLINE EXTENDED FOR LEVEL RUN WITH CONSTANT NGSULAR
C INCREMENT.
C
0275 X=0.70
0276 Z=Z055E
0277 CONTINUE
0278 IF(J3.EQ.5) GO TO 79
0279 IF(J1.GT.1) GO TO 97
0280 ALPHA=ALPHA/PI100
0281 GO TO 93
0282 CONTINUE
0283 IF(J1.EQ.1) GO TO 79
0284 IF(J1.EQ.2) GO TO 79
0285 IF(J1.EQ.3) GO TO 79
0286 ALPHA=ALPHA/INCREE
0287 GO TO 93
0288 CONTINUE
0289 ALPHA=ALPHA+(J-1)*INCREE
0290 CONTINUE
0291 CONTINUE
C
C SPECIAL CASE ONLY FOR THE OBSERVATION MOVES ALONG THE RUNWAY
C CENTERLINE EXTENDED FOR LEVEL RUN WITH CONSTANT NGSULAR
C INCREMENT.
C
0275 X=0.70
0276 Z=Z055E
0277 CONTINUE
0278 IF(J3.EQ.5) GO TO 79
0279 IF(J1.GT.1) GO TO 97
0280 ALPHA=ALPHA/PI100
0281 GO TO 93
0282 CONTINUE
0283 IF(J1.EQ.1) GO TO 79
0284 IF(J1.EQ.2) GO TO 79
0285 IF(J1.EQ.3) GO TO 79
0286 ALPHA=ALPHA/INCREE
0287 GO TO 93
0288 CONTINUE
0289 ALPHA=ALPHA+(J-1)*INCREE
0290 CONTINUE
0291 CONTINUE
C
C START TO CALCULATE THE ELECTRIC FIELD FROM EACH
C ANTENNA; N IS EQUAL TO ANTENNA NUMBERS UNDER
C CALCULATION.
C
0292 DO 130 N=1,YA
0293 IF(I30.NE.J) GO TO 82
0292 CALL VERTEN(N)
0293 IF(IN.GT.1) GO TO 82
0294 CALL VERTEN(N)
0295 IF(IN.GT.1) GO TO 82
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WRITE(6,214)
214      WRITE(6,2151)X(J),Y(J),ZD(J),J2=1,4E
2151       NY=4
C
C IF A-RATIO IS SET TO ZER0, THE DATA INPUT FOLLOWING
C EACH ANTENNA MUST BE COMPLEX POWER IN WATT. THE
C CONVERSION RATIO IS BASED ON TRUE-LINE WATThER.
C EQUATION.
C
0330   IF(A.LT.1.0d-4) GO TO 9475
0331   CESS=CPLX(ISSN),PHISS(N))
0332   CICS=CPLX(FSSN),PHICSS(N))
0333   CICC=CPLX(FSSN),PHICSS(N))
0334   GO TO 9376
0335   9375 CONTINUE
0336   CESS=CPLX(ISSS(TISS(N)))*.90235,PHISS(N))
0337   CIFS=CPLX(FISS(TISS(N)))*.90235,PHICSS(N))
0338   CIFS=CPLX(FISS(TISS(N)))*.90235,PHICSS(N))
0339   9376 CONTINUE
0340   IF(FIFGA,6,1.d0) GO TO 99
0341   IF(FIFGA,6,2.d0) GO TO 92

C C ALLING A PROPER SUBROUTINE TO CALCULATE THE
C HORIZONTALLY POLARIZED ELECTRIC FIELD RADIATES
C FROM AN ANTENNA NUMBER = N.
C
C 9475 GO TO 92
C
C CALL VSUPCV(CET,CEPS1)
0342   CALL VSUPCV(CET,CEPS1)
0343   GO TO 91
0344   91 CALL VSUPCV(CET,NOANT,NRF)
0345   GO TO 91
0346   92 CALL SCAICFT
0347   91 RPH=35*RT((Y-YP(1)**2+(Y-YP(1)**2)**2)
0348   CJ=30000*0.001,1.001)
0349   CEP=COSP(-CJ*PHI)
0350   CEP=COSP(-CJ*PHI)
0351   ETFN=COSN(CEFN)
0352   IFIFGA,6,2,1.d0) GO TO 54
0353   ETFN=COSN(CEFN)

C SUN ESS, ESS, AND EEC FROM ALL ANTENNAS.
C
0354   54 CESS=CET*CESS*CESS
0355   CESS=CET*CESS*CESS
0356   CESS=CET*CESS*CESS
0357   CESS=CET*CESS*CESS

C FILED IS USED ONLY FOR A PROGRAM POSTINGS
C FOR ELECTRICALLY PUBLISHED SIMULATION, FOR EXAMPLE,
C CURRENTS, A-RATIO, 4-RATIO, ALSO SEVERAL
C H-P PLOT COMMANDS WHICH ARE DESCRIBED IN TM-546.
C
0358   170 IF(IF1(10,2011),Y,Z,CET
0359   471 IF(IF1(10,2020,13)
0360   IF(IF1(451,E(CES1,6.009100) GO TO 105
0361   AA
0362   IF(IF1.6.1.d0-4) AA=1.30

193
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0133 TEST=REAL(A*CESS/CECS)
C TEST FOR AN ANOMALOUS CASE: ESS > ECS.
C
0144 IF(DABS(TEST).LT.1.0) GO TO 95
0135 IF(TEST.LT.0.001) GO TO 2.00
0136 IF(TEST.GE.3.001) GO TO 96

0137 C THE EOM EQUATION WHICH IS EXPRESSED IN TERMS OF
C ESS AND ECS.
C
0138 95 DUM=2.00*REAL(CESS/CECS)
C CALCULATE THE CAPTURE CLEARANCE FOR CAPTURE EFFECT SYSTEM.
C
0139 96 IF(NCAP.EQ.1)CALC CAPTEF(M150,DOM,CEC,CECC,*PSI)
0140 UA=DOM*150.00/17500
0141 IF(WREF.EQ.0.00) GO TO 402
0142 TCDI=75.00/((PREF-ALPHA)/(WREF/2.0)

0143 C CALCULATE DIFFERENTIAL CD1 (DCD1) AND MICRO AP.
C
0144 401 TCDI=UA-TCDI
0145 402 IF(NOCALC.EQ.1)GO TO 9200
C LINEAR INTERPOLATION EQUATIONS FOR DETERMINING SLIDE
C PATH AND NINTH ANGLES.
C
0146 IF(DMOLD.GT.97500.00).AND.(DOM.LE.097500)WIDLO=LOWER(DMOLD,
C(DD,ALGLD,ALPHA)
0147 IF(DMOLD.GT.097500).AND.(DOM.LE.087500)WIDHI=UPPER(DMOLD,
C(DD,ALGLD,ALPHA)
0148 IF(DMOLD.GT.087500).AND.(DOM.LE.077500)PATH=CROSS(DMOLD,DOM,
C(ALGLD,ALPHA)
0149 ALGLD=ALPHA
0150 3200 DMOLD=DOM
0151 3200 ECCS=DOMAIN	(CESS)**AA
0152 3200 ECCS=DOMAIN	(CECS)
0153 GO TO 349
0154 UA=0.00
0155 IF(PREF.NE.0.00)DCDI=0.00

C PLOT INITIALIZATIONS
C
0156 349 IF(XAXIS.EQ.0.00)GO TO 350
C CHOICE OF X-AXIS TO BE PLOTTED.
C
0157 IF(X.EQ.1)XAXIS(SI)=Y
0158 IF(X.EQ.2)XAXIS(SI)=ALPHA
0159 IF(X.EQ.3)XAXIS(SI)=X
0160 GO TO (900,901,902,903,904,905,906,907,908,909,999,1Y)
0161 900 QUA=UA
C REVERSING THE CD1 VALUES FOR THE PLOT WHERE THE
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C DIRECT COMPARISON WITH FLIGHT MEASUREMENTS CAN BE
C 'TRUE' + Y-AXIS ON PLOT OUTPUT CORRESPOND TO 90 HZ
C SIDE ON NO-FLIGHT MEASUREMENTS.
C
C IF(JX,NE,21)UA=UA
C
0359 YAXIS(JJ)=UA
0360 G0 TO 350
0361 YAXIS(JJ)=CDI
0362 G0 TO 350
0363 YAXIS(JJ)=ET(1)
0364 G0 TO 350
0365 YAXIS(JJ)=FTPH(1)
0366 G0 TO 350
0367 YAXIS(JJ)=FTPH(2)
0368 G0 TO 350
0369 YAXIS(JJ)=ET(3)
0370 G0 TO 350
0371 YAXIS(JJ)=FTPH(1)
0372 G0 TO 350
0373 YAXIS(JJ)=FTPH(2)
0374 G0 TO 350
0375 YAXIS(JJ)=ET(3)
0376 G0 TO 350
0377 YAXIS(JJ)=FTPH(1)
0378 G0 TO 350
0379 YAXIS(JJ)=FTPH(2)
0380 G0 TO 350
0381 YAXIS(JJ)=ECSHA
0382 G0 TO 350
0383 YAXIS(JJ)=ECSHA
0384 G0 TO 350
0385 YAXIS(JJ)=DAR(UA)
0386 WRITE(X,J003,JX,JY,JZ,PATH,CDI,UA,ET(1),FTPH(1),ET(2),FTPH(2),
<ET(3),FTPH(3),ECSHA,ECSHA)
0387 IF(YJ,JX,347)J,JX,JY,JZ,UA
0388 WRITE(YJ,JX,JY,JZ,UA)
0389 G20000(4,21,JX,JY,UA)
0390 CONTINUE
0391 IF(YJ,JX,347)J,JX,JY,JZ,UA
0392 IF(YJ,JX,347)J,JX,JY,JZ,UA
0393 GO TO 351
0394 IF(YJ,JX,347)J,JX,JY,JZ,UA
0395 GO TO 351
0396 WRITE(X,J003,JX,JY,JZ,PATH,CDI,UA,ET(1),FTPH(1),ET(2),FTPH(2),
<ET(3),FTPH(3),ECSHA,ECSHA)
0397 IF(YJ,JX,347)J,JX,JY,JZ,UA
0398 WRITE(YJ,JX,JY,JZ,UA)
0399 WRITE(YJ,JX,JY,JZ,UA)
0400 351 IF(K3,K1,NE,1)G0 TO 106
0401 IF(K4,K1,NE,21)AND(K4,K7,NE,3)G0 TO 210
0402 IF(K4,K1,NE,21)AND(K4,K7,NE,3)G0 TO 210
0403 105 IF(K4,K1,NE,21)AND(K4,K7,NE,3)G0 TO 210
0404 MOUTH PAINT ROUTINE IS INITIALIZED VALUES TO HAVE
0405 FIXED BOUNDARY AND PLOT IS EASY TO COMPARE WITH EACH
C OTHER.
C MPLOT SUBROUTINE
0422   GO TO (921,922,921,921,11)
0423   921 GO TO (923,924,925,926,927,928,929,930,931,932,933,923,11)
0424   923 XAXIS(NP+1)=XAXIS(I)+.001
0425   XAXIS(NP+2)=XAXIS(I)+.001
0426   YAXIS(NP+1)=100.
0427   YAXIS(NP+2)=100.
0428   CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL)
0429   GO TO 210
0430   924 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL2)
0431   GO TO 210
0432   925 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL3)
0433   GO TO 210
0434   926 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL4)
0435   GO TO 210
0436   927 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL5)
0437   GO TO 210
0438   928 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL6)
0439   GO TO 210
0440   929 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL7)
0441   GO TO 210
0442   930 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL8)
0443   GO TO 210
0444   931 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL9)
0445   GO TO 210
0446   932 CALL MPLOT(XAXIS,YAXIS,NP+1,XYL,YLL10)
0447   GO TO 210
0448   933 XAXIS(NP+1)=XAXIS(I)+.001
0449   XAXIS(NP+2)=XAXIS(I)+.001
0450   YAXIS(NP+1)=100.
0451   YAXIS(NP+2)=100.
0452   CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL)
0453   GO TO 210
0454   934 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL2)
0455   GO TO 210
0456   935 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL3)
0457   GO TO 210
0458   936 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL4)
0459   GO TO 210
0460   937 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL5)
0461   GO TO 210
0462   938 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL6)
0463   GO TO 210
0464   939 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL7)
0465   GO TO 210
0466   940 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL8)
0467   GO TO 210
0468   941 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL9)
0469   GO TO 210
0470   942 CALL MPLOT(XAXIS,YAXIS,NP+2,1,XYL,YLL10)
0471   CONTINUE
0472   IF (XAXISP+1.E.4,OR, YAXISP+1.E.4) GO TO 209
C CREATE A PLT FILE FOR H-P PLOTTER MY ROUTINE TMPLOT.
C
CALL INOPL(XAXIS,YAXIS,XMIN,YMIN,XMAX,YMAX,ND,0,0,0)
CALL PLOT (0.,0.,999)
299 CONTINUE
C
C CONTINUE EXECUTION IF ANOTHER DATA SIMULATION IS AVAILABLE.
C
IF (NECT, EQ, 0) Go TO 1000
STOP
END
SUBROUTINE VOMILS(CET,CEPS1)

C TO CALCULATE THE GO ELECTRIC FIELD.

C PARAMETERS:

C ****INPUTS****

C COMMON / PLATE /

C CEPS1 : COMPLEX GROUND PERMITIVITY.

C ****OUTPUTS****

C GET : THE TOTAL POINT SOURCE ELECTRIC FIELD.

C

0002 IMPLICIT REAL*(4,9,0-1,6,4,0-2)

0004 COMMON / PLATE/ X01(31),Y01(31),Z01(31),NE

0005 COMMON / ANSER/ K, Y, Z

0005 COMMON / ANSER/ K, Y, Z

0007 IF(2-Z01(11))/Z0I(11))/Y0I(11))

C

C DETERMINE THE SLOPE OF THE FIRST PLATE AND THEN REPLACE BY

C A PLANE WITH THE SAME SLOPE. THIS PROGRAM CAN HANDLE

C SLOSHING PLANE WITHOUT VARIATION ALONG X-DIRECTION.

C

0008 Z2= Y01(2)-Z01(2)/Z01(1)

0009 YX= YP(Y1)+Z01(Y1)-2)*Z01(Y1)/1.0/4**2)

0010 XZ= YYYY+Z2*2

0011 YI=YI+XY-YY(NI)

0012 XZ= XZ-XX

0013 XR=XR(NI)

0014 CJ= NCPLX(0.0,1.0)

0015 REN=SORT((X-YY)**2+(Y-Y1)**2+(Z-ZI)**2)

0016 IF(CJANSICPESI,1.0,0.0) GO TO 20

0017 ANG=0.149(Z-ZI),SORT((X-YY)**2+(Y-Y1)**2)

0018 CARJ=COS(ANG)

0019 CARG=COS(ANG)**2

0020 ANG=0.149(CICARJ),2+CICARJ)

0021 JFLAG=0

0022 IF(ANG,GT.3.0) JFLAG=1

0023 CARJ=COS(ANG)

0024 IF(JFLAG,EQ.1) CARJ= -CARJ

0025 CARJ=CARJ/CARJ

0026 CFP=CARJ*CARJ*CARJ*CARJ

0027 GO TO 30

0028 CARJ=0.149(CICARJ)/END

0029 CARJ=0.149(CICARJ)/END

0030 CARJ=CARJ/CARJ

0031 CARJ=CARJ/CARJ

0032 RETURN

0033 END
SUBROUTINE CAPTF (MC1S0,CDM,EC,ECG,PSI)

IMPLICIT REAL*4(A-H,O-Z),COMPLEX*16(C)

C
C PURPOSE:
C TO CALCULATE CLEARSANCE FOR THE CAPTURE EFFECT SYSTEM.
C
C PARAMETERS:
C
***INPUTS***
C MC1S0 : PERCENT MODULATION OF 190 Hz CLEARANCE ONLY.
C DDM : OLD DDM (W/O CLEARANCE).
C EC, ECG : CARRIER AND FIELD STRENGTH OF CLEARANCE AMPLITUDES.
C N : PERCENT MODULATION OF AUDIO FREQUENCIES.
C
***OUTPUTS***
C DDM : DDM WHICH INCLUDES CAPTURE ACTION (MORE DETAILS REFERED
C TO OHIO UNIVERSITY EFF DEPT IN S-461).
C
C
COMPLEX*16 ECC,EC
Q=CDAS(ECC,EC )
B=3/(1.+Q)**2
D{=3.137175070**4
F=31.1297313**2
G=1.75*Q**3
J=1.144775070**4
J=1.2362.3**4.39**4
M=1,01-02-03-04
N=0.9
P=1/4*03
F=(1/(1.+Q))**2
G=(Q/(1.+Q))**3
J*(Q)/(1.+Q))**2
K=1.144775070**4
L=1.2362.3**4.39**4
M=1.144775070**4
N=1.2362.3**4.39**4
P=1/4*03
RETURN
END
SUBROUTINE VECTOR(IO,A,B,C)

C SUBROUTINE TO CARRY ON VECTOR OPERATIONS

C ***INPUTS***
C A,B : THREE ELEMENT ARRAYS
C IO : OPTIONS

C ***OUTPUTS***
C IO=1 C IS THE CROSS PRODUCT OF A,B
C IO=2 C IS THE NORMALIZED CROSS PRODUCT OF A,B
C IO=3 C IS THE UNIT VECTOR DETERMINED BY END POINTS A,B
C IO=4 C(I)=THE DOT PRODUCT OF A,B . C(2)=C(3)=0.
C IO=5 C(I) IS THE PROJECTION OF A ON B . C(2)=C(3)=0.
C IO=6 C=I-1

C ***INPUTS***
C A,B : THREE ELEMENT ARRAYS
C IO : OPTIONS

C DIMENSION A(3),B(3),C(3)
J=0
IF (IO.NE.6) GO TO 50
DO 30 J=1,3
30 C(J)=A(J)-B(J)
RETURN
50 CONTINUE

I=1-3
IF (I) 100,200,300
100 C(I)=A(I)*R(I)-A(3)*R(2)
C(2)=A(1)*R(1)-A(1)*R(3)
C(3)=A(1)*R(2)-A(1)*R(3)
IF (IO.EQ.1) RETURN
GO TO 250
200 DO 250 J=1,3
250 C(J)=A(J)-B(J)
RETURN
300 C(I)=A(I)*R(I)+A(2)*R(2)+A(3)*R(3)
C(2)=B(2)
C(3)=B(3)
IF (IO.EQ.4) RETURN
GO TO 500
500 IF (IO.EQ.6) GO TO 400
GO TO 270
270 C(J)=C(J)/D
RETURN
300 C(I)=C(I)*R(I)+C(2)*R(2)+C(3)*R(3)
C(2)=C(2)-D
C(3)=C(3)-D
IF (IO.EQ.4) RETURN
GO TO 500
500 IF (IO.EQ.6) GO TO 400
GO TO 330
330 RETURN
400 CONTINUE

WRITE (6,900) IO,A,B
900 FORMAT(4X,10E12)

END
SUBROUTINE VGMNZ(CET,MoNAT,WrEP)

C PURPOSE:
C TO ACT AS BUFFER BETWEEN THE MAIN PROGRAM AND THE GTO
C CALCULATION. THE NEEDED DATA ARE INITIALIZED. WEDGE 
C ANGLES ARE CALCULATED. UNITNORMAL VECTOR OF EACH PLATE
C IS DETERMINED.

C PARAMETERS:
C **INPUTS**
C MoNAT: ANTENNA NUMBER UNDER TEST
C WrEP: REPEAT BLOCKAGE TEST FOR DIFFRACTION OR RAYS ONLY.
C ALL COMMON STATEMENTS.

