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LIMITATIONS ON Ku-BAND COMMUNICATIONS DUE TO MULTIPATH

August 1977

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

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Task Order No. B0703

Shuttle Tracking and Communication Support

Antenna and Propagation Evaluation

Design Note

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1.0 SUMMARY

The purpose of this design note is to evaluate the Earth and Orbiter body reflections involving the Tracking Data Relay Satellite (TDRS)/Orbiter communications link. Recommendations address operational conditions in order to avoid critical multipath impacts, modulation preferences during acquisition, and preferred scan limit implementation.

This detailed analysis employs the use of the baselined 36-inch diameter dish and triple channel monopulse system. The Orbiter is assumed to be in a nominal orbiting altitude of 237.57 n.mi. This evaluation shows that the scan limitations for grazing angles relative to Orbiter reflections for the sum and difference radiation patterns are 3.5 and 2.0 degrees respectively. The results show a zero peak shift in the sum pattern at an offset (grazing) angle of 3.5 degrees, and a zero null shift in the difference pattern at an offset (grazing) angle of 2.0 degrees. The results in this design note indicate a possibility of false lock-on when the Orbiter grazing angle is less than 3.5 degrees. Results from the Earth reflections are minimal and not expected to cause any critical variations in the received power of the TDRS/Orbiter r.f. communications link for positive grazing angles. The recommended modulation for the multipath environment is the spread spectrum because a smaller percentage of power would be lost by cancellation.

2.0 INTRODUCTION

The purpose of this design note is to evaluate the effects of multipath from both the Orbiter and the Earth and make recommendations for tracker implementation for the Space Shuttle Orbiter Ku-Band Communications Antenna System. First, background information is given to orient the reader to the definition of multipath and related parameters. This is followed by a discussion pertaining to the factors required to analyze the multipath phenomena which include: geometrical configuration, electrical characteristics, scattering and reflection factors, and path difference. These factors are compiled into two math tools which were developed in References A and B for the analysis of Earth and Orbiter multipath respectively.

The remaining sections of this design note are related to evaluation of multipath on the sum and difference patterns including recommended performance limitations imposed by the Earth and Orbiter. The results of the output from the two math tools are interrelated in the results section to show the rationale for pertinent recommendations. The last section in this design note summarizes the recommendations for proper tracker scan implementation.

3.0 BACKGROUND

The basis for this Earth and Orbiter multipath study had its origin from a general multipath study (Reference C) that indicated some concern on this subject, and recommended further investigation. This initial study indicated that the amplitude of the multipath factor had its null points nearly coinciding with the Pseudo Noise (PN) sideband spacing which was 5.486 kHz. The present spacing is 2.9599 kHz.

The multipath phenomenon is the result of a signal reflected off an object or protrusion in the vicinity of the direct signal causing enhancement or cancellation of part or all of the resultant signal that is transmitted from the Tracking and Data Relay Satellite (TDRS) to the Orbiter. The multipath factor which represents multipath is broken up into a specular and diffuse component. The specular reflected wave is the worst case from a uniform surface, such as the relatively smooth surface of the Orbiter and uniform areas of the Earth. The diffuse wave is scattered over a broad angle greatly reducing the possibility of direct signal perturbation.

Two math tools were developed, which are found in Appendix B; one is related to Earth multipath which is designed to aid in the study of multipath as a function of grazing angle and frequency; the second program is concerned with Orbiter multipath using similar aspects as in the Earth multipath program.

The skin of the Orbiter is covered with a thermal protection system

(TPS) with various-thicknesses to accommodate the different heating loads anticipated on the orbiter's surface during mission operation. The purpose of the TPS is to dissipate external surface heat buildup on the Orbiter. The TPS consists of five layers of material which was analyzed for reflective properties (Reference B). The results of this analysis show that only the outside layer contributes significantly to the reflection coefficient at low grazing angles. The outside layer of the TPS has a thickness of 0.10".

The Ku-Band Communications Antenna is a parabolic dish type antenna with right hand circular polarization (RHCP) having a thirty-six inch diameter. Antennas are deployed from the orbiter's right and left side and will be used only during on-orbit activities. The antenna mountings are located in the forward section of the payload bay. The right antenna may also be used for radar purposes.

The region where multipath will have the most impact for communications is near the line-of-sight where the grazing angles of the signals from the TDRS are small. In this region the reflected signal has a phase shift which approaches 180° causing either a gain or loss of signal strength at the Shuttle Orbiter depending on the path difference between the direct and indirect signal.

4.0 DISCUSSION

The discussion section is divided into seven subsections, in which the rationale for the multipath parameters is developed and incorporated into a computer program that aids in the evaluation of multipath on the Ku-Band Communications Antenna System. The recommended operational limitations will also be discussed to obtain optimum implementation of this antenna system. The first section deals with the two geometrical configurations used to determine the Earth and Orbiter math models and its respective parameters. The electrical properties of the different Earth terrain and Orbiter surfaces are also shown in this section. The second section, 4.2, deals with the development of the reflective and scattering parameters for the respective math models. The third section, 4.3, is concerned with the development of the path difference between a direct and indirect signal which may indicate whether enhancement or cancellation will occur. The incorporation and modifications of the multipath parameters are combined into an equation for both Earth and Orbiter multipath in Section 4.4. The multipath equation is expressed in dB which is called "multipath factor". The Fortran programs written for this multipath evaluation are discussed in Section 4.5. In this section, the modifications made to the basic multipath factor equation are explained relative to the Earth, the Orbiter, and the sum and difference pattern sensitivity to multipath. In Section 4.6, evaluation of the multipath phenomenon is discussed in relation to the sum and difference channels. This evaluation uses a Bessel function to produce the sum radiation pattern

found in Reference D. The difference channel radiation pattern is produced using a sine function approximation which is found in Reference E. These patterns are combined in a computer program with the multipath factor to show the sensitivity of the Ku- Band sum and difference patterns to multipath relative to the Earth and Orbiter. In Section 4.7, the results from the multipath program written as a function of frequency and grazing angle are discussed for both the Earth and Orbiter. The recommended functional implementation of the Ku-Band antenna is made in this section and also documented in the results section for convenience.

The data obtained in this analysis is shown in graphical form and is used to indicate the limitations of the tracking capabilities of the Ku-Band Communication System. From these results, optimum implementation for the Ku-Band antenna is recommended.

4.1 Geometric Configuration

The geometries that are used to analyze multipath relative to the Earth and Orbiter utilize a geometrical optics approach for a sphere and cylinder. The sphere represents the shape of the Earth and the cylinder represents the orbiter's shape. The geometrical configurations for Earth and Orbiter multipath are shown in Figures 1 and 2, respectively. The region of interest for multipath is near the line-of-sight (LOS) or interference region. This is a region with small grazing angles and path differences, resulting in relatively small r.f. phase shifts between the direct and indirect signals. These geometries are

shown in Figures 1 and 2.

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4.1.1 Geometrical Bodies

The geometry of the Earth multipath shown in Figure 1 considers the atmospheric effects and spherical effects on the signal from the TDRS. The atmospheric effects are due to refractive and diffractive bending of the incident wave and reflected wave off the Earth. The effect of the atmosphere is to take 4/3 of the earth's radius which is referred to as the effective radius of the Earth. Figure 1 also shows the pertinent angles and arc distances used to determine the amount of movement of the Orbiter in a fixed orbit traversing around the earth's center while holding the TDRS in a fixed position. The curved surface of the Earth is accounted for by the divergence factor which approaches zero as the grazing angle is encountered making the received field the same as that of free space. The grazing angle, ψ_1, in Figure 1 is encountered when the Orbiter/TDRS line of site passes thru the point of wave impingement on the earth's surface (apex of grazing angle).