C **OUTPUTS**
C CET: THE TOTAL HORIZONTAL POLARIZED COMPLEX ELECTRIC FIELD.

COMMON /A/ P1,P1R)
COMMON /U/ UPLAT(50,1),UNI(1),US(1),UPLATE
COMMON /G/ DVS(50,3),DOV(50,3),FREQ,UNI(1),US(1)
COMMON /E/ FPTS(1,2),INPUT
COMMON /I/ ICON
COMMON /P/ PLATE/ XO(10),YO(10),Z(10),HE
COMMON ANTENNA/ YP(50),YPP(50),ZP(50),AZK,FREQ,NAMTP 
COMMON /G/ GSVR/ YCMR,VRM,CMR
COMMON /IS/ FPTS(2)=XG(V,R,V)
COMMON /F/ FPTS(3)=Z01SVQ
COMMON /E/ OQS(1,1)=Y0P(NANTP)
COMMON /G/ OQS(1,2)=Y0P(NANTP)
COMMON /F/ OQS(2,1)=-Z0P(NANTP)
COMMON /G/ OQS(2,2)=Z0P(NANTP)
DIMENSION YP(1),HPM(N1),IPM(N1),ITAG(1),DRS(50,6), 
ORDERED,APRP(50,3),OMAI(50),THET(1),PHS(1),ET(1),P(1), 
CALculated,PLNT(3),FILE(9),PATERN(6) ,CPLEIN(3) 
C,F(3,1),F(4,1),F(9,1),F(3),F(3),F(1,3),F(5,5),F(5,6), 
VHNTEST(3), 
测试分析,PLN(31),IPM(31),PT(31),V2(31),CENTR(3)

FOFORMAT(2K,7J29,10)

FOFORMAT(2K,7J29,10)

FOFORMAT(2K,7J29,10)

0013 40 FORM(2K,7J29,10)

0014 44 FORM(2K,7J29,10)

0015 46 FORM(1L,2K,4* FIELD POINT*,5X,10D20.10)

0016 00 FPTS(1)=YOVR SR

0017 00 FPTS(2)=YNOSSR

0018 00 FPTS(3)=Z0SVR

0019 00 DRS(N1)=XPP(YNATP)

0020 00 DRS(N2)=YNNATP

0021 00 DRS(N3)=ZVPNATP

0022 00 DRS(N4)=ZVPNATP

0023 00 DRS(N5)=ZVPNATP

0024 00 DRS(N6)=ZVPNATP

0025 00 IF(0.5+X)--1.

0026 00 IF(1.5+X)--1.

0027 00 IF(1.5+X)--1.

0028 00 IF(1.5+X)--1.

0029 00 FORM(20,5X,DIRV(1),2.1)=',3F15.3,1=1.5,17..1,19)

0030 00 FORM(20,5X,DIRV(1),2.1)=',3F15.3,1=1.5,17..1,19)

0031 00 FORM(20,5X,DIRV(1),2.1)=',3F15.3,1=1.5,17..1,19)

0032 00 FORM(20,5X,DIRV(1),2.1)=',3F15.3,1=1.5,17..1,19)
202

C CALCULATE THE UNIT NORMAL OF EACH PLATE.
C
0050 IF ( EVEN .NE. 1) GO TO 252
0051 CALL VECTOR ( 2, PNG, RN, UN )
0052 CALL VECTOR ( 2, YP, XP, ZP )
0053 CALL VECTOR ( 4, IP, IV, VP )
0054 GO TO 251
0055 252 CALL VECTOR ( 2, PNG, RN, UN )
0056 CALL VECTOR ( 2, XP, YP, ZP )
0057 CALL VECTOR ( 4, IP, IV, VP )
0058 CONTINUE
0059 IF ( EVEN .EQ. 1 ) WRITE ( 6, 44 ) UN(1:1, I = 1, 3)
0060 IF ( I .EQ. XP(1) ) GO TO 419
0061 WRITE ( 6, 44 ) I
0062 STOP
0063 419 DN 256 LI = 1, 3
0064 256 UPLATE(1,1:1) = UN(1:1,1)
0065 11 = 1 + 2
0066 12 = 1 + 2
0067 13 = 1 + 2
0068 14 = 1 + 2
0069 254 CONTINUE
C CALCULATED THE WEDGE ANGLES
C
0070 DN 248 LI = 1, NPLATE
0071 LI = 2 + 3
0072 RN(1:1) = UPLATE(1:1, I)
0073 249 RN(1:1) = UPLATE(1:1, I:1)
0074 IF ( I .EQ. 1 ) GO TO 248
0075 CALL VECTOR ( 4, RN, PNG, UN )
0076 DMAT(1:1) = PMAT(1:1, I)
0077 CALL VECTOR ( 1, RN, PNG, UN )
0078 IF ( I .EQ. 1 ) DT0 = 360. - W4(1:1)
0079 248 CONTINUE
0080 NPST = NPLATE - 1
0081 DO 301 J = 1, NPST
0082 IF ( EDGE(J) .NE. J + 2 )
0083 301 CONTINUE
0084 J = J + 1
FORTAN IV 5 LEVEL 21  FORTRAN DATE = 81078  12/45/81

0095 IF(IFGEO) = 0
0096 LENGTH = 2.*PI/12K
0097 DD 501 I = 1,3
0098 DD REI(J) = 0.
0099 P(I) = 0V(I,1)
0100 W(1) = 0V(2,1)
0101 501 JJ(I)=J(I)
0102 CALL VECTOR(1,2,3,4,YP)
0103 CALL VECTOR(1,2,3,4,YP)
0104 CONVERT SOURCE DATA TO SEGMENT END POINTS
0105 220 DD 330 J = 1,4
0106 P(I) = WELT(I) + RSI(1,4)/LENGTH
0107 310 DD 350 J = 1,2
0108 IF(NANT.EQ.1 .OR. NANT.EQ.3) GO TO 231
0109 310 231 X = NISTAN
0110 231 Y = NISTAN
0111 231 Z = 3.
0112 232 DD 340 J = 1,3
0113 232 340 P(I) = 0V(I,1)
0114 230 DD 240 J = 1,4K
0115 230 240 P(I) = 0V(I,1) + PSI(I,1)
0116 240 DO 240 J = 1,4
0117 240 CONTINUE
0118 240 DD 250 J = 1,4
0119 250 CONTINUE
0120 IFGEO = CMPLX(0.,0.)
0121 EPONG = CMPLX(0.,0.)
0122 END = CMPLX(0.,0.)
0123 END = CMPLX(0.,0.)
0124 172 ANT(I) = PSI(I,1)/LENGTH
FOOTNOTE IV: LEVEL 21

10125  I=1
10126  ETP(1)=(0,0.1)
10127  FTP(I)=(0,0.1)
10128  CALL TRANS(1,ANT,FATS,US,RA,TI,P1)
10129  IF(ICON.FJ.L).WRITE(A,46)(FPT(IJK),JK=1,3)

C COMPUTE GEOMETRICAL DIFFRACTION FIELDS BY TWO SUBROUTINES.

10130  CALL VENG(NSV,ONV,OS,PE,TL,PL,RA,ETGON,EPDGO)
10131  CALL VEDIF(ANGE,NSV,ONV,OS,PE,TL,PL,RA,ETDIF,FPDT)

C CONVERT WAVELENGTH TO METERS

10132  WLEN=WLEN*.1044
10133  ETP(I)=ETGON+ETDIF
10134  ETMI=EPDGO+FPDT

C FOR HORIZONTALLY POLARIZED FIELD, ONLY ETP IS USED.
C ETT IS THE VERTICALLY POLARIZED FIELD ALSO PROVIDED.

10135  CET=ETP(I)/WLEN
10136  HRE=1
10137  IF(ICON.EQ.0) GO TO 300
10138  WRITE(6,41)
10139  CALL VAMPHA(ETT(I),ETM(I))
10140  41 FORMAT(2X,'THE TOTAL FIELD IS')
10141  300 RETURN
10142  END
205

**Fortran IV & Level 21**

**VENGO**

**DATE = 3/17/76**

**12/45/57**

**SUBROUTINE VENGO**

*Implicit Real* (A-H, O-Z)

**C**

**Purpose - To Compute the Geometrical Diffraction Fields;**

**C**

Direct, Reflected, Doubly-Reflected, Reflected-Diffracted,

**C**

Reflected, and Triple Reflected Fields.

**C**

**Parameters***

**C**

**Input***

**C**

**Output***

**C**

*Required Subroutines:*

**C**

**Common /A/ UPLAT(31), JUM(3), JST(3), NPLATE
C**

**Common /G/ FTPS(1), ANT(3)
C**

**Common /I/ ICON
C**

**Common /J/ JST, JREF, JRAJ, IBRA, JRAJ
C**

**Common /K/ JFREE, JATTENU, JPLATE(5), JCMR(3), JCMR(3)
C**

**Complex*16 ETGON, EPGEN, ETRE, EPRT, ETP, ETPR, ETPR, ETPR, ETPR, ETPR
C**

**CETPO, EPRPO, EPRPO, EPRPO, EPRPO, EPRPO, EPRPO, EPRPO, EPRPO, EPRPO
C**

**Dimension DPV(50, 1), RPST(1), RS(5), RS(5), RS(5), RS(5), RS(5), RS(5), RS(5),
C**

**FRM(3), RPR(31), RPR(31), RPR(31), RPR(31), RPR(31), RPR(31), RPR(31), RPR(31),
C**

**ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1),
C**

C**

**ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1), ETPO(1),
C**

**Input Field Values to Zero**

**C**

**Start Print Ray Contributions at New Page (Easy To Read).**

**C**

**IF(ICON.NF.0) WRITE(6, 202)**

**C**
\begin{verbatim}
0029  202 FORMAT(i111)
0030          DO 300 I=1,13
0031          RS(I1)=RS(I1,11)
0032          RS2(I1)=RS(I1,11)
0033   300 RS(I1)=(RS(I1)+RS2(I1))/2.0
C         DETERMINED IF THE DIRECTED RAY EXISTS
C         IF(JDIR.EQ.1) GO TO 600
0034          CALL VLOGIIANT,FPTS,DRV,LP,LPLATE,LOK)
0035          IF(LOK.EQ.1) GO TO 600
C         COMPUTE DIRECT RAY
0036          CALL SOURCE(RS1,RS2,THETA,PHI,PE(1),R,FTD,EPO)
C         ADDED DIRECTED FIELD.
C         EPD=EPD/ATTENU
0039          ETGN=ETGN+ETD
0040          EPD=EPO/ATTENUETGON=ETGN+EPD
0041          IF(ICON.EQ.0) GO TO 600
0042          WRITE(6,200)
0043          CALL VAMPHA(ETD,EPD)
C         THIS IS THE MAIN LOOP THAT DEAL WITH REFLECTED, DOUBLE-
C         REFLECTED, REFLECT-DIFFRACTED, 3RD FIELDS.
C         IF(IF.NE.1)GO TO 412
0044          IF(ICON.EQ.0)WRITE(6,205) LP
0045          IF(IFNE.2)GO TO 612
0046          205 FORMAT(18) START TO CALCULATED THE RAYS FROM PLATE, SX, LX
C         DETERMINED IF REFLECTED POINT EXISTS
C         IF(IF.NE.1)GO TO 620
0047          LP2=LP+2
0048          LPD=LP
0049          CALL VEXIST(ANT,DRV,LPD,2,DO,US,IC)
C         DOES THE IMAGE POINT LIE BELOW THE IMAGING PLANE ?
C         IF NOT CONSIDER THE NEXT PLATE .
C         IF(ICON.EQ.-1.AND.LPD.EQ.1) GO TO 601
0050          IF(IFNE.1) GO TO 601
C         CHECK BLOCK FROM ANTENNA TO PLATE LP.
C         NPRE=LP-1
C         IF(NPRE.LT.1) GO TO 412
0052          CALL VLOGIIANT,NO,DRV,LP,LPLATE,LOK)
0053          IF(LOK.EQ.1) GO TO 601
C         CHECK BLOCK FROM THE REST OF THE PLATE
C         LX=LP+1
C         IF(LX.GT.NPATE) GO TO 405
C         CALL VLOGIIANT,FPTS,DRV,LX,LPLATE,LOK)
0059          IF(IFNE.1) GO TO 601
0060          405 DD 400 JZ=1,3
\end{verbatim}
FORTRAN IV G LEVEL 21

0061 TEMP(J2)=DRV(LP2,J2)
0062 400 UN(J2)=UPLAT(LP,J2)
0063 CALL IMAGE(RS,TEMP,UN,SM)
C COMPUTED REFLECTED FIELD.

0064 CALL TRANS1(SM,FPTS,RA,R2,TETA,PHII)
0065 IF (ICON.EQ.1) WRITE(6,101) SM,00
0066 CALL IMAGE(RS1,TEMP,UN,RS1P)
0067 CALL IMAGE(RS2,TEMP,UN,RS2P)
0068 IF (JREF.EQ.1) GO TO 601
0069 CALL SOURCE(RS2P,RS2P,TETA,PHII,PE(1),R2,ETR,EPR)

C ONLY THE PLATE SPECIFIED (JPLATE**) GOT ATTENUATION.

0070 IF (JPLATE(1).EQ.LP) EPR=EPR/ATTENU
C ADDED SINGLY REFLECTED FIELD FROM PLATE LP.

0071 ETGN=ETGN+ETR
0072 EPGN=EPGN+EPR
0073 IF (ICON.EQ.1) GO TO 601
0074 WRITE(6,271) LP
0075 CALL VDMPHIA(ETR,EPR)

C CHECKED DOUBLE-REFLECTED AND REFLECTED-DIFFRACTED RAYS

0076 DO 413 J2=1,3
0077 TEMP(J2)=DRV(LP2,J2)
0078 UN(J2)=UPLAT(LP,J2)
0079 413 CONTINUE
0080 CALL IMAGE ANT,TEMP,UN,S1)
0081 CALL IMAGE(RS1,TEMP,UN,SI)
0082 CALL IMAGE(RS2,TEMP,UN,RS2)
0083 IF (ICON.EQ.1) WRITE(6,215) (S1,J2), J2=1,3,LP
0084 215 FORMAT(ZS1=,1,JO25,1,10)
C FIND THE SECOND REFLECTED PLATE FOR POSSIBLE OF
C DOUBLE REFLECTED RAY.

C LP HAS THE FIRST REFLECTED PLATE NO.
C THIS IS THE MAIN LOOP FOR DOUBLE REFLECTED FIELD.

0085 DO 414 LN=LP,NPLATE
0086 IF (LN.EQ.LP) GO TO 414
0087 LN2=LN+2
0088 DO 415 J2=1,3
0089 415 CONTINUE
0090 TEMP(J2)=DRV(LM2,J2)
0091 CALL IMAGE(RS1,TEMP,TEM4,S1)
0092 IF (ICON.EQ.1) WRITE(6,216) (S1,J2), J2=1,3,LM
0093 216 FORMAT(ZS1=,1,JO25,1,10,10)
0094 CALL IMAGE(RS1,TEMP,TEM,SIII)
0095 CALL IMAGE(RS1,TEMP,TEM,SIII)
0096 IF (PROD.EQ.1) CALL VDMPD(S1,LN,SM,SI,SM,SI,RA,LM,
C ETGND,EPGRD)
0097 ETGN=ETGN+ETGND
0098 EPGN=EPGN+EPGRD
C
C  DOnF THE SECOND IMAGE LIE FLOW THE DOUBLE REFLECTED PLATE?
  DO 210 IR=1,2,3
C
0090 CALL VECTOR(6,ST,SI1,UR1)
0100 CALL VECTOR(4,ST,TE4,0,0)
0110 IF(D0121.LEQ.0) GO TO 414
0120 CALL VECTOR(3,ST,FPTS,UR)
0130 LNN=LN
0140 IF(ICON.EQ.1) WRITE(6,217) (UR(J2),J2=1,7),LN
0150 217 FORMAT(2X,UR*,J,320,10,110)
0160 CALL VEXIST(S1,DRV,LRN,1,CO,UR,IC)
0170 C C CHECK REFLECTING POINT N0 EXISTING ON PLATE LN.
C
0180 IF(ICON.EQ.1.AND.1C.EQ.1 ) GO TO 414
0190 IF(ICON.EQ.1) WRITE(6,212) (UR(J2),J2=1,3),LN
0200 212 FORMAT(2X,UR*,J,320,10,110)
0210 IF(ICON.EQ.-1) GO TO 414
C C CHECK REFLECTED POINT WITHIN REFLECTED PLATE.
C
0220 CALL VECTOR(3,00,ST,UR)
0230 LP=LP
0240 CALL VEXIST(N0,DRV,LP,1,RP,UR,IC)
0250 IF(LP.EQ.1) GO TO 414
0260 IF(IP.EQ.1) WRITE(6,213) (RP(J2),J2=1,3),LP
0270 213 FORMAT(2X,RP*,J,320,10,110)
0280 IF(ICON.EQ.-1) GO TO 414
C C CHECK BLOCKED FROM PLATE LN TO THE LAST PLATE NPLATE.
C
0290 ISTART=LN+1
0300 IF((START,ST,NPLATE) GO TO 421
0310 CALL VLOGI1(N0,FPTS,DRV,1START,NPLATE,LOK)
0320 IF(LOK.EQ.1) GO TO 414
C C CHECK BLOCKED FROM ANTENNA TO FIRST REFLECTING POINT (RP).
C
0330 421 ISTEP=LP-1
0340 IF((STEP,LT,1) GO TO 423
0350 CALL VLOGI1(RP,ANT,DRV,ISTEP,LK)
0360 IF(LK.EQ.1) GO TO 414
C C CHECK BLOCKED BETWEEN THOSE TWO PLATES LP, LN.
C
0370 423 IF((ARS(LP,LN).NE.1) GO TO 425
0380 CALL VEXIST(LP0,LP,LN,LP,DRV,LK)
0390 IF(LK.EQ.1) GO TO 414
0400 GO TO 418
0410 425 ISTART=LP+1
0420 ISTEP=LP-1
0430 IF((RP,NO,DRV,ISTART,ISTEP,LK)
0440 418 FORMAT(2X,RP*,J,320,10,110)
0450 CALL VLOGI1(LP,NO,DRV,ISTART,ISTEP,LK)
0460 IF(LK.EQ.1) GO TO 414
C C CALCULATED DOUBLE-REFLECTED FIELD
C
0470 CALL SOURCE(1,AS1,RS2,TP1,TETA,PHI1)
0480 CALL SOURCE(1,AS1,RS2,TP1,TETA,PHI1,PE1,1,RP,EP1)
0490 418 FORMAT(2X,RP*,J,320,10,110)
C C AMEND DOUBLE REFLECTED FIELD.
C
C$137 IF(LGON.EQ.0) GO TO 426
C$138 IF(LGON.EQ.0) GO TO 426
C$139 IF(LGON.EQ.3) GO TO 414
C$140 MAP(6,210) LF=TN
C$141 CALL VAMP(AEPP,EPRR)
C$142 210 XREFlected FROM PLATE,14,2X,TO PLATE,14,2X,
C"FIELD IS")
C$143 414 CONTINUE
C C CHECK REFLECTED-DIFFRACTED RAY
C C 900 IF(NPLATE.LE.2) GO TO 426
C C THIS IS THE LOOP FOR REFLECTED-DIFFRACTED RAY.
C C IF ONE WANTS TO HAVE THE BACKWARD RAY FIELD,
C C ONE MUST CHANGE : LM=LP,UPPLATE TO LM=2,UPPLATE (AND TRY7).)
C$145 DO 426 LM=LP,NPLATE
C$146 IF(LP+1.EQ.LM) GO TO 426
C$147 DO 427 J2=1,3
C$148 E(J2)=EVL4*(J2)
C$149 E(J2)=EVL4*(J2)
C$150 UN(J2)=UPPLAT(LP,J2)
C$151 TEM(J2)=ORVL(LP,J2)
C$152 427 TEM(J2)=UPPLAT(LM,J2)
C C FIND DIFFRACTION POINT ( RP )
C C CALL VEXIST(SI,PTS,E,FL,RP,ACTAN).
C C 426 IS THE LOOP FOR FDR RAY CALCULATION.
C C CHECK THE REFLECTION POINT MUST BE ON THE PLATE LP.
C C IF NOT NEXT EDGE IS CONSIDERED.
C C CALL VECOR(3,51,DPX,PM)
C$154 LPP=LP
C$155 CALL VEXIST(SI,DRV,LPP,1,PF1,DP,ICUT)
C$156 IF(LP+1.EQ.LM) GO TO 426
C$157 IF(LP.EQ.1.AND.ICUT.EQ.1) GO TO 426
C$158 IF(LP-1.EQ.1) GO TO 426
C C DOES DIFFRACTED POINT LIE UPPER HALF-PLANE OF (LP)
C C CALL IMAG(E(RP,TEM,UN,PM)
C$159 CALL VECOR(3,RP,DPX,PM)
C$160 CALL VECOR(4,RP,DPX,PM)
C$161 CALL VECOR(5,RP,DPX,PM)
C$162 IF(LP.EQ.1.LE.3) GO TO 426
C C CHECK BLOCLED FROM PREVIOUS PLATES.
C C LPP=LP-1
C$163 IF(LP+1.LE.1) GO TO 431
C$164 CALL VLAGIL(ANT,RF1,DRV,1,LPP,LOC
C$165 IF(LOC.EQ.1) GO TO 426
C C CHECK BLOCKED BETWEEN REFLECTED PLATE AND DIFFRACTED EDGE.
C
C
431 CALL VECTO(I1,RP,FL,RP)

IF LP,GE,LP GO TO 441

IF(1J.0.E-1,HP.E-1) GO TO 428

CALL VECMIR(FL,RP,LP,LY-1,DRV,LOK)

IF LOK,GE,-1 GO TO 426

GO TO 430

CALL VECMIR(FL,RP,DRV,LP,LY-1,LOK)

IF LOK,GE,-1 GO TO 426

GO TO 430

428 CALL VECMIR(FL,RP,DRV,LP,LY-1,LOK)

IF LOK,GE,-1 GO TO 426

GO TO 430

433 IF(LP.EQ.-1,HP.EQ.1) GO TO 436

CALL VECMIR(FL,RP,LP,LY,DRV,LOK)

IF LOK,GE,-1 GO TO 426

GO TO 430

436 CALL VECMIR(FL,RP,DRV,LP,LY-1,LOK)

IF LOK,GE,-1 GO TO 426

C

CHECK BLOCKED REFLECTION FIELD.

C

430 ISTART=LP+1

0153 IF ISTART.GT.IHP.0) GO TO 432

0154 CALL VECMIR(RP,FRPTS,DRV,ISTART,4PLATE,LOK)

IF LOK,GE,-1 GO TO 429

C

432 IF(JR.0.EQ.0) GO TO 429

CALL VECMIR(RP,FRPTS,DRV,ISTART,4PLATE,LOK)

MJ=1

0159 CALL VECMIR(FRPTS,FRPTS,SY,EI,RS21,PS11,PE11,2A(LM-1),TDE,PDE,

C3,TDE,PDE,DRV,RP,RETOQ,MJ,LP,LY)

0150 IF(MJ,0.EQ.1) GO TO 426

C

ADDED REFLECTED-DIFFRACTED FIELD.

C

0151 EGO=EG0+ET0

0152 EPO=EP0+EB0

0153 IF(ICEQ.EQ.1) GO TO 429

0154 LDEP=LDEP+1

0154 WRITE(20,L4)LP,FGE

0156 CALL VAMPH1(ET0,EP0)

C

C

CALCULATE REFLECTED-DIFFRACTED-REFLECTED FIELD.

C

0157 429 IF(JR.0.EQ.0) CALL VECMIR(FRPTS,SY,EI,RS11,RS21,PE11,2A(LM-1),

C3,TDE,PDE,DRV,LP,LY)

0154 EGO=EG0+ET0

0159 EPO=EP0+EB0

C

C

CALCULATE REFLECTED-DIFFRACTED-REFRACTED FIELD.

C

0200 IF(JR.0.EQ.0) CALL VECMIR(FRPTS,SY,EI,PS11,PS21,PE11,2A,

C3,TDE,PDE,DRV,LP,LY)

0201 EGO=EG0+ET0

0202 EPO=EP0+EB0
ETGON and EPSON are the sum of direct, RR, RO, and RRR ray contributions.

THE END OF DO-LUMP WHICH CHECKS FOR ALL RR, RO, AND RRR COMBINATIONS.

THE END OF DO-LUMP WHICH CHECKS FOR ALL RR, RO, AND RRR COMBINATIONS.

CALCULATE TRIPLE-REFLECTED FIELD.

NOTE: JRRN ENCODED FOR TRIPLE-REFLECTED FIELD CALCULATING OPTION.

IF(JRRN.EQ.0)CALL VRRR(DPV,RS1,RS2,P11,ETRRR,EPARR)

CALL VARR(DPV,RS1,RS2,P11,ETRRR,EPARR)

CALL VARR(DPV,RS1,RS2,P11,ETRRR,EPARR)

218 FORMAT(2X, 'REFLECTED FROM PLATE', I4,2X,'TO EDGE', I4,

C' FIELD IS')

211 FORMAT(15X, 'DIRECT FIELD.')

213 FORMAT(2X, 'REFLECTED FROM PLATE', I4)

204 FORMAT(2X, 'THE FIELD CONTRIBUTED FROM DIRECT, RR, RO, RRR,',

C'RRR, RR, RO, RO, RO, AND RRR ARE')

RETURN

END
FUNCTION ATGN2(Y,Y)

C     IMPLICIT REAL*4(A-H,O-Z)

C     PURPOSE - TO SET ATAN2(Y,Y)=0.0 WHEN X=0.,Y=0.

IF(Y.NE.0.0.D0.AND.Y.NE.0.0.D0) GO TO 3

ATGN2=0.

RETURN

ATGN2=DATAN2(X,Y)

END
0001 COMPLEX FUNCTION CSQR(X)
0002 IMPLICIT REAL(A-H,O-W),COMPLEX*16 (X)
      C
      C PURPOSE:
      C TO FORCE ATG/2 VALUE TO BE BETWEEN -PI AND +PI.
      C
      C PARAMETER:
      C ****INPUTS****
      C X : COMPLEX ARGUMENT.
      C
0003 COMMON /AX,PL,PI190
0004 CPHASE=ATAN2(IMG(X),REAL(X))
0005 IF(CPHASE.GT.PI) CPHASE=CPHASE-PI
0006 CSQR=CHG*MATPL(2.*SIN(CPHASE/2.),DSR(CPHASE/2.))
0007 RETURN
0008 END
FUNCTION COT(X)
IMPLICIT REAL(A-H,O-Z)
C
PURPOSE : TO CALCULATE THE COTANGENT VALUE FOR A GIVEN ARGUMENT
C
PARAMETER : ***INPUTS***
C X : ARGUMENT IN RADIANS.
C
CXX = C(X)
SVX = S(X)
COT = 1.0
IF (NABS(SVX).GT.1.0-50) COT = CXX/SVX
RETURN
END
COMMON /A/ PI,P1190
IF (X-.5.) 20,20,10
C LARGE ARGUMENT APPROXIMATION
10 X2=X*X
X3=X2*X
X4=X2*X2
F=DCMPLX(1.-3./(4.0*X2)+75./(16.*X4),1./(2.*X)-15./(8.*X3))
RETURN
20 IF (X-.2) 40,30,30
C EXACT EXPRESSION
30 PO=DSQRT(PI*2.00)
Z=P*DCMPLX(1.00,Y)
CALL CSXIC,S,X)
C=5-5
S1=5-5
F=DCMPLX(X)*CDEXP(Z)*PO*DCMPLX(S1,C1)
RETURN
C SMALL ARGUMENT APPROXIMATION
40 P14=PI/4.00
Z=DSQRT(P14*X)-2.*X*CDEXP(DCMPLX(0.00,P14))-2.*X*X*CDEXP(DCMPLX(0.00,P14))
RETURN
END
FUNCTION SGN(X)
IMPLICIT REAL*(A-H,O-Z)
C PURPOSE - TO GIVE MINUS SIGN IF X IS NEGATIVE OR VICE VERSA
C
0003 IF (X) 1,2,3
0004 1 SGN=-1.
0005 RETURN
0006 2 SGN=0.
0007 RETURN
0008 3 SGN=1.
0009 RETURN
0010 END

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SUBROUTINE TRANS(OP, A, d, E, TH, PHI)

C PURPOSE
C
C TRANSFORM ORIENTATION OF A FROM A TO B
C
C TRANSFORM A TO A AND PHI
C
C COMMON /AI PI,P1190
C
C DIMENSION A(3),A(13),E(1),E(11),E(2)(3),D(3)
C
C GO TO (10,20,10)
C
010 CALL VECTOR(E,A,d,E)
011 CALL VECTOR(D,A,d,E)
012 D1=PI*COS(E(3))/PI180
013 D2=PI*COS(E(1))/PI180

C TRANSFORM RECTANGULAR COORDINATE TO SPHERICAL COORDINATE.
C
014 RETURN

C TRANSFORM SPHERICAL COORDINATE TO RECTANGULAR COORDINATE.
C
20 TH=TH*PI180
020 PHI=PHI*PI180
021 R(1)=RAD*OSIN(TH)*OCOS(PHI)
022 R(2)=RAD*OSIN(TH)*OSIN(PHI)
023 R(3)=RAD*OCOS(TH)
024 CALL VECTOR(R,E1,E2)
025 CALL VECTOR(E1,E2)
026 RAD*E2(E1)
027 CALL VECTOR(E1,E2)
028 TH=TH*PCOS(E(3))/PI180
029 PHI=PHI*PCOS(E(1))/PI180
030 RETURN
031 END
SUBROUTINE VQRT(FPTS,ST,E1,RS1,RS2,PU,DW,ETSIM,EPSUM,NOV,
CLP,LM)

IMPLICIT REAL(A-H,O-Z)
C

PURPOSE:
C
TO CALCULATE REFLECTED-DIFFRACTED-REFLECTED FIELD.
C
C
PARAMETERS:
C
***INPUTS***
C
FPTS : FIELD POINT
C
SI : IMAGE SOURCE POINT
C
E, E1 : TWO END POINT OF THE DIFFRACTING EDGE.
C
RS1, RS2 : TWO END POINTS OF IMAGE ANTENNA.
C
O4 : WEDGE ANGLE WHERE THE EDGE IS BELONGED.
C
ORV : PLATE DATA
C
DP : DIFFRACTING POINT ON THE EDGE
C
ETAO : DIFFRACTING ANGLE.
C
LP, LM : TWO REFLECTING PLATES.
C
C
***OUTPUTS***
C
ETSUM, EPSUM : THETA AND PHI COMPLEX ROR FIELD COMPONENTS.
C

COMMON /LUTK/ (K9,3),UN(3),US(3),UPLATE
COMMON /L/ ICON
COMMON /W/ ECON
COMMON /W/ EPROM,ETSIM,EPSUM,PU
DIMENSION FPTS(3),FPTT(3),ORV(50,3),C1(3),Q2(3),Q2(3),E(3),
C(E(3),F2(3),ETF(3),SI(3),RS1(3),PS2(3),DP(3)
ETSUM=0D,0)
EPSUM=0D,0
ISTART=LM+1
IF(ISTART.GT.NPLATE) RETURN

C
START CHECKING ALL REFLECTING PLATE FOR POSSIBLE ROR RAYS.
C
DO 400 L=ISTART,UPLATE
C
ERROR=0D,0
EPROM=0D,0
Q2=0D,0
Q2=0D,0
J2=1,1
CALL IMAGE(FPTS,F2,UN,FPTT)
C
CHECK IMAGING FIELD POINT LIES BELOW PLANE LA.
C
CALL VECTOR(E,FPTS,FPTT,D1)
CALL VECTOR(4,DI,UN,D2)
IF(D1.EQ.0.0) GO TO 400
C
CALCULATE DIFFRACTING POINT (DP). RETAO.
C
CALL WEISSI,FPTT,E,E1,DP,RE Tao
C
FIND REFLECTION POINT (RF1)
C
CALL VECTOR(3,DP,FPTT,US)
INST=LA
C
CALL WEISS(FPTT,NOV,INST,RF1,US,ICUT)
0024  IF (IST.EQ.1.AND.ICUT.EQ.1) GO TO 430  VN016740
0025  IF (ICUT.EQ.1) GO TO 400  VN016749
0026  C
0027  IF (ISRS.LT.LA1+NE.L) GO TO 493  VN016749
0028  CALL VMEGH(TMP,RFI,LM,LA,DRV,LOK)
0029  IF (FILENAME.EQ.1) GO TO 400  VN016749
0030  GO TO 405  VN016749
0031  CALL VLOG(FOR,REF,DRV,LM,LA,LOK)
0032  IF (FILENAME.EQ.1) GO TO 400  VN016749
0033  C
0034  CHECK BLOCKAGE BETWEEN PLATE LA-1.
0035  403
0036  CALL VLOG(IF,RFI,DRV,LM,LA,LOK)
0037  IF (FILENAME.EQ.1) GO TO 400  VN016749
0038  C
0039  IF (LAI.EQ.LA+1)
0040  405
0041  IF (FILENAME.EQ.1) GO TO 404  VN016749
0042  CALL VLOG(IF,RFI,DRV,LM,LA,NPLATE,LOK)
0043  IF (FILENAME.EQ.1) GO TO 400  VN016749
0044  C
0045  C
0046  406
0047  CALL CALCULATE ROR FIELD.
0048  404
0049  CALL TRANS(1,DF,PFTI,US,2,TQE,P2E)
0050  406
0051  CALL VEND(IF,FPTI,SI,E,FL,RF,PSI,PU,DW,TQE,P2E,
0052  <R2,ETROR,EPDR,DRV,DF,RETAQ,4J,LP,LY)
0053  IF (FILENAME.EQ.1) GO TO 400  VN016749
0054  406
0055  C
0056  IF (FILENAME.EQ.1) GO TO 400  VN016749
0057  C
0058  EPSUM=EPSUM+ETROR
0059  C
0060  EIF(EQ.1) GO TO 400  VN016749
0061  C
0062  C
0063  WRITE(4,200)LP,EDGE,LA
0064  C
0065  CALL VMEPH(IFR,EPROR)
0066  200
0067  FOR4=(2X,'REFLECTED FROM PLATE1,14,2X,'TO EDGE1,14,2X,
0068  <REFLECTED FROM PLATE1,14)
0069  200
0070  CONTINUE  VN016749
0071  400
0072  RETURN  VN016749
0073  END  VN016749
SUBROUTINE VRDIF(PNTS,SI,EL,E2,R1,R2,PE,ORV,ORU,ORUM,IMUM,UPLE)
        IMPLICIT REAL*8(A-H,O-Z)
        C
        PURPOSE:
        TO CALCULATE THE REFLECTED-DIFFRACTED-DIFFRACTED RAYS.
        C
        PARAMETERS:
        ***INPUT***
        PNTS : OBSERVATION POINT
        SI : IMAGE OF ANTENNA W.R.T. PLATE LP.
        R1, R2 : IMAGE OF ANTENNA TWO END POINTS W.R.T. PLATE LP.
        ORV : ARRAY CONTAINS WEDGE ANGLES.
        LP : REFLECTING PLATE.
        LM : PLATE WHERE EDGE (EL, E2) IS BELONGED (RELATION EDGE+LM+1)
        ORV : ARRAY CONTAINS VERTAX POSITIONS
        PE : SOURCE INPUT CURRENT (COMPLEX)
        ***OUTPUT***
        ETSUM, EPSUM : THETA AND PHI COMPLEX FIELD COMPONENTS.
        C
        REQUIRED SUBROUTINES:
        V2DIF, VL0S11, VL0S12, TRANS, VENDIF, VVLQMA
        C
        0003 COMMON /V/ UPLAT(50,3),VJ(3),SIM1,NIPLATE
        0004 COMMON /#/ ICON
        0005 COMMON (*) ETSUM,ETSUM,EP00,ETDIF,EPDIF,PE
        0006 DIMENSION PNTS(3),SIM1,NS1,NS2,NS3,ORV(50,3),
               EF1(3),EF2(3),E4(3),OQ(1,2)
        0007 ETSUM=(0.,0.)
        0008 EPSUM=(0.,0.)
        C
        EXCLUDE THE LAST EDGE.
        C
        0009 NS1=LM+2
        0010 IF(NS1.GT.NPLATE) RETURN
        0011 ETDIF=(2.,0.)
        0012 EPDIF=(0.,0.)
        C
        CALCULATE COMBINATIONS OF R00 RAY.
        C
        0013 DO 510 LR=NS1,NPLATE
        0014 LP2=LR+2
        C
        SETUP SECONDARY EDGE (E3,E4).
        C
        0015 DO 510 J2=1,3
        0016 E3(J2)=ORV(LR2,J2)
        0017 410 E4(J2)=ORV(LR2-1,J2)
        C
        CALCULATE DIFFRACTION POINTS (Q1,Q2)
        C
        CALL V2DIF(PNTS,SI,EL,E2,F3,E4,OQ,PE,EPDIF,ETSUM,EP00)
        C
        CHECK RBLCKAGE FROM Q1 TO Q2.
        C
C WRITE: THE BLOCKAGE TEST IS SECTION FROM ANTENNA TO Q1.
C WAS PERFORMED IN SUBROUTINE VENDO (GOOD ONLY 2-D CASE).
C
0219 ISTART=LR+1
0220 ISTOP=LR-2
C IF((START.LT.ISTOP) GO TO 510
C ISTART=ISTD
C ISTOP=Ly+1
C CHECK BLOCKAGE IN BETWEEN TWO EDGES.
C
0221 510 CALL VLOGI1(Q1,DP,DRV,ISTART,ISTD,PLOG)
C CHECK BLOCKAGE FROM Q2 TO OBSERVATION POINT FPTS.
C
0223 ISTANT=LR+1
C NOTE: USER MUST MAKE SURE THAT FOREST EDGE IS LOWER THAN
C THE PREVIOUS EDGE.
C
0224 IF((START.GT.NPLATE) GO TO 520
C 520 CALL VLOGI1(Q2,FPTS,DRV,ISTART,NPLATE,PLOG)
C CALL VLOGI1(Q2,FPTS,DRV,ISTART,NPLATE,PLOG)
C IF(LR.EQ.1) GO TO 500
C
0227 592 M=0
0229 CALL TRANS(1,02,12P,T,H,S,PHIS)
C CALCULATE FIELD INCIDENT ON FIRST DIFFRACTING EDGE.
C
0229 CALL VENODF(Q2,O2,SL,E1,E2,P1,P2,PE,LR1-1,T,H,S,PHIS,
C RETROD,EPD,FQ1,RET1,MJ,LH,LR)
C IF((J.M.E.1) GO TO 500
C
0230 CALL TRANS(1,02,FPTS,US,F,H,S,PHIS)
C CALCULATE FIELD DIFFRACTED FROM Q1 TO Q2, AND TO FPTS.
C
0232 M=2
0233 CALL VENODF(FPTS,SI,Q1,F3,E4,RS1,RS2,PE,LR1-2,T,H,S,PHIS,
C RETROD,EPD,FQ2,BETA,MJ,LR,LR)
C IF((J.M.E.1) GO TO 500
C
0234 CALL TRANS(1,02,FPTS,US,F,H,S,PHIS)
C ADDTED REFLECTED-DIFFRACTED-DIFFRACTED FIELD.
C
0235 ETSU=ERTU+ETROD
0236 ETSU=EPTHU+EPFD
0237 IF((CC.EQ.0) GO TO 500
0239 LR2=LR+2
0240 WRITE(6,200) LR,LR2,LR2
0240 200 FORMAT(2X,'REFLECTED FROM PLATE',14,2X,'TO EDGE',
C 14,2X,'AND TO EDGE',14)
0241 CALL VZMTHF(ETROD,EPD)
0242 CONTINUE
0243 RETURN
C DEBUG INIT(FPTS,SI,E1,E2,RS1,RS2,LP,LH,Q1,Q2,RET1,E3,E4,
C LK,ISTART,ISTD)
0244 END
SUBROUTINE VRRO(S1, LP, SIT, LN, RS11, RS21, DRV, PE, ETAU, EPSU, EPSU4)

IMPLICIT REAL*(1-H,N-Z)

C PURPOSE :
C TO CALCULATE REFLECTED-REFLECTED-DIFFRACTED FIELDS.