The geometry for Orbiter multipath is illustrated in Figure 2; the Orbiter is assumed to be a smooth cylinder rotating in a circular orbit around the Earth approaching the point for acquisition of the TDRS signal. The approach taken for this aspect is to consider the TDRS to be in the far field, therefore implying that the direct and indirect paths are parallel upon incidence to the orbiter's thermal protection system. The effect of the TPS on the reflected signal was evaluated

in Reference C. Results indicated that the top layer of the TPS has the major effect compared to the other four layers of the TPS at near grazing angles.

4.1.2 Electrical Characteristics

The electrical properties of the objects from which the TDRS signal is reflected should be considered in order to have a meaningful result relative to the scattering and reflection of the signal. The Earth and Orbiter multipath were considered from a number of surfaces which are listed in Table I with the conductivity in Siemens/meter and relative dielectric constant.

MATERIAL	CONDUCTIVITY (Siemens/meter) σ	COMPLEX DIELECTRIC CONSTANT(ε_r) at 13.775 GHz
Top Layer TPS	1.102×10^{-2}	$4.8 - j1.44 \times 10^{-2}$
Sandy Soil	10^{-5}	$3 - j1.31 \times 10^{-5}$
Wet Soil	10^{-3}	$80. - j1.31 \times 10^{-3}$
Fresh Water	10^{-2}	$80 - j1.31 \times 10^{-3}$
Salt Water	4	80-j5.24
Ice	5×10^{-3}	$2.92 - j6.532 \times 10^{-9}$

TABLE I ELECTRICAL PROPERTIES OF ORBITER/EARTH SURFACES

4.2 Scattering and Reflection Parameters Relative to Earth and Orbiter Multipath

The scattering coefficient for the specularly reflected wave off the Orbiter is calculated using equation (1) Reference F, which is used for both the Earth/Orbiter surfaces listed in Table 1.

$$|\rho_s| = \exp - \left(\frac{4\pi}{\lambda} \sigma_{rms} \sin \Psi_1\right) \qquad (1)$$

$|\rho_s|$ is the scattering coefficient magnitude (no units)

σ_{rms} is the root-mean-square roughness height in meters

Ψ_1 is the grazing angle in radians

λ is the wavelength in meters

π is 3.14159265358979324

The specular scattering coefficient is considered to have a value of unity for the Orbiter surface multipath calculations. The unity scattering factor indicates that the Orbiter is assumed to have a smooth surface.

The scattering coefficient will alter the reflection coefficient in such a way that the resultant specular reflection component will be $|\hat{R}_s| = \rho_s |\hat{R}_c|$. The baselined polarization for the Ku-Band Communication Antenna is circular. The circular reflection coefficient, $|\hat{R}_c|$, consists of two components, vertical and horizontal as shown in equation (2).

$$|\hat{R}_c| = \left|\frac{\hat{R}_V + \hat{R}_H}{2}\right| \quad \text{(Reference G)} \quad (2)$$

$\hat{R}_V$ is the vertical reflection coefficient (Reference H) (no units)

$\hat{R}_H$ is the horizontal reflection coefficient (Reference H) (no units)

The respective vertical and horizontal components in equation (2) are calculated by the following equations (Reference H).

$$|\hat{R}_V| = \sqrt{\frac{1 + \frac{b_V}{2}(1 - \cos 2\,\Psi_1) - m_V \sin \Psi_1}{1 + \frac{b_V}{2}(1 - \cos 2\,\Psi_1) + m_V \sin \Psi_1}} \quad (3)$$

$$|\hat{R}_H| = \sqrt{\frac{1 + \frac{b_h}{2}(1 - \cos 2\,\Psi_1) - m_h \sin \Psi_1}{1 + \frac{b_h}{2}(1 - \cos 2\,\Psi_1) + m_h \sin \Psi_1}} \quad (4)$$