C PARAMETERS :
C
C *INPUTS***
C S1 : SOURCE IMAGE POINT W.R.T. PLATE LP
C SIT : SI IMAGE W.R.T. PLATE LN
C LP, LN : TWO REFLECTING PLATES.
C RS11, RS21 : TWO END POINTS OF TWICE IMAGE SOURCE ANTENNA
C DRV : PLATE DATA
C PE : SOURCE INOUT CURRENT
C
C *OUTPUTS***
C ETAU, EPSU : THETA AND PHI COMPLEX RAD FIELD COMPONENTS.

COMMON /V/ UP1AT(90,3), UN(7), US(3), UPLATE
COMMON /G/ FPTS(11), AN(11)
COMMON /G/ IC3N
COMMON /G/ ETR0, EPS0, ETAU, EPSU, EPSU4, PE

DIMENSION O1(11), 02(11), 03(11), 04(11), E1(3), E2(3), SI(3), SIT(3),

CDRV(90,3), ELN(3), ELP(3), CO1(3), CO2(3), RS11(3), RS21(3), DNX(50))

ETSU4(0,0,1)
EPSU(40,0,1)

NEXT=LY+1

1 IF(NEXT.GT.ULATE) RETURN

010 DT=100 LA=NEXT, UPLATE
0110 ETR0=00,0,1

0140 EPR90=00,0,1

0150 IF(LA.LE.0,0,1) GO TO 100

0160 LEDGE1=LA+2

0170 LEDGE2=LAGE2=LA+2-1

C SETUP EDGES INFORMATIONS THAT ARE RELONG TO PLATE LN
C AND ITS UNIT NORMAL VECTOR.

0180 DO 101 J2=1,3
0190 E1(J2)=ORVLEDGE1,J2
0200 E2(J2)=ORVLEDGE2,J2
0210 UN(J2)=UPLATE(LN,J2)
0220 ELN(J2)=ORVILN(J2)
0230 ELP(J2)=ORVILP(J2)

101 CONTINUE

0240 CALL VVHETE(SIT, FPTS, E1, E2, RP, ETAU)

C DOES -AP- LOCATED IN THE UPPER HALF-PLANE OF A PLATE LN ?
C
0250 CALL IMAGE(RP, ELN, LN, 01)
0260 CALL VECTOR(6, RP, 01, 02)
0270 CALL VECTOR(4, LN, 02, 03)
0280 IF(D03(1,1),0,1) GO TO 100

C CHECK REFLECTION POINT IS WITHIN THE FIRST REFLECTED PLATE LP ?

C
0300 CALL VECTOR(1, AN, S1, 03)
0301 CALL VECTOR(1, AN, S1, 03)
CALL VXEXIST(ANT,DRV,LPP,1,QO1,03,IC)
0033 IF(LP.EQ.1 .AND .IC.EQ.1) RETURN
0034 IF(IC.EQ.-1) RETURN
C
C CHECK REFLECTION POINT IS WITHIN THE SECOND REFLECTING PLATE LN ?
C
0035 LN=LN
0036 CALL VECTOR(S1,LNP,PP,03)
0037 CALL VXEXIST(S1,DRV,LN,1,002,03,IC)
0038 IF(LVN.EQ.1 .AND .IC.EQ.1) GO TO 100
0039 IF(IC.EQ.-1) GO TO 100
C
C CHECK BLOCK BETWEEN FIRST REFLECTED POINT -QO1- TO ANTENNA (ANT) .
C
0040 IF(LP.LP,11) GO TO 117
0041 CALL VLOGI1(ANT,QO1,DRV,1,LP-1,LOK)
0042 IF(LOK.EQ.1) GO TO 100
C
C CHECK BLOCK BETWEEN PLATE LP,LN .
C
0043 117 IF(LN(LP-LP).GT.1) GO TO 114
0044 CALL VIERGH(QO1,002,LP,LN,DRV,LOK)
0045 IF(LOK.EQ.1) GO TO 100
0046 GO TO 104
0047 114 IF(LP.GT.LN) GO TO 110
0048 ISTART=LP+1
0049 ISTOP=LN-1
0050 GO TO 111
0051 110 ISTART=LN+1
0052 ISTOP=LP-1
0053 111 CALL VLOGI1(QO1,002,DRV,ISTART,ISTOP,LOK)
0054 IF(LOK.EQ.1) GO TO 100
C
C CHECK BLOCK BETWEEN DIFFRACTION POINT TO FIELD POINT .
C
0055 104 IF(LA+1.LT.NPLATE) GO TO 102
0056 CALL VLOGI1(RP,PTS,DRV,LA+1,NPLATE,LOK)
0057 IF(LOK.EQ.1) GO TO 100
0058 102 GO TO 112
0059 CALL VLOGI1(RP,PTS,DRV,LA-1,NPLATE,LOK)
0060 IF(LOK.EQ.1) GO TO 100
C
C CHECK BLOCK BETWEEN REFLECTED PLATE LN TO DIFFRACTION POINT (RP)
C
0061 103 IF(LA+1.LT.RP) GO TO 103
0062 IF(LA+1.RANGE) GO TO 112
0063 CALL VRHME(QO2,RP,LR,LA-1,DRV,LOK)
0064 IF(LOK.EQ.1) GO TO 100
0065 GO TO 115
0066 112 CALL VLOGI1(QO2,RP,DRV,LA+1,LA-2,LOK)
0067 IF(LOK.EQ.1) GO TO 100
0068 GO TO 115
0069 103 IF(LA+1.LT.RP) GO TO 116
0070 CALL VLOGI1(RP,PTS,DRV,LA+1,NPLATE,LOK)
0071 IF(LOK.EQ.1) GO TO 100
0072 GO TO 115
0073 116 CALL VLOGI1(QO2,RP,DRV,LA+1,LA+1,NPLATE,LOK)
0074 IF(LOK.EQ.1) GO TO 100
FORTRAN IV PROGRAM

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0075 115 MJ=0
0076  CALL TRANS(PP,FPTS,N1,R,THS,PHIS)
0077  CALL VEMD(IFPTS,FPTS,S1,E2,RS11,RS21,RE,DOALLA-11),
0078    <THS,THS,R,ETRDE,ETRDE,DRV,RP,ETDA,MJ,KN,LIT)
0079  IF(*J,JNE,11) GOTO 100
0080  ETSUM+ETSUN+ETRRO
0081  FPSUN+EPSUN+EPROM
0082  IF(ICH,EQ,0) GOTO 100
0083  WRITE(6,330)LP,LN,LEDGE
0084  CALL VIMPH(ETRRO,EPROM)
0085  100 CONTINUE
0086  RETURN
0087  END

VOL18910
VOL18929
VOL18930
VOL18940
VOL18950
VOL18960
VOL18970
VOL18980
VOL18990
VOL19000
VOL19010
VOL19020
VOL19030
VOL19040
VOL19050
VOL19060
VOL19070
VOL19080
SUBROUTINE VR4(DRV, RS1, RS2, RS1, PA, ETSUM, EPSUM)
C
IMPLICIT REAL*4 (A-H, O-Z)
C
PURPOSE:
TO CALCULATE THE TRIPLE REFLECTED FIELD.
C
PARAMETERS:
***INPUT***
C
DRV : PLATE DATA
C
RS1, RS2 : TWO END POINTS OF SOURCE
PA : SOURCE INPUT CURRENT
C
***OUTPUT***
C
ETSUM, EPSUM : THEETA AND PHI COMPLEX RRR FIELD COMPONENTS.
C
REQUIRED SUBROUTINES :
VELG1, VECTOR, VEIXST, IMAGE, SOURCE, MERGE, VAMPHA
C
NOTE : RS2, RS1 -- REVERSE ORDER FOR PHASE REVERSAL.
C
C
COMMON /AI/ UPLAT(50,3), UM(3), US(3), NPLATE
COMMON /P/ PFS(3), ANT(3)
COMPLEX /A/ ETSUM, EPSUM, ETPRR, EPXRR, PA
DIMENSION RS1(3), RS2(3), SI(3), SII(3), SIII(3), ULP(3), ULQ(3), ULR(3),
C(3), EL(3), EL(3), DII(3), DIII(3), DLL(3), DLL(3), DLL(3), DLL(3),
C(3), CII(3), CIII(3), RS(3), RS(3), DS(3), DR(3), J)

C
C
INTEGRATIONS
C
C
DO 5 LP=1, NPLATE
DO 10 J1=1, 3
ULP(J1)=UPLAT(LP, J1)
60 FLQ(J2)=DPV(J2, J2)
CALL IMAGE(AIT, ELQ, ULP, SI)
CALL VECTOR(4, Q1, ULP, D2)
IF(FIIJ.LE.J) GO TO 5
CALL IMAGE(RS2, ELQ, ULP, RSII)
CALL IMAGE(RS2, ELQ, ULP, RSII)
DO 4 LO=LP, NPLATE
IF(ILQ.EQ.1) GO TO 4
DO 2 J1=1, 3
ULQ(J1)=UPLAT(LP, J1)
61 FLQ(J2)=DRV(LQ, J2)
CALL IMAGE(RS1, ELQ, ULP, SI)
CALL VECTOR(4, SI, SII)
CALL VECTOR(4, Q1, ULP, D2)
IF(DIIJ.LE.J) GO TO 4
CALL IMAGE(RSIII, ELQ, ULP, C1)
CALL IMAGE(RSIII, ELQ, ULP, C2)
DO 3 LO=LP, NPLATE
IF(IlQ.EQ.3) GO TO 3
ETPRR(3,J) = 0
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0014   ERRTR=10.0+1
0015   NN a2 J2=1.0+1
0014   UL4(J2)=UPRT(L9,J2)
0017   52   ELR(J2)=NPV(L9,J2)
0019   CALL IMAGE(SII,ELR,L9,SIII)
0019   CALL VECTOR(A,SII,SIII,01)
0020   CALL VECTOR(4.0,UL4,02)
0021   IF(I2(I).LE.0.0) GO TO 3
0022   CALL IMAGE(C3,ELR,UL4,SIIII)
0023   CALL IMAGE(C2,ELR,UL4,SIII)

C CHECK THE RAY HITS 3 PLATES.
0024   CALL VECTOR(1,SIII,FPTS,01)
0025   LRR=LL
0026   CALL VEXIST(SIII,DRV,LR1,LR1,01,IC)
0027   IF(IEC.EQ.1.0) GO TO 3
0028   CALL VECTOR(3,SIII,LR1,01)
0029   LQQ=LL
0030   CALL VEXIST(SIII,DRV,LQQ,1.0,02,IC)
0031   IF(IEC.EQ.1.0) GO TO 3
0032   CALL VECTOR(3,SIII,LR2,02)
0033   LL=LP
0034   CALL VEXIST(SIII,DRV,LP1,1.0,03,1C)
0035   IF(IEC.EQ.1.0) GO TO 3
0036   IF(IEC.EQ.1.0) GO TO 3

C CHECK BLOCKAGE FROM ANTENNA TO FIRST REFLECTED POINT QLP.
0039   IF(LP.EQ.1.0) GO TO 50
0040   CALL VLOGIC(ANT,OQP,DRV,1.0,LP,1.0,0K)
0041   IF(LOC.EQ.1) WRITE(6,211)
0042   IF(LOC.EQ.1) GO TO 3
0043   IF(LOC.EQ.1) WRITE(6,201)
0044   CALL VLOGIC(ANT,OQP,DRV,LP1,0PLATE,0K)
0045   IF(LOC.EQ.1) GO TO 3

C CHECK BLOCKAGE FROM THE THIRD REFLECTED POINT QLR TO FPTS.
0046   50   IF(LOC.EQ.1) WRITE(6,201)
0047   CALL VLOGIC(LRR,FPTS,DRV,LR1,0PLATE,0K)
0048   IF(LOC.EQ.1) WRITE(6,201)
0049   IF(LOC.EQ.1) GO TO 3
0050   IF(LOC.EQ.1) GO TO 31
0051   IF(LOC.EQ.1) GO TO 31
0052   IF(LOC.EQ.1) GO TO 31

C CHECK BLOCKAGE FROM QLP TO QLG.

0054   51   IF(LOC.EQ.1) WRITE(6,203)
0055   CALL VLOGIC(LQP,QLP,DRV,LR,0K)
0056   IF(LOC.EQ.1) GO TO 3
0057   IF(LOC.EQ.1) GO TO 3
0058   GO TO 55
0059   IF(LOC.EQ.1) GO TO 55
0060   CALL VLOGIC(LQP,QLP,DRV,LP1,0K)
0061   IF(LOC.EQ.1) WRITE(6,203)
FORTRAN IV 3 LEVEL 21 VRRR DATE = AL074 12/45/93
0040 IF(LMK,FL,1) GO TO 3
0041 GO TO 44
0042 53 CALL VLOGIII(LO,OLP,ORV,LO+1,LP-1,LOK)
0043 IF(LMK,EC,1) WRITE(A,203)
0044 IF(LMK,EC,1) GO TO 3
C CHECK 3LACKAGE FROM -QLQ- TO -QLR-
0045 IF(LMK,FLR-LR,FLR,1) GO TO 56
0046 CALL WERFCL(LOCQLR,LO,LO,LP,ORV,LOK)
0047 IF(LMK,EC,1) GO TO 3
0048 GO TO 54
0049 56 IF(LMK,FLR-LR) GO TO 57
0050 CALL VLOGIII(LO,OLR,OPV,LO+1,LR-1,LOK)
0051 IF(LMK,EC,1) WRITE(6,204)
0052 IF(LMK,FL,1) GO TO 3
0053 GO TO 54
0054 57 CALL VLOGIII(OLR,OLP,ORV,LR+1,LO-1,LOK)
0055 IF(LMK,EC,1) WRITE(6,204)
0056 IF(LMK,EC,1) GO TO 3
C THE TRIPLE REFLECTED RAY PASS ALL THE LOGIC TEST.
C C CALCULATE ELECTRIC FIELD.
0097 53 CALL TRANSII,III,OPTS,US,US,TETA,PHI)
0098 CALL SOURCEII,III,III,III,III,TETA,PHI,PA,PA,ETARR,ETARR)
0099 ETARR=ETARR+ETARR
0100 PSUM=PSUM+PSUM
0101 IF(PSUM,.EQ.O) GO TO 3
0102 WRITE(A,2701P,QLRLO
0103 CALL VS4(PH1(ETARR,ETARR)
0104 3 CONTINUE
0105 4 CONTINUE
0106 5 CONTINUE
0107 200 FORMAT(X,TRIPLE REFLECTED FIELD FROM PLATE 1,15,2X,TO PLATE 1,
0108 15,2X,TO PLATE 1)
0109 201 FORMAT(X,NEED HIGHER MODE FIELD -NR0- 1)
0110 202 FORMAT(X,NEED HIGHER MODE FIELD -RR0- 1)
0111 203 FORMAT(X,NEED HIGHER MODE FIELD -RRR- 1)
0112 204 FORMAT(X,NEED HIGHER MODE FIELD -RRRD- 1)
0113 RETURN
0114 EVD
SUBROUTINE VHELP(P1,P2,L1,L2,DV,OK)
IMPLICIT REAL*8(A-H,O-Z)
C
PURPOSE:
C TO DETERMINE WHETHER THE EDGE FORMED BY MERGING PLATES
C BLOCKS THE RAY.
C
PARAMETERS:
C *******INPUTS*****
C
P1: POINT ON PLATE L1
C P2: POINT ON PLATE L2
C L1, L2: REFLECTING PLATES
C DV: PLATE DATA
C
*******OUTPUTS*****
C
OK: Coded for blockage.
C
OK = -1 (not block); = 1 (block).
C
DIMENSION REF(1),O1(3),O2(3),P1(1),P2(1),Q(1),DV(50,3),
EDGE1(1),EDGE2(1)

0004 REF(1) = 0.
0005 REF(2) = -1.
0006 REF(3) = -1.
0007 CALL VECTOR(1,P1,P2,DV)
0008 OK = -1
0009 IF(IL1.LT.L2) GO TO 100
0010 ON 2 J2 = 1,3
0011 EDGE1(J2) = DV(IL2*2+2,J2)
0012 1 EDGE1(J2) = DV(IL2*2+1,J2)
0013 100 DO 2 J2 = 1,3
0014 100 2 J2 = 1,3
0015 EDGE1(J2) = DV(IL2*2+1,J2)
0016 2 EDGE1(J2) = DV(IL2*2+1,J2)
0017 50 CALL INTSEG(EDGE1,REF,P1,O1,Q,IC)
0018 IF(IC.EQ.1) RETURN
0019 IF(O1(3).EQ.EDGE1(1)) OK = 1
0020 RETURN
0021 EV0
SUBROUTINE VETFIE(ENGE,ORV,OMA,ORR,REP,THS,PHIS,R,ETD,FPO)

IMPLICIT REAL*(A-H,O-Z)

C PURPOSE: TO CALCULATE THE TOTAL DIFFRACTED FIELD

C PARAMETERS:

C ***INPUTS***
C EDGE = ARRAY TO IDENTIFY DIFFRACTED EDGES
C ORV = PLATE DATA
C ORS = ARRAY CONTAINS ANTENNA TWO END AND CENTER POINTS
C DPE = SOURCE INPUT CURRENT
C THS, PHIS, R: THETA AND PHI ANGLES AND DISTANCE
C MEASURED FROM ANTENNA LOCATION TO OBSERVATION POINT

C ***OUTPUTS***
C ETDR, FPO: THETA AND PHI COMPLEX FIELD COMPONENTS

C REQUIRED SUBROUTINES:
C VEXIS, VLOGI, VLOGII, VDIF.

C COMMON /V: VPLATE(50,3),VUN(3),VUS(3),VPLATE
C COMMON /SC/ JDI, JDJ, JDR, JDD, JDRR, JDRR
C COMMON /FG/ FPOT(31),FNT(31)
C COMMON /SG/ ICON
C COMMON /REP/ JRPR(50,31),JREPR(50,31),JREPP, NW
C COMPLEX*4 ETD, EPOR, SUMT, SUMP, ETDR, EPOR, DPE(501), ETOS, EPOR, ETORD, VD1(310)
C EPOH, ETORD, EPOR, EPPO
C DIMENSION UH(3), UTC(3), ORS(50,3), WRH(50,3), DRT(3), ORS(31),
C DCR(31), E2CR(31), E3CR(31), E4CR(31), E5CR(31), E6CR(31), E7CR(31), E8CR(31), E9CR(31)
C CRH(31), CRH(31), CRH(31), CRH(31), CRH(31), CRH(31), CRH(31), CRH(31), CRH(31)
C C INITIALIZATIONS

C C SETUP ANTENNA LOCATION
C C THIS IS THE MAIN LOOP FOR DIFFRACTED FIELD AND

0010 SUMT=(0.0,0.0)
0011 SUMT=(0.0,0.0)
0012 ETDR=(0.0,0.0)
0013 ETDR=(0.0,0.0)
0014 ETDR=(0.0,0.0)
0015 ETDR=(0.0,0.0)
0016 ETDR=(0.0,0.0)
0017 ETDR=(0.0,0.0)
0018 ETDR=(0.0,0.0)
0019 ETDR=(0.0,0.0)
0020 ETDR=(0.0,0.0)
0021 ETDR=(0.0,0.0)
0022 ETDR=(0.0,0.0)
0023 ETDR=(0.0,0.0)
0024 DD J=1,3
0025 RS1(J)=R5S(1,J)
0026 RS2(J)=R5S(1,J+1)
0027 302 CONTINUE

229
C ALSO COMBINATIONS OF DIFFRACTED-REFLECTED FIELD.
C
0028 DD 300 LP=2,NPLATE
C
0029 EDGE (K2) AND PLATE (LP) RELATION.
C
0030 IF(EDGE(LP-1).EQ.0) GO TO 303
0031 DD 301 J2=1,3
0032 RM(J2)=R/OV(K2,J2)
0033 301 RM(J2)=R/OV(K2-1,J2)
C
C LIM1 DEFINED A WEDGE AND AN EDGE BETWEEN THOSE
C TWO WERE THE ONE THAT DEFINED A DIFFRACTED POINT.
C
0034 LIM1=LP-1
0035 IF(J2NE.F0.11) GO TO 306
0036 CALL VBA F(RMT,FRTS,PM,LM,1,8,MA,T,BETA)
0037 CALL TRANS(L,OPT,PRTS,US,RT,THS,OPT
0038 MJ=1
0039 ITEMP=0
C
C CALCULATED SINGLE-DIFFRACTED FIELD
C (BLOCKAGE TESTS ARE PERFORMED IN SUBROUTINE VENDIF).
C
0040 CALL VENDIF(PMT,FRTS,AMT,PM,LM,1,8,MA,T,BETA,
0041 LM,1,8,MA,T,BETA,MJ,ITEMP,LP)
C
C ADDED DIFFRACTED FIELD.
C
0042 SUMT&=SUMT+EDOT
0043 SUMP&=SUMP+EDOT
0044 IF(ICON.LE.0) GO TO 306
0045 WRITE(4,2001)X2
0046 CALL VAMPHA(EDOT,EPOT)
C
C THIS IS THE MAIN LOOP FOR DIFFRACTED-REFLECTED FIELD.
C IF ONE WANTS TO HAVE BACK-WARD OR FIELD,
C ONE MUST CHANGE LJ=LP,NPLATE TO LJ1=1,NPLATE.
C
0047 306 IST=LP+1
0048 IF(IST.GT.NPLATE) GO TO 300
0049 DO 304 LJ=IST,NPLATE
0050 DO 305 J=1,3
0051 U1(J2)=PIPLATE(LJ,J2)
0052 U2(J2)=PIPLATE(LJ*2,J2)
0053 305 CONTINUE

C THE ARRAY OF JREDI(*,*) CONTAINS THE LOGIC INFORMATION
C WHETHER THE DIFFRACTED RAY IS POSSIBLE.
C JREDI(*,*) = 0 NO MEANING
C = 1 MAY BE EXISTED
C = -1 NOT POSSIBLE TO EXIST.
C
0054 IF(JREDI(LP-1,NW).EQ.-1) GO TO 304
C
C IMAGE FIELD POINT TO THE REF-PLATE (LJ) AND CHECK WHETHER
C THAT POINT LIES BELOW A PLANE CONTAINS PLATE LJ.
C
0055 CALL IMAGE(FPTS,U2,U1,UR) VOI22200
0056 CALL VECTOR(J,FPTS,UR,C1) VOI22210
0057 CALL VECTOR(J,C1,U1,C) VOI22220
0058 IF(C1.LT.EQ.0.) GO TO 316 VOI22230
0059 CALL VFRAMANT.UR,VR,RL,OPT,RETUD) VOI22240
0060 CALL TRANS1(OPT,UR,US,R,THS,PHI3) VOI22250
C CHECK IMAGING OF A DIFFRACTION POINT (OPT) LIES BELOW THE PLANE LJ. VOI22260
C
0061 CALL IMAGE(OPT,U2,U1,NO) VOI22270
0062 CALL VECTOR(J,OPT,DO,C1) VOI22280
0063 CALL VECTOR(J,C1,U1,C) VOI22290
0064 IF(C1.LT.EQ.0.) GO TO 304 VOI22300
0065 CALL VECTOR(J,OPT,UR,C1) VOI22310
C CHECK THE REFLECTED POINT (C) WITHIN THE REFLECTED PLATE LJ.
C
0066 J22=J1 VOI22320
0067 CALL VFX(ISTOPT,DVR,J22,1,C1,IC) VOI22330
0068 IF(1C1.EQ.0.) WRITE(6,210) LJ,IC,(C(J22),J22=1,3) VOI22340
0069 210 F̂ORWARD REF PLATE*, [15,1, CUT ??,[5, 1 INTERSECT AT*,3020,10] VOI22350
0070 IF(J22.EQ.0.) GO TO 316 VOI22360
0071 IF(IC.EQ.-1) GO TO 316 VOI22370
C CHECK BLOCKAGE BETWEEN OPT TO C.
C
0072 IF(J22.EQ.0.) GO TO 316 VOI22380
0073 IF(1C1.EQ.0.) GO TO 310 VOI22390
0074 CALL VHEP(DOPT,C,LP,LJ,DRL,LPK) VOI22400
0075 IF(1C1.EQ.0.) GO TO 316 VOI22410
0076 GO TO 304 VOI22420
0077 310 CALL VLOG11(DOPT,C,DRV,LP+1,LJ+1,LPK) VOI22430
0078 IF(1C1.EQ.0.) GO TO 316 VOI22440
0079 338 ISTART=IJ+1 VOI22450
0080 IF(1C1.EQ.0.) GO TO 313 VOI22460
C CHECK BLOCKAGE FROM C TO FIELD POINT FPTS.
C
0081 CALL VLOG11(C,FPTS,DRV,ISTART,NPLATE,LPK) VOI22470
0082 IF(1C1.EQ.0.) GO TO 314 VOI22480
0083 313 ISTOP=LP+2 VOI22490
0084 IF(1C1.EQ.0.) GO TO 314 VOI22500
C CHECK BLOCKAGE FROM ANTENNA TO DIFFRACTION POINT (OPT).
C
0085 CALL VLOG11(OPT,ANT,DRV,1,ISTOP,LPK) VOI22510
0086 IF(1C1.EQ.0.) GO TO 316 VOI22520
C CHECK BLOCKAGE FROM ANTENNA TO DIFFRACTION POINT (OPT).
C
0087 314 MJ=3 VOI22530
0088 CALL VENDIFUR,OPT,ANT,PM,RY,RS2,PS1,OPT1,LPW1,THS,PHI3, VOI22540
0089 IF(J22.EQ.0.) GO TO 316 VOI22550
C ADDED DIFFRACTED-REFLECTED FIELD.
C
0090 SUMT=SUMT+ETOR VOI22560
0091 SUMP=SUMP+EPDR VOI22570
231
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0092 IF(ERRC,LE,0) GO TO 116
0093 WRITE(*,2339) K2,LJ
0094 CALL VMPH(FLTPN,EP0R)
0095 116 IF(NPLATE.LT.5) GO TO 304
C CALCULATE ORR FIELDS BY ROUTINE VORR.
0096 IF(JDRR,EE.1) GO TO 317
0097 CALL VORR(ORR,R1,RS2,ORP1,ORP2,LP,LJ,ETORR,EP0R)
0098 SUM=SUM+ETORR
0099 SUM=SUM+EP0R
0100 317 JSTART=LJ+2
0101 IF(JSTART.GT.NPLATE,OR.JDRR,EE.1) GO TO 304
C THIS IS THE MAIN LOOP FOR DIFFRACTED-REFLECTED-DIFFRACTED
C FIELD CALCULATION. NO INTENTION TO HAVE BACKWARD FIELD OR
C HANDLE TILTED PLATES.
0102 DO 500 L2=JSTART,NPLATE
0103 IF(JED1(LP-1,NW)) 500,506,506
0104 506 L1=L1-1
0105 LI=L1+L2
0106 LR2=LI+2
0107 LR3=LR2-1
C SET-UP SECOND DIFFRACTED EDGE INFORMATION.
C
0108 DO 501 J2=1,3
0109 F3(J2)=DRE(L2,J2)
0110 501 E4(J2)=DRER(L3,J2)
0111 CALL I4GEMT(2,UL,UL1,1)
0112 CALL I4GEMT(4,UL1,UL2,1)
C CHECK SECOND DIFFRACTED EDGE MUST LOCATE ABOVE THE
C REFLECTING PLATE LJ.
C
0113 CALL VECTOR(6,3,EL1,C1)
0114 CALL VECTOR(4,1,UL1,C)
0115 IF(II(C1),LE,0.) GO TO 500
C FIND DIFFRACTION POINTS (DP1,DP2).
C
0116 CALL V2DIFANT(HR,RM1,EL1,E2,DP1,DP2,BETA)
C CHECK THE REFLECTING POINT WHICH MUST BE LOCATED WITH IN THE
C REFLECTING PLATE LJ.
C
0117 CALL VECTOR(3,DP1,DP2,ND)
0118 LJ=LJ-LJ
0119 CALL VEXIST(DP1,DP2,LJ,1,ND,IC)
0120 IF(LJ.EQ.1) GO TO 500
0121 IF(LJ.EQ.1) GO TO 500
0122 CALL IMAGE(DP2,UL2,UL1,C1)
C CHECK BLOCKAGE FROM FIRST DIFFRACTED POINT TO REFLECTING PLATE LJ.
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VETOIF

LI=LP+1
0124
0125 IF(LI.GT.NPLATE) GO TO 502
0126 CALL VLOGI1(CP1,DRV,LJ1,LJ1-1,LOK)
0127 IF(LJ1.EQ.1) GO TO 500
0128 502 IF(LJ1.EQ.14-LJ1-1) GO TO 503

C
C CHECK BLOCKAGE FROM REFLECTING PLATE LJ TO SECOND
C DIFFRACTION POINT.

C
LJ1=LJ1+1
0129 IF(LJ1.GT.NPLATE) GO TO 503
0130 CALL VLOGI1(CP1,DRV,LJ1,LJ1-1,LOK)
0131 IF(LJ1.EQ.1) GO TO 500
0132 IF(LJ1.EQ.14-LJ1-1) GO TO 503

C
C CHECK BLOCKAGE FROM SECOND DIFFRACTION POINT TO FIELD POINT.

C
ISTART=LI+1
0133 503 IF(ISTART.GT.NPLATE) GO TO 504
0134 CALL VLOGI1(CP1,FPT5,DRV,ISTART,NPLATE,LOK)
0135 IF(LOK.EQ.1) GO TO 500
0136 IF(ISTART.GE.7) GO TO 504
0137 CALL VLOGI1(CP1,FPT5,DRV,1,LR-2,LOK)
0138 IF(LOK.EQ.1) GO TO 500

C
C CHECK BLOCKAGE FROM THE FIRST DIFFRACTION POINT TO ANTENNA.

C
ISTOP=LP-2
0139 504 IF(ISTOP.LE.LR-1,WI,EQ.1) GO TO 505
0140 CALL VLOGI1(CP1,DRV,1,ISTOP,LOK)
0141 IF(LOK.EQ.1) GO TO 500
0142 IF(LOK.EQ.14-LR-1) GO TO 505

C
M=0
0143 505 IF(M.GE.2) GO TO 600
0144

C
CALCULATE THE ORG FILEDS.

C
CALL TRANS1(0P1,0P2,US1,TH1,PH1)
0145
0146 CALL VENDIF(0P1,0P2,AN1,MR1,RS1,0P11,DWA1,LP-1,TH1,PH1)
0147 IF(M.GE.11) GO TO 500
0148 CALL TRANS1(C1,FPT5,US1,TH1,PH1)
0149 CALL IMAG11(0P1,0P2,UL1,UL2)
0150 CALL IMAG11(0P1,0P2,UL1,UL2)
0151 M=M+2
0152 CALL VENDIF(FPT5,C,0D1,E1,E4,PS1,PS2,0P11,DWA1,LR-1,TH1,PH1)
0153 IF(M.GE.11) GO TO 500
0154 SUM=SUM+40RD
0155 SUM=SUM+40RD
0156 IF(M.GE.11) GO TO 500
0157 CALL VMAG11(0P1,0P2,UL1,UL2)
0158 CALL VENDIF(0P1,0P2,UL1,UL2)
0159 500 CONTINUE
0160 304 CONTINUE
0161 312 IF(NPLATE.LT.4) GO TO 300

C
C THIS IS THE MAIN LOOP FOR DUALY-DIFFRACTED FIELD.

C
NST=LP+2
0162
0163 IF(NST.GT.NPLATE) GO TO 300
C SET-UP EDGES INFORMATIONS.
C
0169  LP2=LP#2
0170  LP2=LP#2
0171  DO 401 J=1,3
0172  EQ(J3)=DRVILP2,J2)
0173  EQ(J2)=DRVILP2-1,J2)
0174  EQ(J2)=DRVILP2,J2)
0175  EQ(J2)=DRVILP2-1,J2)
0176  431 CONTINUE
C
C FIND DIFFRACTING POINTS ON BOTH EDGES DEFINED BY CORNERS
C (E1E2 : E3E4).
C
0177  CALL VOFTANT,FPTS,E1,E2,E3,E4,DP1,DP2,RETA)
0178  IF(LP#-2)
0179  IF(LP#LT.1,CRT,RETH(LP#-1,NW),EQ.1) GO TO 402
C
C CHECK BLOCKAGE FROM PLATE ONE TO LPP.
C
0180  CALL VLOGILLANT,DP1,DRV1,LPP,LOK)
0181  IF(LOK.EQ.1) GO TO 400
C
C CHECK BLOCKAGE BETWEEN THE TWO EDGES.
C
0182  402 IF(ERHILP#-LP),GT.2) GO TO 404
0183  CALL VLOGSH(DDP1,J2,LP#-1,J2,DRV,LOK)
0184  IF(LOK.EQ.1) GO TO 400
0185  GO TO 403
0186  404 CALL VLOGH1(DP1,DP2,DRV,LP#-1,J4-2,L2)
0187  IF(LOK.EQ.1) GO TO 400
0188  403 ISTRT=LP#-1.
0189  IF(ISTRT,T,NPLATE) GO TO 406
0190  IF(FIRST+T,LOK) GO TO 407
C
C CHECK BLOCKAGE FROM THE SECOND DIFFRACTED EDGE TO THE
C LAST PLATE (INPLATE).
C
0191  406 CALL VLOGH2(DP2,FPTS,DRV,ISTART,NPLATE,LOK)
0192  IF(LOK.EQ.1) GO TO 605
0193  406 YJ=0
0194  CALL TRANS1,DP1,DP2,US,R,THS,PHIS)
C
C CALCULATE DUBLY-DIFFRACTED FIELD.
C
0195  CALL VOFTANT(DP2,DP3,ANT,E1,E2,RSL,PS2,DPE1,L2,NDVILP#-1,THS,
C PHIS,P,ETDN,EPD3,DRV,DP1,RETA,MJ,LP,
C
0196  IF(494,N.E.1) GO TO 400
0197  CALL TRANS(1,DP2,FPTS,US,R,THS,PHIS)
0198  M#2
0199  CALL VOFTANT(FPTS,ANT,DP1,E3,E4,RSL,PS2,DPE1,L2,NDVILP#-1,THS,
C PHIS,P,ETDN,EPD3,DRV,DP2,RETA,MJ,LP,L4)
C
0200  GO TO 400
0200 IF(I(1),IF(1,1)) GO TO 400
0201 C ADDED DOURLY-DIFFRACTED FIELD.
0202 C SUM=SUM-ET00
0203 C I.F(INN.LE.9) GO TO 407
0204 C WRITE(1,234) LP2,LM2
0205 C CALL VANGRA(ET00,EP00)
0206 C CONTINUE
0207 605 IF(TEXT,LT.5) GO TO 400
0208 607 CONTINUE
0209 C THIS IS THE MAIN LOOP FOR DIFFRACTED-DIFFRACTED-REFLECTED
C (OR) FIELD.
C NOTE: SEVERAL BLOCKAGE TESTS ARE PERFORMED IN DO RAY TEST.
0210 C ON 500 LS=ST,TEXT
0211 C IF(JP2),JLIP-1,NC1,EQ.-1) GO TO 600
0212 C LS2,LS2=Z2+2
0213 C IF(1,1,J2=1,3
0214 C IF(1,1,J2=1,3
0215 C U1(J2)=ULAT(IS,J2)
0216 C U2(J2)=ULAT(IS2,J2)
0217 601 U2(J2)=AVR(ULS2,J2)
0218 C FIELD POINT (FPTS) AND SECOND DIFFRACTING POINT (DP2) MUST
C LIE ON THE LOWE HALF PLANE WHICH INCLUDES PLATE LS.
0219 C CALL IMAGE(FPTS,ULS2,ULS1,UR)
0220 C CALL VECTOR(4,CI,ULS2,ULS1,UR)
0221 C IF(111,LE.9.1) GO TO 600
0222 C CALL V31(IFANT,UR,E1,F2,E3,E4,OP2,DP2,BETA)
0223 C CALL V1(IF2,DP2,DP2,ULS1,CI)
0224 C CALL VECTOR(4,CI,ULS2,ULS1,UR)
0225 C IF(111,LE.9.1) GO TO 600
0226 C CALL VECTOR(4,CI,ULS2,ULS1,UR)
0227 C THE REFLECTED POINT (C) MUST LIE ON THE REFLECTING
C PLATE LS.
0228 C J22=LS
0229 C CALL VEXIST(OP2,AVR,J22,1,CI,IC)
0230 C IF(J22.EQ.1,SM1,IC,EQ.1) GO TO 600
0231 C CHECK BLOCKAGE FROM OP2 TO REFLECTING POINT C.
0232 C IF(1,1,LE.11) GO TO 602
0233 C ISTART=ST
0234 C STOP=LS-1
0235 C CHECK BLOCKAGE FROM REFLECTING POINT TO FIELD POINT.
0236 602 ISTART=LS+1
IF (START .GT. NPLATE) GO TO 633
CALL VLOGIC(FPTS,DRV,START,NPLATE,LK)
IF (LLOG.EQ.1) GO TO 600
IF (LS.EQ.1) GO TO 603
CALL VLOGIC(FPTS,DRV,LS-1,LK)
IF (LLOG.EQ.1) GO TO 600
CALL TRANS1(DP1,UR,US,R,THS,PHIS)
C CALCULATE DOR FIELD.
C
VJ = 0
CALL TRANS1(DP1,DP2,US,R,THS,PHIS)
CALL VENIF(LP,DP2,MT,EL,E2,R2,RS1,DP1),WALLP-1,THS,
C PHIS,ET,ET0N,ERROR,REV,DP1,BETA,MJ,LP,L01
IF (VJ,N.EQ.1) GO TO 600
VJ = 2
CALL VENIF(U2,ANT,MP,EL,E2,R2,DP1),WALLU-1,THS,PHIS,
C ET,ET0N,ERROR,REV,DP1,BETA,MJ,LS,L41
IF (VJ,N.EQ.1) GO TO 600
C ADDED DOR FIELD.
C
SUFFIX = SUM*ETOR
SYM = SUM*EDOR
IF (CONV.L.E.0) GO TO 600
WRITE(*,211) LP2,LP2,LS
CALL VXPHAETOR(ETOR)
C
IF (VJ,N.EQ.1) GO TO 600
C
CONTINUE
C
303 CONTINUE
C
ETOR = SUM
ETOR = SYM
IF (CONV.L.E.0) GO TO 307
WRITE(*,207)
C
END
C
C
RETURN
END
SUBROUTINE VOOR(DRV,RS1,RS2,PE,LW,LJ,ETSUM,EPSUM)

IMPLICIT REAL*8(A-H,O-Z)

PURPOSE:

TO CALCULATE DIFFRACTED-REFLECTED-REFLECTED FIELDS.