Ψ_1 is the grazing angle in radians

b_V, b_h, m_V, and m_h are complex parameters used to calculate the vertical and horizontal reflection components (Equations 5a-5d)

$$b_V = \frac{\varepsilon_r^2 + X^2}{S^2 + q^2} \quad (5a)$$

$$b_h = \frac{1}{S^2 + q^2} \quad (5b)$$

$$m_v = \frac{2(S\varepsilon_r + qX)}{S^2 + q^2} \qquad (5c)$$

$$m_h = \frac{2S}{S^2 + q^2} \qquad (5d)$$

ε_r is the relative dielectric constant of either the Earth or Orbiter surface (no units)

S is a function of grazing angle and complex dielectric constant (equation 6a)

X is the imaginary component of relative dielectric constant (equation 6b)

q is a function of S and X (equation 6c)

$$S = \sqrt{\frac{\left[(\varepsilon_r - \cos^2\Psi_1)^2 + X^2\right]^{1/2} + (\varepsilon_r - \cos\Psi_1)}{2}} \qquad (6a)$$

$$X = 1.80X10^{10}\left(\frac{\sigma}{F}\right) \qquad (6b)$$

$$q = \frac{X}{2S} \qquad (6c)$$

σ is the conductivity of the respective reflecting surface in Siemens/meter

F is the frequency in Hz

The reflection coefficient approaches unity for small grazing

angles and decreases as the grazing angle increases. Along with the circular reflection coefficient there is also the circular phase lag, ϕ_c, which has a vertical and horizontal phase component. The simplified form for the calculation of the circular phase lag is written in equation (7) as

$$\phi_c = \frac{\phi_V + \phi_H}{2} \qquad (7)$$

ϕ_V is the vertical phase lag in radians

ϕ_H is the horizontal phase lag in radians

The horizontal and vertical phase lag components are given in equations (8) and (9) (Reference H) as

$$\phi_V = \tan^{-1}\left(\frac{X \sin \Psi_1 - q}{\varepsilon_r \sin \Psi_1 - S}\right) - \tan^{-1}\left(\frac{X \sin \Psi_1 + q}{\varepsilon_r \sin \Psi_1 + S}\right). \qquad (8)$$

$$\phi_H = \tan^{-1}\left(\frac{-q}{\sin \Psi_1 - S}\right) - \tan^{-1}\left(\frac{q}{\sin \Psi_1 + S}\right) \qquad (9)$$

The phase lag is a function of the dielectric and conductive properties of the reflective surface, grazing angle, and frequency of the transmitted signal from the TDRS.

4.2.1 Earth Reflective Characteristics

The reflective characteristics of Earth refer to the shape of the reflecting surface and the atmospheric environment. The spherical shape of the Earth is taken into account by the spherical divergence factor, D_e. The spherical divergence factor is an abstract measure of the reflected field off the Earth received at the Ku-Band Antenna on the Orbiter as it approaches the TDRS in its circular orbit about the Earth. The divergence factor approaches zero as the grazing angle, Ψ_1, approaches zero making the received field the same as that of free space. The grazing angle is that angle between the path made by the incident component of the indirect signal and a plane tangent at the point of wave impingement on the surface of the Earth. The spherical divergence factor for Earth is calculated by equation (1) found in Reference I as.

$$D_e = \frac{a_e(r_1 + r_2)\sin\tau_2\cos\tau_2}{\sqrt{[(a_e + z_2)r_1\cos\tau_3 + (a_e + z_1)r_1\cos\tau_1](a_e + z_1)(a_e + z_2)\sin\theta}} \qquad (10)$$

a_e	is the effective radius of the Earth in meters (8.986333333×10^6 meters)
r_1 & r_2	are the distance components of the indirect wave in meters
z_2	is the altitude of the TDRS in meters
z_1	is the altitude of the Orbiter in meters
τ_1	is the angle between a line from earth's center to the Orbiter and the selected wave moving towards the Orbiter in radians
τ_2	is the complement of the grazing angle; the angle between the normal on the tangent at the point of reflection and the incident wave of the indirect

signal in radians

τ_3 is the angle between a line from the earth's center to the TDRS and the incident component of the indirect signal in radians

θ is the angle made by the arc distance between the Orbiter and TDRS relative to the earth's center in radians