PARAMETERS:

***INPUTS***

DRV : PLATE DATA
RS1,RS2 : SOURCE END POINTS.
PE : SOURCE INPUT CURRENT
LW : WEDGE ANGLE
LJ : REFLECTING PLATES. ONE IS REFLECTED PLATE
THE OTHER IS THE PLATE TO DEFINE EDGE.

***OUTPUTS***

ETSUM, EPSUM : THETA AND PHI OR COMPLEX FIELD COMPONENTS.

FPTS(U,FPTS(3),3),NT(3)

COMPLEX FILED INITIALIZATIONS.

FPTSU=(0.,0.)
EPSUM=(0.,0.)
NEXT=LJ+1

IF(NEXT.LT.NPLATE) RETURN

SETUP ARRAYS.

LP2=LP2
DN 60 J2=1.1
ULPJ2=UPLAT(IL,J2)
ELP(J2)=DRV(LP2,J2)
ELP(J2)=DRV(LP2,J2)

CONTINUE

DO 60 LT=LANEXT,NPLATE

FPTS(3)=10.,0.,1
FPDPN=10.,0.,1
DO 1 J2=1,3

ULT(J2)=UPLAT(ILT,J2)
ELT(J2)=DRV(LT*2,J2)

CONTINUE

CALL IMAGE(FPTS,ELT,ULT,FI)

CHECK IMAGE POINT (FPTS) LIES BELOW THE REFLECTED PLATE LT.

CALL VECTOR(5,FPTS,FI,FI)

CALL VECTOR(4,0,ULT,ULT)

IF(TYP(1).EQ.0) GO TO 55
C CHECK IMAGING POINT (FI1) LIES BELOW THE REFLECTED PLATE LJ.
C
0031 CALL IMAGE(FI,FLJ,ULJ,FI1)
C
0032 CALL VECTOR(6,FI,FI1,01)
0033 CALL VECTOR(4,01,ULJ,02)
0034 IF(D02(1),LE,0.0) GO TO 55
0035 CALL VBETA(INT,FI1,ELP,ELP1,OPT,RETAO)
C CHECK THE DIFFRACTION POINT LIES ON THE UPPER HALF-PLANE
C OF PLATE LJ.
C
0036 CALL IMAGE(OPT,FLJ,ULJ,01)
0037 CALL VECTOR(4,OPT,03,01)
0038 CALL VECTOR(4,01,ULJ,02)
0039 IF(02(1),LE,0.0) RETURN
C FIN) THE REFLECTION POINT ON PLATE LJ.
C
0040 CALL VECTOR(1,OPT,FI1,01)
0041 LJ=LJ
0042 CALL VEXIST(OPT,ORV,LIJ,01,RLJ,01,IC)
0043 IF(LIJ.EQ.1.AND.IC.EQ.1) GO TO 55
0044 IF(IC.EQ.-1) GO TO 55
C FIND THE REFLECTED POINT ON PLATE LT.
C
0045 CALL VECTOR(3,RLJ,FI1,01)
0046 LT=LT
0047 CALL VEXIST(RLJ,ORV,LT,01,PLT,01,IC)
0048 IF(LT1.EQ.1.AND.IC.EQ.1) GO TO 55
0049 IF(1.EQ.-1) GO TO 55
C CHECK BLOCKAGE FROM ANTENNA TO DIFFRACTION POINT (OPT).
C
0050 IF(ILP=2,LT,0.0) GO TO 300
0051 CALL VLOGL(LANT,OPT,ORV,1,LP-2,LOK)
0052 IF(LOK.EQ.1) GO TO 95
C CHECK BLOCKAGE FROM SECOND REFLECTING PLATE LT TO FIELD POINT.
C
0053 300 IF(LT1.EQ.1,GT,PLATE) GO TO 302
0054 CALL VLOGL(LLT,FPTS,ORV,LT,1,PLATE,LOK)
0055 IF(LOK.EQ.1) GO TO 95
C CHECK BLOCKAGE BETWEEN DIFFRACTION POINT (OPT) AND FIRST
C REFLECTING POINT (RLJ).
C
0056 302 IF(ILP=LP-LJ,NE,0.0) GO TO 305
0057 CALL V4ERGH(OPT,RLJ,LP,LJ,ORV,LOK)
0058 IF(LOK.EQ.1) GO TO 95
0059 GO TO 306
0060 305 CALL VLOGL(OPT,RLJ,ORV,LP+1,LJ-1,LOK)
0061 IF(LOK.EQ.1) GO TO 95
C CHECK BLOCKAGE BETWEEN FIRST REFLECTION POINT (PLJ) TO SECOND
C REFLECTION POINT (PLT).
C
0062 50A IF (FIRSTPL-LJT-NE.1) GO TO 308
0063 50A CALL VERGHR(PLJ,RLT,LT,DRY,LOK)
0064 50A IF(LOK.EQ.1) GO TO 55
0065 50A GO TO 310
0066 50A CALL VLOGHE(PLJ,RLT,DRY,LT+1,LT-1,LOK)
0067 50A IF(LOK.EQ.1) GO TO 55
C
C START TO CALCULATE NEW FIELD.
C
0068 310 MJ=0
0069 310 CALL TRANSIL,OPT,FII,USR,THS,PHIS)
0070 310 CALL VERDIFIF(FII,ANT,FLP,ELPI,PS1,PS2,PE,DRY,THS,PHIS)
0071 310 IF(PLJ-NE.1) GO TO 55
C ADD NEW FIELD TO THE PREVIOUS CONTRIBUTIONS.
C
0072 310 ETSum=ETSUM+ETorr
0073 310 EPSUM=EPSUM+EPorr
0074 310 IF (ICON.EQ.3) GO TO 55
0075 310 K2*PL*2
0076 310 WRITE(6,203)*K,PLJ,LT
0077 310 CALL VAMPHE(ETorr,EPorr)
0078 55 CONTINUE
0079 230 FORMAT(2X,'DIFFRACTED OFF EDGE',I4,2X,'TO PLATE',I4,
0080 2X,'REFLECTED FROM PLATE',I4)
0081 230 RETURN
0081 END
SUBROUTINE CSX(C,S,X)

IMPLICIT REAL*4(A-M,O-Z)

C PURPOSE
C COMPUTES THE FRENSNEL INTEGRALS.

C DESCRIPTION OF PARAMETERS
C C - THE RESULTANT OUTPUT OF G(X)
C S - THE RESULTANT OUTPUT OF S(X)
C X - ARGUMENT

C FROM SUBROUTINE CS(C,S,X) OF IMSI'S SCIENTIFIC SUBROUTINE PACKAGE

C DIMENSION X

C X=0.09

C IF (Z.LE.4.)

C IF (Z.LE.4.)

C C=DSQRT(Z)

C C=DSQRT(Z)

C S=(4.-Z)*(4.+Z)

C S=(4.-Z)*(4.+Z)

C C=C*(((((5.107885E-11*Z+5.244297E-9)*Z+5.451182E-7)*Z

C C=C*(((((5.107885E-11*Z+5.244297E-9)*Z+5.451182E-7)*Z

C +3.271344E-5)*Z+1.02544E-3)*Z+1.102544E-2)*Z+1.34995E-1)

C +3.271344E-5)*Z+1.02544E-3)*Z+1.102544E-2)*Z+1.34995E-1)

C S=S*(((6.677691E-10*Z+5.803159E-3)*Z+5.091141E-6)*Z

C S=S*(((6.677691E-10*Z+5.803159E-3)*Z+5.091141E-6)*Z

C C=RETURN

C C=RETURN

C IF (Z.GT.4.)

C IF (Z.GT.4.)

C D=DCOS(Z)

C D=DCOS(Z)

C S=0.5*(S-A)*B

C S=0.5*(S-A)*B

C RETURN

C RETURN

END
SUBROUTINE INTERSECTION(UN, CO, U, NO, IERR)

IMPLICIT REAL*8(A-H,O-Z)

C PURPOSE - TO COMPUTE THE INTERSECTION OF A PLANE (DETERMINED BY
C ONE POINT AND ITS NORMAL UNIT VECTOR) AND A LINE (DETERMINED BY
C A POINT AND ITS DIRECTION)

C PARAMETERS

**INPUTS**

1) : THREE ELEMENT ARRAY TO DETERMINE THE POINT ON THE PLANE
C UN : THREE ELEMENT ARRAY, NORMAL UNIT VECTOR OF THE PLANE
C NO : THREE ELEMENT ARRAY, POSITION OF A POINT ON THE LINE
C U : THREE ELEMENT ARRAY, UNIT VECTOR IN DIRECTION OF THE LINE

**OUTPUTS**

NO : THREE ELEMENT ARRAY, INTERSECTION POINT
C IERR = 1 IF THE LINE IS PARALLEL TO THE PLANE, OTHERWISE = 0

C REQUIRED SUBROUTINE : VECTOR

DIMENSION DX(1), DM(1), DU(1), UN(1), UX(1), UX(1), C(1)

121450
121460
121470
121480
121490
121500
121510
121520
121530
121540
121550
121560
121570
121580
121590
121600
121610
121620
121630
121640
121650
121660
121670
121680
121690
121700
121710
121720
121730
121740
121750
121760
121770
121780
121790
121800
121810
121820
121830
121840
121850
121860
121870
121880
121890
121900
121910
121920
121930
121940
121950
121960
121970
121980
121990
122000
122010
122020
122030
122040
122050
122060
122070
122080
122090
122100
122110
122120
122130
122140
122150
122160
122170
122180
122190
122200
122210
122220
122230
122240
122250
122260
122270
122280
122290
122300
122310
122320
122330
122340
122350
122360
122370
122380
122390
122400
122410
122420
122430
122440
122450
122460
122470
122480
122490
122500
122510
122520
122530
122540
122550
122560
122570
122580
122590
122600
122610
122620
122630
122640
122650
122660
122670
122680
122690
122700
122710
122720
122730
122740
122750
122760
122770
122780

C END
SUBROUTINE VEXIST(0S, X, Y, Z, U, V, IC)

IMPLICIT REAL*4(C-Z)

C
C PURPOSE - TO DETERMINE IF DIRECT RAY OR REFLECTED RAY EXISTS
C
C PARAMETERS
C
### INPUT ###
C
OS : THREE ELEMENT ARRAY , POSITION OF THE SOURCE
X : ARRAY TO DETERMINE THE POSITION OF VERTICES
Y : THE NUMBER OF A PLATE THAT INTERESTED
Z : OPTIONS : 1 FOR DIRECT RAY
C
### OUTPUT ###
C
IC : THREE ELEMENT ARRAY , UNIT VECTOR ALONG SCATTERED DIRECT.
C
C
C REQUIRED SUBROUTINES :
C
VECTORS, IMAG, INTRASC, TRIPLE
C
C
COMMON /F/ UPLAT(50, 31), UH31(3), NPLATE
COMMON /G/ FPLAT(31), NHT31
COMMON /H/ IC
DIMENSION OS(31, X(5), 31), UAT31, U(31), TEMP1(31), TEMP2(31), ORI31,
<ORI31>, C(31), C2(7)

IC = 1
IFLAG = 0
L = N/2.
I = I
I = I
IFLAG = 1
L = N/2 + 1
ON 10 J = 1, 3
ON 10 J = 1, 3
ON 10 J = 1, 3
OJ(J) = 0.
ON(J) = UPLAT(N, J)
ON(J) = UPLAT(N, J)
ON(10) = TEMP1(J)
ON(10) = TEMP1(J)
OJ(J) = TEMP(J)
OJ(J) = TEMP(J)
IF(IFLAG = 1) GO TO 70
C
C REVERSE THE UNIT NORMAL FOR EVERY EVEN PLATE NUMBER.
C
DO 71 J = 1, 3
71 UI(J) = -UI(J)
70 GO TO (20, 21, 22, 17)
C
C CHECK THE EXISTENCE OF THE RAY.
C
CALL INTRASC(TEMP, UN, OS, U, V, IC)
IF(IFLAG = 1) GO TO 72
C
C CODING FOR NOT BLOCK : N = 1, IC = 1.
C
C
IC = 1
N = 1
RETURN
72 DO 93 I = 1, 4
0330       11*14+1-1
0331       13*14-1  VOI28370
0332       IF(11,14,14) 11*14-3  VOI28390
0333       n = J*11  VOI28400
0334       TEMP2(J2) = X(11,J2) - X(13,J2)  VOI28410
0335       TEMP2(J2)*Q(J2) = Y(J,J2)  VOI28420

0336     40    CONTINUE  VOI28430
0337    CALL TIPLE(TEM1,TEM2,UA,0)  VOI28440
0338       IF(10,8,11) GO TO 40  VOI28450
0339       IC=-1  VOI28460
0340       N=0  VOI28470
0341       RETURN  VOI28480
0342     50    CONTINUE  VOI28490
0343       N=0  VOI28500
0344       RETURN  VOI28510

C       CHECK IF AN IMAGE LIE BELOW THE IMAGING PLANE.
C
0345     21    CALL VECTOR(A,OS,OR,Cl)  VOI28520
0346    CALL VECTOR(A,Cl,UN,C2)  VOI28530
0347       IF(C2(J1).GT.0.) GO TO 40  VOI28540

C       CODING FOR NO IMAGE.
C
0348       N=1  VOI28550
0349       IC=-1  VOI28560
0350       RETURN  VOI28570

0351     30    CALL VECTOR3(OR,PETS,C1)  VOI28580
0352    CALL INPSC(TEM1,UN,0R,Cl,00,1ER1)  VOI28590
0353       IF(1ER2.4E-1) GO TO 72  VOI28600

C       CODING OF THE REFLECTED RAY DOES NOT EXIST.
C
0354       IC=-1  VOI28610
0355       N=1  VOI28620
0356       RETURN  VOI28630

0357     22    CALL INPSC(TEM1,UA,0S,0Q,1ER1)  VOI28640
0358       IF(1ER1.4E-1) GO TO 72  VOI28650
0359       N=1  VOI28660
0360       RETURN  VOI28670
0361       END  VOI28680
FORTAN IV : LEVEL 21

3001  SOURCE(ION,RS1,RS2,TH,PHI,PE,R,ETH,EPHI)      V0128740
0002  IMPLICIT REAL*(A-H,O-Z)
C
C  PURPOSE:
C  TO COMPUTE THETA AND PHI COMPONENTS OF SHORT DIPOLE ANTENNA
C
C  PARAMETERS
C
***INPUT***
C  IOP CONTROL NUMBERS
C  IOP = 1: COMPUTE INCIDENT FIELD (E-T,E-P) AT DIFF. PNTS.
C  POINT: TE
C  IOP = 2: COMPUTE FAR FIELD OF EITHER SOURCE OR IMAGE
C  RS1=(X1,Y1,Z1) COORDINATES OF SOURCE (IMAGE) POINT P1
C  RS2=(X2,Y2,Z2) COORDINATES OF SOURCE (IMAGE) POINT P2
C  NOTE: THE SOURCE (IMAGE) VECTOR IS DIRECTED FROM P1 TO P2
C  PHI=POLAR ANGLE (DEGREES) AT XS,YS,ZS
C  PE= ELECTRIC DIPOLE MOMENT IN NL
C  PE=(1,0,0,0) FOR DELTA FUNCTION SOURCE
C  PE=(XS,YS,ZS)*NL FOR FINITE SOURCE
C  R = DISTANCE FROM SOURCE TO OBSERVATION POINT
C  IOP = 1 : R IS THE DISTANCE S* FROM SOURCE AT (X*,Y*,Z*)
C  TO DIFFRACTION POINT QE AT (X0,Y0,Z0)
C  IOP = 2 : R=(X,Y,Z) RADIAL DISTANCE (FAR FIELD)
C
***OUTPUT***
C  IOP = 1: THE SPHERICAL COMPONENT OF EITHER THE SOURCE OR THE IMAGE
C  AT THE FAR FIELD IN SCattered DIRECTION
C  IOP = 2 : THE SPHERICAL COMPONENT OF EITHER THE SOURCE OR THE IMAGE
C  AT THE FAR FIELD IN SCATTERED DIRECTION

0003  COMMON /2/ PI,PI180
0004  COMMON /3/ J,C,ES,PE,ETH,EPHI
0005  DIMENSION RS1(3),RS2(3),PS1(3),URS(3)
0016  G3(X,Y,Z,TH,PHI)=X*DSIN(TH)*DCOS(PHI)+Y*DSIN(TH)*DSIN(PHI)+Z*
0017  (DCOS(TH))
0018  PHI=(TH,PHI,CA,CA,CG)*COS(TH)*CA*COS(PHI)+CA*DSIN(TH))
0019  G3(CA,CA,PHI)=CA*COS(PHI)-CA*DSIN(TH)
C
C  COMPUTE CONSTANTS.
C
0019  J=(0.0,1.0)
0019  PI=3.14159265358979
0019  C0=DC4PLX(0.000.-6.0,0.0)
0020  IF(IOP.EQ.31) GO TO 1
C
C  CHANGE ANGLE TO RADIANS.
C
0013  T=TH*PI/180
0014  T2=PHI*PI/180
0015  IF(IOP.EQ.21) GO TO 100
C
C  COMPUTE UNIT VECTOR IN DIRECTION OF SOURCE.
C
0017  CALL VECTOR(3,RS1,RS2,URS)

0018  V0128120
0018  V0128130
0018  V0128140
0018  V0128150
0018  V0128160
0018  V0128170
0018  V0128180
0018  V0128190
0018  V0128200
0018  V0128210
0018  V0128220
0018  V0128230
0018  V0128240
0018  V0128250
0018  V0128260
0018  V0128270
0018  V0128280
0018  V0128290
0018  V0128300
0018  V0128310
0018  V0128320
0018  V0128330
0018  V0128340
0018  V0128350
FORTRAN IV: LEVEL 21

0010  Date = 01076  12/45/53

0010  ETH=R(T1,T2,URS1(1),URS2(1),URS3(1))ES
0019  EPRI=EPSURS1(1),URS2(1),T2)*ES
0020  CALL VARY(ETH,EPHI,T1,T2)
0021  RETURN

C
C COMPUTE FAR-FIELD FOR EITHER SOURCE OR IMAGE
C AND COMPUTE XS,YS,TS.

0022  100 DO 200 I=1,1
0023  RS1(I)=(RS1(I)+RS2(I))/2.0
0024  200 CONTINUE

C
C O IS THE PROJECTION ON TO UNIT VECTOR R
C
0025  DO=OS(RS1(I),URS2(I),T1(T1),T2)
0026  ES=CO*EPSURS1(I)*EPSURS2(I)*EPSURS3(I)
0027  CALL VARY(ETH,EPHI,T1,T2)
0028  RETURN

C
C UNIT VECTOR IN DIRECTION OF SOURCE.
C
0029  CALL VECTR(RS1(I),RS2(I),URS1(I),URS3(I))
0030  ETH=R(T1,T2,URS1(1),URS2(1),URS3(1))FS
0031  CALL VARY(ETH,EPHI,T1,T2)
0032  RETURN

C
C TH=PI/2.
0033  PHI=PI/2.
0034  URS1(1)=1.
0035  URS2(0).
0036  URS3(0).
0037  ES=EPHI/CO*EPSURS1(I),URS2(I),PHI)
0038  AN=REAL(ES)
0039  AN=IMAG(ES)
0040  R=ATAN2(AN,AN)
0041  R=ATAN2(R,P1)
0042  IF(R,LT.0) R=R
0043  ALP=RS1(3)-RS2(3)
0044  MLI=RS1(2)-RS2(2)
0045  ALPA=ATAN2(MLA,AL)
0046  RS2(1)=RS1(1)
0047  RS2(1)=RS1(2)*COS(ALPA)
0048  RS2(1)=RS1(3)*SIN(ALPA)
0049  RETURN
0050  END

245
SUBROUTINE V4PHAS(CT,CP)
       IMPLICIT REAL*(A-R,D-E,P),COMPLEX*16(C)

C PURPOSE:
C TO CONVERT COMPLEX QUANTITY INTO AMPLITUDE AND PHASE.
C
C PARAMETERS:
C
C ***INPUTS****
C
C CT,CP : TWO COMPLEX QUANTITIES
C
C ***OUTPUTS****
C AUTOMATICALLY WRITE ON OUTPUT FILE

COMMON /A/ PI,P1190
       AT=4DJAS(CT)
0325 PT=4ATGN2(DIJAG(CT),REAL(CT))/P1190
0326 AP=4ATGN2(DIJAS(CP),REAL(CP))/P1190
0327 WRITE(5,20111,A,PT,AP)
0329 201 FORMAT(6X,40.8)
0330 RETURN
0331 END
SUBROUTINE VARRY(CT,CE,TR,PR)
IMPLICIT COMPLEX(*),REAL(*)

C

PURPOSE:

TO COMPUTE THE ARRAY FACTOR AND MULTIPLY WITH

THE INDIVIDUAL PATTERN (PATTERN MULTIPLICATION)

PARAMETERS:

***INPUTS***

CE : COMPLEX ELECTRIC FIELD

TR, PR : THETA AND PHI ANGLES IN RADIANS

***OUTPUTS***

CT : ELECTRIC FIELD WITH ARRAY PATTERN

COMMON /AI/ CI4(5),CI5(5),CI6(5),DQ1,ST,W
COMMON /A/ PI,PHI

IF (DQ1.EQ.11) RETURN

CI1=CI4(W)
CI2=CI5(W)
CI3=CI6(W)
PSI1=OSIN(PR)
PSI2=PSI1

CI1=COMPLEX(0.00,PSI1)
CI3=COMPLEX(0.00,PSI3)

CE=CI2*CI1*OSIN(CI3)+CI3*OSIN(CI3)*
(COS(CI1(PHI,1)*OSIN(PR)))/COS(CI2(PHI,1))
CT=CT*OSIN(DQ2)*OSIN(TR)-COS(DQ2)*COS(TR)

RETURN

END
C TEST PARALLEL RAY.
C
0011 IF(LIC.EQ.1.AND.LC.EQ.1) GO TO 300
0012 IF(LIC.EQ.-1) GO TO 300
C TEST RAY CUT PLATE.
C
0013 CALL VECTOR(3,SPT,DUM,C1)
0014 CALL VECTOR(3,EPT,DUM,C1)
0015 CALL VECTOR(4,C1,C1)
0016 IFICIC1.LT.0.1 GO TO 300
0017 LCHECK=1
0018 RETURN
0019 WRITE(6,200) LSTART,LSTOP
0020 200 FORMAT(2X, ERROR FROM VLOGIL , LSTART =*, LSTOP =*)
0021 RETURN
0022 CONTINUE
0023 RETURN
0024 END
SUBROUTINE IMAGE(OS, O4, UN, OR)
IMPLICIT REAL*4(A-H,O-Z)

C PURPOSE - TO DETERMINE THE IMAGE OF A POINT THROUGH A PLANE

C PARAMETERS

***INPUTS***
C OS : THREE ELEMENT ARRAY, POSITION OF SOURCE POINT
C O4 : THREE ELEMENT ARRAY, POSITION OF A POINT ON THE PLANE
C UN : THREE ELEMENT ARRAY, NORMAL UNITVECTOR OF THE PLANE

***OUTPUT***
C OR : THREE ELEMENT ARRAY, POSITION OF THE IMAGE

C REQUIRED SUBROUTINE : VECTOR

DIMENSION OS(3), O4(3), OR(3), C(3), SM(3), UN(3)

DO 5 I = 1, 3
5 SM(I) = OS(I) - CN(I)
CALL VECTOR (4, SM, UN, C)
DO 15 I = 1, 3
15 OR(I) = OR(I) - 2 * CN(I) * UN(I)
RETURN
END
SUBROUTINE VRETA(A,F,E1,F2,DP,VRETA)
IMPLICIT REAL*4(A-H,O-Z)

PURPOSE:
TO DETERMINE THE DIFFRACTION POINT AND AN ANGLE
BETAO WHICH ALWAYS EXIST FOR 2-D PROBLEM.

PARAMETERS:

*** INPUT ***
A : SOURCE POINT.
F : OBSERVATION POINT.
E1, F2 : ARE THE VERTICES DEFINING AN EDGE.

*** OUTPUT ***
DP : DIFFRACTION POINT.
BETA : ANGLE TO MATCH THE PHASE AT DP IN DEGREE.

REQUIRED SUBROUTINE : VECTOR


COMMON /A/P1,P1130
COMMON /A/ICON

FORCE THE EDGE POINTS.

IF(E2(J2).GT.E1(J2)) GO TO 1
DO 2 J2=1,3
2 E1(J2)=E2(J2)
E2(J2)=E1(J2)

SET UP THE REFERENCE POINTS ON EDGE 1-2.
1 D(1)=A(1)
D(2)=E(1)
D(3)=E(3)
P(1)=F(1)
P(2)=E(2)
P(3)=E(3)

FIND ANGLE W.R.T. XZ PLANE.

AD2=ABS(D(1)-A(1))
AD1=ABS(D(2)-A(2))
ALR1=DATA2(AD2,AD1)
CALL VECTOR(&P,F,D1)
CALL VECTOR(&F1,D1,D2)
R=D2(1)

TRANSFORM F DOWN TO A PLANE WHICH INCLUDES LINE A-O.

TEM(1)=F(1)
F2=R*DSIN(ALR1)
FY=R*DCOS(ALR1)
C QUADRANT 4.
C IF(A(2).GE.A(2)).AND.(A(3).GT.A(3))) GO TO 402
0026
C QUADRANT 3.
C IF((A(2).GT.A(2)).AND.(A(3).GE.A(3))) GO TO 401
0027
C QUADRANT 2.
C IF((A(2).GE.A(2)).AND.(A(3).GT.O(3))) GO TO 400
0028
C QUADRANT 1.
C TEM(2)=P(2)-FY
0029
C TEM(1)=P(1)-FZ
0030
C GO TO 500
0031
C 400 TEM(2)=P(2)+FY
0032
C TEM(1)=P(1)+FZ
0033
C GO TO 500
0034
C 401 TEM(2)=P(2)+FY
0035
C TEM(1)=P(1)+FZ
0036
C GO TO 500
0037
C 402 TEM(2)=P(2)-FY
0038
C TEM(1)=P(1)+FZ
0039
C 500 CONTINUE
0040
C FIND BETAO.
C CALL VECTOR(3,E1,E2,E12)
0041
C CALL VECTOR(4,O1,E12,O2)
0042
C CALL VECTOR(4,01,E12,O2)
0043
C BETA=ARCOS(DP1(1)/P130)
0044
C CALL VECTOR(3,E1,E12,O2)
0045
C CALL VECTOR(4,O1,O2,03)
0046
C AL=ARCOS(DP1(1))
0047
C CALL VECTOR(4,A,E1,O1)
0048
C CALL VECTOR(5,O1,O1,O2)
0049
C AE1=O2(1)
0050
C E1=E1+DSIN(AL)/DSIN(ETA#PI180)
0051
C FIND DIFFRACTION POINT.
C DP(1)=E1(1)+E1
0052
C DP(2)=E1(2)
0053
C DP(3)=E1(3)
0054
C IF(ICON.EQ.1) WRITE(6,202)DP(I),I=1,3
0055
C IF(ETA.GT.90.) BETA=180.-BETA
0056
C CALL VECTOR(3,DP,A,01)
0057
C CALL VECTOR(4,O1,E12,O2)
0058
C SET=ARCOS(DP2(1)/PI10)
0059
C IF(SET.GT.90.) SET=180.-SET
0060
C CALL VECTOR(3,DP,F,D1)
0061
C CALL VECTOR(4,O1,E12,O2)
0062
C RET=ARCOS(DP2(1)/PI10)
0063
C IF(RET.GT.90.) RET=180.-RET
0064
C IF(ICON.EQ.1) WRITE(6,203) RET,RET
0065
C
0066 IF(NABS(BETT-RET).GE.0.001)WRITE(6,204)RETT, RET
0067 202 FORMAT(2X,'INTERACTION POINT',2X,3D20.4)    V0132260
0068 203 FORMAT(2X,'CHECK RET',2X,2D20.4)          V0132270
0069 204 FORMAT(2X,'ERROR FORM SUBROUTINE VSFA, FIND RETA?',2X,2D20.4)    V0132280
0070 RETURN                                         V0132290
0071 END                                             V0132300
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      VENDDIF
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0001  SUBROUTINE VENDDIF,FPT,ANT,RM,RS1,RS2,PE,WA,THS,PHS,R.
      0010  (ETON,EPDN,ITEM,RD,AREA,IN,WN,IN)
      0011  IMPLICIT REAL*(A-H,O-Z)
      0012  C
      0013  C PURPOSE - TO COMPUTE THE DIFFRACTED FIELD FROM AN EDGE
      0014  C
      0015  C PARAMETERS:
      0016  C
      0017  ***INPUT***
      0018  C
      0019  C FPT : OBSERVATION POINT
      0020  C ANT : SOURCE POINT
      0021  C RM : DIFFRACTION POINT
      0022  C BET0 : ANGLE TO MATCH PHASE AT RM
      0023  C RM,RL : ARRAYS, END POINTS OF THE EDGE
      0024  C RS1,RS2 : ARRAYS, END POINTS OF THE SOURCE
      0025  C WA : WEDGE ANGLE
      0026  C PE : SOURCE INPUT CURRENT
      0027  C THS, PHS : FIELD POINT ANGLES
      0028  C R : NUMER RADIAL DISTANCE
      0029  C NN : DUMMY INTEGRAL FOR FUTURE PROGRAM EXPANSION
      0030  C IN, IN+1 : ARE THE PLATES FORM THE WEDGE
      0031  C IN2 : DEFINE AN EDGE NUMBER
      0032  C IN = 1 : RAY EXIST
      0033  C ***OUTPUT***
      0034  C FD*,EPDN : COMPLEX NUMBERS, THETA AND PHI COMPONENTS
      0035  C
      0036  C REQUIRED SUBROUTINES:
      0037  C VECTOR, SOURCE, CONVRT, VLOG11
      0038  C
      0039  COMMON /I/ PI,P100
      0040  COMMON /P/ UPLAT(97,31,UM,31,WISE,31,INPLATE
      0041  C COMMON /P/ PLATE(50)
      0042  C COMMON /FREE/ ATTEN, UPLATF(50), JCORF(50), JCORL(50)
      0043  C COMMON /PERP/ JKEF(90,31), JREDR(90,31), JREP, NW
      0044  C COMPLEX*16 J,PE,ETON,EPDN,ETH,EPHI,EPER,EPAR,OS,C4,EPAD,EPED,AT,
      0045  C,CM,ECTON,EPDN,ATENU
      0046  DIMENSION RM(31),RM(31),RS1(31),RS2(31),RD(31),C1(31)
      0047  ,RM(31),RM(31),UJX31,ITEM(31),C1(31),UXS(31)
      0048  ,RPT(31),C21171,Cl(31),ITEM(31),ANT(3),FPT(3)
      0049  C
      0050  C EDGE CONVENTION
      0051  C
      0052  IF(IN=1,ST, RM(J1)) GO TO 4
      0053  DO S J2=1,3
      0054  CJ2=RM(J2)
      0055  RM(J2)=RM(J2)
      0056  S RM(J2)=RM(J2)
      0057  FJ=PI*2.
      0058  J=1.0,0.0
      0059  C
      0060  C INITIALIZE FIELD TO ZEPH
      0061  C
      0062  IF(IN=EQ.2) GO TO 1
      0063  FTD=(0.0,0.0)
      0064  EPDN=(0.0,0.0)
      0065  C
      0066  C
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0022  IF(IN,GT,NPLATE) RETURN
C                                      V0132890
0023  CALL VECTOR(I*,IN,IN-1)         V0132900
0024  CALL VECTOR(IN,4*4,4*1)         V0132910
0025  CALL VECTOR(IN,4*4,4*1)         V0132920
0026  IF(IN,NE,1) GO TO 307