4.2.2 Orbiter Reflective Characteristics

The reflective properties of the orbiter's surface, which is assumed to be a cylinder, is accounted for by the cylindrical divergence factor which has been found to be the square root of the spherical divergence. The radius of the orbiter's cylindrical fuselage is 2.992 meters. The cylindrical divergence is a function of the grazing angle, Orbiter radius, and the height of the Ku-Band antenna from the orbiter's surface. The TDRS is assumed to be in the far field which will result in incident parallel wave paths for the direct and indirect signals. The cylindrical divergence is calculated by use of equation (11).

$$D_{cy} = \sqrt[4]{\frac{a \sin \Psi_1}{[a \sin \Psi_1 + 2r_2]\left(\left(1 + \frac{z_1}{a}\right) \sin\left(\cos^{-1}\left(\frac{a^2 - (a + z_1)^2 - r_2^2}{2a(a + z_1)}\right)\right)\right)}} \quad (11)$$

a is the radius of the orbiter's fuselage in meters ($a = 2.9921005843281686563$ m.)

Ψ_1 is the grazing angle made by the incident wave of the indirect signal and tangent at the reflection point in radians (Reference Figure 2)

z_2 is the Ku-Band antenna height from the orbiter's surface in meters

r_2 is the reflected distance component of the indirect signal in meters

The cylindrical divergence factor for the Orbiter has been shown to be the square root of the spherical divergence that is found in Reference I. The effective radius parameter, a_e, is replaced by the orbiter's radius, a, in equation (11) because operation of the Ku-Band Communications will only occur during on-orbit activities where there are no refractive and diffractive effects from an atmosphere.

4.3 Path Difference Relative to Earth and Orbiter

The final factor required to compose an equation to calculate a reasonable value for the magnitude of multipath due to the Earth and Orbiter is the path difference. Two path difference equations will be discussed in this section, one for the Earth geometry and one for the Orbiter geometrical configuration. The Earth path difference, Δr, is a function of altitude and path traveled by the Orbiter and TDRS relative to the earth's center. There are three components required to calculate the Earth path difference, the incident and reflected path distances of the indirect signal, and the path distance of the direct signal. The two components of the indirect signal are calculated by equations (12) and (13) in meters found in Reference I.

$$r_1 = \sqrt{a_e^2 + (a_e + z_2)^2 - 2\, a_e\, (a_e + z_2) \cos \frac{d_1}{a_e}} \qquad (12)$$

$$r_2 = \sqrt{a_e^2 + (a_e + z_1)^2 - 2a_e(a_e + z_1) \cos \frac{d_2}{a_e}} \qquad (13)$$

a_e is the effective earth's radius in meters (8.986333333×10^6 meters)

z_1 is the altitude of the Orbiter in meters

z_2 is the altitude of the TDRS in meters

d_1&d_2 are the arc distances for the incident and reflected signal of the indirect wave in meters (reference figure 1)

The path of the direct signal between the TDRS and Orbiter is calculated by equation (14) in meters.

$$r = a_e \sqrt{\left[\left(\frac{z_1}{a_e}\right)^2 + \left(\frac{z_2}{a_e}\right)^2 - 2\left(\frac{z_1}{a_e}\right)\left(\frac{z_2}{a_e}\right) + 2\left[1 + \frac{z_1}{a_e} + \frac{z_2}{a_e} + \left(\frac{z_1}{a_e}\right)\left(\frac{z_2}{a_e}\right)\right]\left[1 - \cos\left(\frac{d}{a_e}\right)\right]\right]} \quad (14)$$

d is the arc distance of the direct signal relative to the spherical surface of the Earth in meters