0027  C CHECK PAY BLOCKS FROM -Y DIRECTION
C                                      V0132930
0028  C IN2=IN-1
0029  301  NPRE=IN-2
0030  JPRE=IN-2
0031  IF(INP,F,LT,1) GO TO 305
0032  CALL VLOGI1(RD,4,4,1,INP,LOC)
0033  IF(LOC,NE,1) GO TO 305
0034  JPRE=IN2,WE,1=1
0035  RETURN
C                                      V0132950
C CHECK PAY BLOCKS FROM THE REST OF THE PLATE .
C                                      V0132960
0036  IN1=IN1+1
0037  IF(IN1,GT,NPLATE) GO TO 302
0038  CALL VLOGI1(RD,4,4,1,IN1,4,LP,LOC)
0039  IF(LOC,NE,1) RETURN
0040  IF(IN,LE,21) GO TO 302
0041  CALL VLOGI1(RD,4,4,1,IN-2,LOC)
0042  IF(LOC,NE,1) RETURN
C                                      V0132970
C COMPUTE THEA ,PHI ,S-PRIME (SP) ,FROM SOURCE TO RD .
C                                      V0133000
0043  302  CALL TRANS1,ANT,*0,4,SP,TA,PA
0044  FOR THE SPECIAL CASE ,DOUBLE DIFFRACTED FIELD .
C                                      V0133010
0045  IF(IN,NE,2) GO TO 2
0046  CALL VECTOR(6,RP,T,4,N,4,1)
0047  CALL VECTOR(5,N,N,1,C1)
0048  CALL VECTOR(6,RP,T,4,N,4,1)
0049  SP=SP+1
0050  GO TO 3
C                                      V0133050
C COMPUTE INCIDENT FIELD AT DIFFRACTION POINT RD
C                                      V0133060
0051  2  CALL SOURCE1,RS1,RS2,TA,PA,PE,SP,TH,EPHI
0052  IF(IN,NE,5,4,*0,4,1,4,4) GO TO 3
0053  TH=THATTEM
0054  EP=EPHIEPPL
0055  EPHEEPHIATTEM
0056  3  IF(IN,NE,1) WRITE6,202 ETH,EPHI
C                                      V0133080
C REFER VERTICES RM, RPM TO COORDINATE SYSTEM AT THE SOURCE
C                                      V0133090
0057  CALL VECTOR(6,4,4,4,4,4,4)
0058  CALL VECTOR(4,4,4,4,4,4)
C                                      V0133100
C CONVERT FIELD COMPONENTS BY FIXED COORDINATE SYSTEM
C                                      V0133110
```

BEGIN
CALL CONVPRT(THS,PHS,RM,RMI,-1,EPD,EPD,AT,AP)
END
SUBROUTINE TRIPLE (A, B, C, D)

IMPLICIT REAL*4(A-H, O-Z)

PURPOSE - TO COMPUTE THE SCALAR TRIPLE PRODUCT OF VECTORS A, B, C

PARAMETERS

***INPUTS***

A, B, C : THREE VECTORS

***OUTPUT***

D : RESULT OF TRIPLE PRODUCT

REQUIRED SUBROUTINE : VECTOR

DIMENSION A(3), B(3), C(3), E(3), F(3)

CALL VECTOR (1, A, B, F)

CALL VECTOR (4, E, C, F)

RETURN

END
SUBROUTINE CONVERT (THETA, PHI, XM, XM1, IO, E1, E2, ET1, ET2)

IMPLICIT REAL*4 (A-H, O-Z)

C
C PURPOSE - TO CONVERT FROM RAY-FIXED COORDINATES TO
Spherical coordinates or vice versa
C
C PARAMETERS
C
C ***INPUT***
C THETA and PHI : ANGLES IN DEGREES TO DETERMINE THE DIRECTION
OF THE RAY (IN SPHERICAL COORDINATES)
C XM, XM1 : THREE ELEMENT ARRAYS TO DETERMINE THE POSITIONS OF
VERTICES OF DIFFRACTING EDGE
C IO = 1 : CONVERT FROM SPHERICAL COORDINATE TO RAY FIXED,
IO = -1 : VICE VERSA
C E1, E2 : THETA AND PHI COMPONENTS (IO = 1)
C OR PERPENDICULAR AND PARALLEL COMPONENTS (IO = -1)
C ***OUTPUT***
C ET1, ET2 : PERPENDICULAR AND PARALLEL COMPONENTS (IO = 1)
C OR THETA AND PHI COMPONENTS (IO = -1)
C
C REQUIRED SUBROUTINES: VECTOR, TRIPLE

C
C COMM VAP PI,P169
C COMM F1,E2,E71,ET2
C CURSOM XM, XM1, THETA(3), U(3), UF(3), UPH(3), W(3)
C THETA = THETA*PI/180
C PHI = PHI*PI/180
C COST = COS(THETA)
C SINT = SINT(COST)
C COSP = COS(PHI)
C SINP = SIN(PHI)
C
C UNIT VECTORS IN SPHERICAL COORDINATE SYSTEM
C
C UTHETA = COS (THETA) 
C UPHI = SIN (THETA) 
C U11 = SINT*CO5
C U12 = SINT*SINP
C U13 = C5
C
C COMPUTE COSINE AND SINE OF ANGLE OF ROTATION
C
C CALL VECTOR (3, XM, XM1, UF(3))
C IF (IO.EQ.1) CALL VECTOR (2, U, UPHI)
C IF (IO.EQ.-1) CALL VECTOR (2, U, UF, UPHI)
C CALL TRIPLE (UTHETA, UPHI, U, SINT)
C SINT = SINT*SP
C COSP = COS (PHI)
C SINP = SIN (PHI)
C U31 = COST
C U32 = SINT
C U33 = SINT*COST
C
C TRANSFORMATION
C
C ET1 = COSP*E1 + SINP*E2
C ET2 = -SINP*E1 + COSP*E2
C RT=RT
C END
Purpose: To compute diffraction coefficients $d_s, dh$

**Input**
- PHI: diffracted angle
- PHI$: incident angle at the edge
- RETAO: angle between the incident ray and the tangent to the edge
- S: distance from field point to the edge along the diffracted ray path
- SP: distance from the source point to the edge along the incident ray
- WA: wedge angle
- SL: distance parameter when externally provided (when ILOP=4)
- ILOP: control number:
  - ILOP=1: Plane-wave incidence
  - ILOP=2: Cylindrical wave incidence
  - ILOP=3: Spherical or Conical-wave incidence
- UN: unit normal of illuminating plate

**Output**
- AS: amplitude of the field along diffracted ray (not applicable when ILOP=4)
- DS: soft diffraction coefficient
- DH: hard diffraction coefficient

**Common Blocks**
- COMMON /PI/PI(3)
- COMMON /DSV(57,3),DSV(59,3),FG0,UNI(31),USI(33)
- COMMON /ICON/

**References**

**Compute Necessary Constants**
- PI=2.00*PI
- PI*=1/4.00
- A=33.3
- CYL=63.3,1.1
- K=K
- GS=1.
- GH=1.
C TEST FOR GLAZING INCIDENT.
0017 IF (PHIP.GT.1.0-3) GO TO 151
0018 G5=0.0
0019 GH=0.5
0020 L51 VG=350.-W5
0021 EPS1=0.001
C COMPUTE ANGLES ETA-ZERO, BETA-POSITIVE, BETA-NEGATIVE
0022 W5=H5/IG5.
0023 BETAP=(PHI*PHIP)*PI80
0024 RETA=(PHI-PI80)*PHIP
C CHOOSE DISTANCE PARAMETER FOR TYPE OF EDGE ILLUMINATION
0026 IF (ILOP.EQ.1) L=W5*SIN(BETA*PI80)**2
0027 IF (ILOP.EQ.2) L=W5*SP/(S*SP)
0028 IF (ILOP.EQ.3) L=W5*SP/(S*SP)*OSIN(BETA*PI80)**2
0029 IF (ILOP.EQ.4) L=SL
C COMPUTE AS, SP THE AMPLITUDE OF THE FIELD ALONG THE DIFFRACTED RAY.
0030 IF (ILOP.EQ.1) AS=1.0/DOSORT(S)
0031 IF (ILOP.EQ.2) AS=1.0/DOSORT(S*SIN(BETA*PI80))
0032 IF (ILOP.EQ.3) AS=1.0
C COMPUTE ANGULAR ARGUMENTS FOR COTANGENT FUNCTION
0033 ANG1=(PI+ETAN1)/2.0*WN
0034 ANG2=(PI-ETAN1)/2.0*WN
0035 ANG3=(PI+ETAP)/2.0*WN
0036 ANG4=(PI-ETAP)/2.0*WN
C CALCULATE N* AND N-
0037 NNP=(PI+ETAN1)/PI1*WN**4.500
0038 NNP=(PI-ETAN1)/PI1*WN**5.500
0039 NNP=(PI+ETAP)/PI1*WN**5.500
0040 NNP=(PI-ETAP)/PI1*WN**5.500
C COMPUTE ARGUMENTS OF TRANSITION FUNCTION P(X) X=KL4
0041 ARG1=PI1*Q(BETAN1,WN,WN)
0042 ARG2=PI1*Q(BETAN1,WN,WN)
0043 ARG3=(PI+ETAP,WN,WN)
0044 ARG4=(PI-ETAP,WN,WN)
C OS AND ON CALCULATED BY KELLER'S FORM WHEN FIELD POINT IS NOT IN TRANSITION REGIONS
0045 IF (ICN.EQ.1) WRITE(6,112) METAO, RETAP, RETAN, L, AS, ANGL, ANG2, ANG3, AN
0046 C00, ARG1, ARG2, ARG3, ANA
0047 C000, ARG1, ARG2, ARG3, ANA
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0047

0048

113

0049

IF (IANGLE.W) GO TO 90

0050

IF (IARG.W) GO TO 90

0051

IF (IARG.L) GO TO 50

0052

IF (IARG.N) GO TO 50

0053

CN=SN(T+W)*C*EXP(-A*PI*WPI*T+SN(T+W)*BS**190)

0054

K1=1.0/DCSCTPI(W)*DCSCTB(TAN/WTN))

0055

K2=1.0/DCSCTPI(W)*DCSCTB(TAN/WTN))

0056

CS=GS*K0*(X1-K2)

0057

DN=SN*(X1+K2)

0058

IF (ICCCN.EQ.11) WRITE(6,114) C3,K1,K2

0059

114

FOREAT(2X,1I10.4,X1,F10.4,K1,F10.4,K2,F10.4)

RETURN

C C CALCULAT THE FOUR TERMS OF THE DIFFRACTION COEFFICIENT

C

50

CS=CS*C*EXP(-ANG4*PI*WPI*T+SN(T+W)*BS**190)

0061

IF (IARGS4.EQ.1) GO TO 100

0062

EPS=(ANG4*PI*WPI*T+SN(T+W)*BS**190)

0063

C1=H(110.4),PI)

0064

IF (ICCCN.EQ.11) WRITE(6,121) C1

0065

121

FOREAT(1X,1I10.4,X1,F10.4,K1,F10.4,K2,F10.4)

GO TO 150

C

100

C1=G(TAN4.1)*F(ANG4)

0066

150

IF (IARGS4.EQ.1) GO TO 200

0067

EPS=(ANG4*PI*WPI*T+SN(T+W)*BS**190)

0068

C2=H(110.4),PI)

0069

IF (ICCCN.EQ.11) WRITE(6,124) C2

0070

124

FOREAT(1X,1I10.4,X1,F10.4,K1,F10.4,K2,F10.4)

GO TO 250

200

C2=G(TAN4.1)*F(ANG4)

0071

250

IF (IARGS4.EQ.1) GO TO 300

0072

EPS=(ANG4*PI*WPI*T+SN(T+W)*BS**190)

0073

C3=H(110.4),PI)

0074

IF (ICCCN.EQ.11) WRITE(6,127) C3

0075

127

FOREAT(1X,1I10.4,X1,F10.4,K1,F10.4,K2,F10.4)

GO TO 350

300

C3=G(TAN4.1)*F(ANG4)

0076

350

IF (IARGS4.EQ.1) GO TO 400

0077

EPS=(ANG4*PI*WPI*T+SN(T+W)*BS**190)

0078

C4=H(110.4),PI)

0079

IF (ICCCN.EQ.11) WRITE(6,131) C4

0080

131

FOREAT(1X,1I10.4,X1,F10.4,K1,F10.4,K2,F10.4)

GO TO 450

400

C4=G(TAN4.1)*F(ANG4)

0081

FOREAT(1X,1I10.4,X1,F10.4,K1,F10.4,K2,F10.4)

RETURN

C

C COMPUTE DS AND DH

C

0091

IF (ICCCN+E.1) GO TO 500

0092

FASE=0F(ARG1)

0093

BAR=ID(C(14.1)

0094

WRITE(4,1111)RA,FASE,C1

0095

FASE=0F(ANG2)
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0096  BB=COI(ANG)
0097  WRITE(6,111)BB,FASE,C2
0098  FASE=F(ARR3)
0099  BB=COI(ANG)
0100  WRITE(6,111)BB,FASE,C3
0101  FASE=F(ARR4)
0102  BB=COI(ANG)
0103  WRITE(6,111)BB,FASE,C4
0104  111 FORMAT(1X,' G0*,D20.10,* FERNEL*,D20.10,* RESULT*,D20.10)
0105  WRITE(6,122)G0,GS,CO
0106  122 FORMAT(1X,' G0*,D20.10,* GS*,D20.10,* CO*,D20.10)
0107  500 CONTINUE  
0108  3H=G0*CO*(C1+C2+C3+C4)
0109  9S=GS*CO*(C1+C2-C3-C4)
0110  RETURN 
0111  END
SUBROUTINE V2DIF(F,E1,E2,E3,E4,DP1,DP2,ETA)

IMPLICIT REAL*4(1-H,O-Z)

C PURPOSE :
C TO DETERMINE TWO DIFFRACTION POINTS ON TWO EDGES.
C
C PARAMETERS :
C ***INPUTS***
C S : SOURCE LOCATION
C F : OBSERVATION POINT
C E1, E2 : TWO END POINTS OF THE FIRST EDGE
C E3, E4 : TWO END POINTS OF THE SECOND EDGE
C
C ***OUTPUTS***
C DP1, DP2 : TWO DIFFRACTION POINTS
C ETA : THE DIFFRACTING INCIDENT ANGLE
C
C REQUIRED SUBROUTINES :
C VECTOR, VETA
C
C D2(3),D3(3),E1(3),E2(3),E3(3),E4(3)
C
COMMON /P1/P1(19)

0006 IF(E2(1).GT.E1(1)) GO TO 2
0007 DO 1 J2=1,3
0008 E1(J2)=E1(J2)
0009 E2(J2)=E1(J2)
0010 1 IF(E2(J2).GT.E1(1)) GO TO 2
0011 2 IF(E4(J2).GT.E2(1)) GO TO 3
0012 DO 4 J2=1,3
0013 E1(J2)=E4(J2)
0014 E2(J2)=E4(J2)
0015 4 E4(J2)=E1(J2)

C POINT W.R.T. EDGE 1-2
0016 O(1)=A(1)
0017 O(2)=E2(2)
0018 O(3)=E1(3)

C POINT W.R.T. EDGE 3-4
0019 P1(1)=F(1)
0020 P2(2)=E4(2)
0021 P3(3)=E4(3)
0022 E4=O*ABS(E2(3)-E4(1))
0023 E4=O*ABS(E2(1)-E4(2))

C FIND SLOPE OF THE PLANE *PL* DEFINED BY EDGE 1-2,3-4
0024 ALP=O*ATAN2(E4,E4)
0025 ALP=ALP/P(L190)
0026 IF(CON.EQ.1)WRITE(6,201)ALP

C 201 FORMAT(2X,ALP=*,PI,ALPHA)
0027 CALL VECTOR(6,A(0),O)

0028
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0030 CALL VECTOR(5,01,01,02)
0031 B1=DPI(1)
0032 C TRANSFORM POINTS A INTO PLANE PL.
0033 CALL VECTOR(6,F,P,31)
0034 IF(F(2).LT.0.001) GO TO 400
0035 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 402
0036 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0037 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0038 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0039 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0040 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0041 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0042 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0043 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0044 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0045 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0046 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0047 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0048 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0049 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0050 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0051 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0052 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0053 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0054 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0055 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0056 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0057 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0058 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0059 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 400
0060 IF((F2(2).GT.E2(2)).AND.(E2(3).GT.E4(3))) GO TO 401
0061 CALL VECTOR(6,F,P,31)
0062 CALL VECTOR(6,F,P,31)
0063 CALL VECTOR(6,F,P,31)
0064 CALL VECTOR(6,F,P,31)
0065 CALL VECTOR(6,F,P,31)
0066 CALL VECTOR(6,F,P,31)
0067 CALL VECTOR(6,F,P,31)
0068 CALL VECTOR(6,F,P,31)
0069 CALL VECTOR(6,F,P,31)
0070 CALL VECTOR(6,F,P,31)
0071 CALL VECTOR(6,F,P,31)
0072 CALL VECTOR(6,F,P,31)
0073 CALL VECTOR(6,F,P,31)
0074 CALL VECTOR(6,F,P,31)
0075 CALL VECTOR(6,F,P,31)
0076 CALL VECTOR(6,F,P,31)
0077 CALL VECTOR(6,F,P,31)
0078 CALL VECTOR(6,F,P,31)
0079 CALL VECTOR(6,F,P,31)
FIN THE PLANE DEFINED BY I1, I2.

TO DETERMINING WHETHER THE PATH FROM DIFFRACTION POINT TO OBSERVATION POINT OR SOURCE POINT WAS NOT POSSIBLE.

PARAMETERS:

***INPUT***

SPT, EPT : TWO END POINTS ON A LINE UNDER TEST

DV : PLATE DATA

I1, I2 : ENCODED EDGES UNDER BLOCKAGE TEST

***INPUT***

L0K = 1 MEANS : PATH WAS NOT POSSIBLE,
-1 MEANS : PATH WAS POSSIBLE.

REQUIRED SUBROUTINES : VECTOR, IMAGE

APPROACH :

FIND THE PLANE DEFINED BY I1, I2.

FIND UNIT NORMAL TO THE PLANE.

IMAG ALL THE EDGES BETWEEN I1 & I2 W.R.T. THIS PLANE.

TEST IMAGING POINTS WHETHER THEY ALL LIE ABOVE THE PLANE.

IF THEY ARE NOT, THE PATH WAS NOT POSSIBLE.

COMMON /F, ICON

DIMENSION DV(50,3), P1(3), P2(3), P3(3), UN(3), D1(3), D2(3),

C(3), SPT(3), EPT(3)

L0K=1

I1=I1+2

I2=I2+2+2

P1(1)=SPT(1)+1000.

P1(2)=SPT(2)

P1(3)=SPT(3)

P2(1)=EPT(1)+1000.

P2(2)=EPT(2)

P2(3)=EPT(3)

CALL VECTOR(E,F,P1,F,P2)

CALL VECTOR(1,1,F,P1,F,P2)

CALL VECTOR(1,1,F,P1,F,P2)

IF(UN(1).LE.0) GO TO 4

DO 5 J2=1,3

5 UN(J2)=UN(J2)

DO 8 J1=111,122,2

8 DO 9 J2=1,3

9 UN(J2)=UN(J2)

CALL IMAGE(1,1,F,UN,D1)

CALL VECTOR(1,1,1,F,UN,D2)

CALL VECTOR(4,F2,UN,P1)

IF(ICON.NE.1) GO TO 10

ICON EQ 1 WRITE THE FOLLOWING.
```
0027 WRITE(6,201) (11,122)
0028 201 FORMAT(1X, [11,122 *)&,*X,21(I3))
0029 WRITE(6,203) (SP(J3),J3=1,3)
0030 WRITE(6,201)(EPS(J3),J3=1,3)
0031 WRITE(6,203) ( UN(J3),J3=1,3)
0032 WRITE(6,203) ( D1(J3),J3=1,3)
0033 WRITE(6,201) ( D1(J3),J3=1,3)
0034 WRITE(6,201) (*3(1)
0035 10 IF(PT(1).GE.0.) RETURN
0036 CONTINUE
C SET LOK FOR NO LINE-OF-SIGHT BLOCKAGE.
C
0037 LOK=-1
0038 RETURN
0039 203 FORMAT(2X,1024.10)
0040 202 FORMAT(2X,*3(1),*29.10)
0041 END
```
SUBROUTINE VTERNN

C PURPOSE : LINEAR INTERPOLATION TERRAIN ELEVATIONS.

C PARAMETERS :

***INPUTS***

C PSEUDO 3-D TERRAIN DATA FROM FILEDEF 14.

C ***OUTPUTS***

C NEW PROFILE ALONG A LINE ORIGINATED FROM AN ANT TO OBSERVATION

C POINT. ASSIGNED IN COMMON PLATE/

C

IFLAG = 0

READ(14,1000)(A2(I),I=1,N)

IFbuster THEN |

IF(IFLAG.EQ.1) THEN |

RETURN

ENDIF

END subroutine VTERNN
0032 CALL VECTOR(3,A1,12,A1)
0033 CALL INTRSC(T1,J4,A1,A0,IERR)
0034 X0(I)=X(I)
0035 IF(X0(I).GT.42(I)) OR. X0(I).LT. A1(I)) GO TO 22
0036 Y0(I)=D(I)
0037 Z0(I)=D(I)
0038 IFLAG=I
0039 GO TO 21
0040 22 A1(I)=42(I)
0041 A1(I)=42(I)
0042 A1(I)=42(I)
0043 21 CONTINUE
0044 20 CONTINUE
0045 RETURN
0046 RETURN
0047 END
SUBROUTINE TMPLT(X,Y,XMIN,YMIN,XMAX,YMAX,N,TYP,E,IP,A,ISY)
C
PURPOSE: TO CREATE A H-P PLOT FILE ON FILE DEFINITION II.
C
PARAMETERS:
C
***INPUTS***
C
TYPES OF PLOTS POSSIBLE WITH THIS SUBROUTINE ARE AS FOLLOWS:
C
TYPE=1: LINE PLOT-- NO SMOOTHING
C
TYPE=2: LINE PLOT-- SMOOTHING
C
TYPE=3: SYMBOL PLOT-- NO CONNECTING LINE
C
TYPE=4: SYMBOL PLOT--LINE CONNECTING DATA POINTS
C
TYPE=5: SMOOTHED DASHED LINES
C
IPAS INDICATES THE NUMBER OF POINTS BETWEEN SYMBOLS
C
ISY IS THE INTEGER EQUIVALENT OF THE SYMBOL TO BE USED
C
IN THE PLOT. IT MUST BE WITHIN THE RANGE OF 0-13, INCLUSIVE.
C
FOR DASHED LINES ISY IS THE TYPE OF DASH LINE FROM 1 TO 4
C
FOR TYPE=3 AND SYM NOT DASHED LINES ALSO PRODUCED
C
***OUTPUTS***
C
1 PLOT FILE.
C
SURNRTINES USED HERE ARE THE IBM CANNED ROUTINES.
C
COMMON/ASHPK/IX,IY
C
DIMENSION X(252),Y(252),XPLT(252),YPLT(252),RUF(5100)
C
CALL PLTS(RUF,25000,II)
C
=0
C
XFACT=10.
C
YFACT=10.
C
IF(IX.EQ.2) GO TO 40
C
IF(IY.GE.3) GO TO 50
C

40
C
IF(IY.GE.3) GO TO 41
C

41
C
PATTERN-A COI VS DISTANCE WITH THE FOLLOWING NORMALIZED FACTORS.
C
C
XFACT=8.2
C
YFACT=6.12
C
GO TO 50
C

40
C
PATTERN-B COI VS ANGLE WITH THE FOLLOWING NORMALIZED FACTORS.
C
C
XFACT=6.28
C
YFACT=7.91
C
GO TO 50
C

40
C
AMPLITUDE VS ANGLE WITH THE FOLLOWING NORMALIZED FACTORS.
C
C
XFACT=8.2
C
YFACT=5.0
C
CONTINUE
C

50
C
CONTINUE
C

5
0026 IF(X(I).LT.XMIN) OR (X(I).GT.XMAX) GO TO 20 V0139920
0027 IF(Y(I).LT.YMIN) OR (Y(I).GT.YMAX) GO TO 20 V0139930
0028 YPLT(J)=(X(I)-XMIN)*IS5/(XMAX-XMIN) V0139940
0029 YPLT(J)=(Y(I)-YMIN)*IS5/(YMAX-YMIN) V0139950
0030 J=J+1 V0139960
0031 GO TO 5 V0139970
0032 CONTINUE V0139980
0033 IF(I.GT.N.AND.J.LE.2) GO TO 7 V0139990
0034 IF(J.LE.2) GO TO 4 V0140000
0035 NPTS=J-1 V0140010
0036 XPLT(NPTS+1)=0. V0140020
0037 XPLT(NPTS+2)=1. V0140030
0039 XPLT(NPTS+2)=1. V0140040
0039 YPLT(NPTS+2)=1. V0140050
0040 XYP=0 V0140060
0041 IF(TYPE.EQ.1) NPTS=-NPTS V0140070
0042 IF(TYPE.EQ.2) KYP=-NPTS V0140080
0043 IF(TYPE.EQ.3) KYP=NPTS V0140090
0044 IF(TYPE.EQ.4) NPTS=-NPTS V0140100
0045 IF(TYPE.EQ.5) NPTS=NPTS V0140110
0046 IF(TYPE.EQ.6) NPTS=-NPTS V0140120
0047 IF(TYPE.EQ.7) JOASH=SYM V0140130
0048 IF(TYPE.EQ.8) JOASH=SYM V0140140
0049 CALL FLASH (JOASH,0.,0.,XYRATO) V0140150
0050 CALL FSYR(2,23) V0140160
0051 CALL FLINE(XPLT,YPLT,NPTS,1,KYP,SYM) V0140170
0052 IF(I.GT.N) GO TO 7 V0140180
0053 GO TO 4 V0140190
0054 CONTINUE V0140200
0055 RETURN V0140210
0056 END V0140220