The Orbiter path difference, Δr_o, is a function of the grazing angle and antenna height above the orbiter's surface. The path difference is calculated using equation (15) found in Reference J as

$$\Delta r_o = 2z_1 \tan \Psi_1 \quad (15)$$

since $z_2 >> z_1$

$$\tan \Psi_1 = \frac{z_1 - z_2}{d} \approx \frac{z_2}{d}$$

z_2 is the altitude of the TDRS in meters

z_1 is the height of the Ku-Band antenna above the orbiter's surface in meters

Ψ_1 is the grazing angle in radians

4.4 Earth and Orbiter Multipath Factors

The Earth and Orbiter multipath factors which represent a direct and indirect component compose the received signal (field) at the Ku-Band Communications Antenna on the Orbiter. This field is a result of the transmitted signal from the TDRS. The resultant multipath factor for both Earth and Orbiter encompasses the five factors outlined in Sections 4.1-4.3 which are the electrical properties of the reflecting surface, the geometrical shape of the reflecting object, reflection properties of the reflective surfaces, surface roughness, and the path difference of the direct and indirect signal. The multipath factor representing the multipath phenomena is a voltage ratio parameter. Equation (16) is used to represent Earth multipath.

$$L_{MP}(dB) = 20 \log \left| 1 + \rho_s \left(\frac{r}{r_1 + r_2}\right) D_e \left|\hat{R}_c\right| e^{-j\left(\frac{2\pi}{\lambda} \Delta r + \phi_c\right)} \right| \quad (16)$$

ρ_s	is the scattering coefficient (no units)
$\frac{r}{r_1+r_2}$	is the differential loss factor between the direct and indirect signal (no units)
D_e	is the spherical divergence factor (no units)
$\hat{R}_c$	is the circular polarized reflection coefficient magnitude (no units)
Δr	is the path difference of the direct and indirect wave in meters relative to the Earth in meters
ϕ_c	is the phase lag of a circular polarized wave in radians
π	is 3.14159265358979324
λ	is the wavelength in meters

Equation (16) is used to account for the multipath impact on the sum and difference radiation patterns as will be shown in section 4.6. This equation is also used to account for the variation of frequency and grazing angle to evaluate the limitations of the tracking subsystem of the Ku-Band Communications Antenna relative to the Earth.

The same factors that apply for Earth multipath will also apply for Orbiter multipath with some modification. These factors that are modified include the scattering coefficient, the differential loss factor between the direct and indirect signal, path difference, and the divergence factor. The remaining factors, reflection coefficient and electrical surface properties, still must be considered. The surface of the Orbiter is assummed to be smooth having a scattering coefficient equal to unity. Another modification is the differential loss factor between the direct and indirect signal which is negated considering the TDRS to be in the far field. The approach taken is to consider the direct and indirect traveling waves to have parallel paths incident to the surface of the Orbiter. The path difference, therefore, will be a function of grazing angle and the height of the Ku-Band antenna above the surface of the Orbiter. The only other major modification for Orbiter multipath relative to Earth multipath is the divergence factor which requires the divergence to be from the cylindrical surface of the Orbiter. The cylindrical divergence has been proven to be the square root of the spherical divergence factor. This multipath parameter is calculated assuming the TDRS to

be in the far field. After incorporation of these modifications, the Orbiter multipath equation used in the computer program is shown as equation (17), which is a voltage calculation.

$$L_{MP}\ (dB) = 20 \log \left| 1 + \rho_s\ D_{cy} |\hat{R}_c| e^{-j\left(\frac{2\pi}{\lambda}\ \Delta r_o + \phi_c\right)} \right| \quad (17)$$

L_{MP}	is the multipath factor in dB
ρ_s	is the scattering coefficient equal to one (no units)
D_{cy}	is the cylindrical divergence factor (no units)
$\hat{R}_c$	is the circular reflection coefficient magnitude for a circular polarized wave (no units)
Δr_o	is the path difference between the direct and indirect signal relative to the Orbiter in meters
ϕ_c	is the reflection coefficient circular phase lag in radians
λ	is the wavelength in meters
π	is 3.14159265358979324

The factors in these multipath equations, 16 & 17, which are varied to evaluate the multipath phenomena include frequency, grazing angle, and electrical surface properties pertaining to the Earth and Orbiter.

4.5 Fortran Programs

The computer programs developed for this analysis are designed for the 1108 EXEC II system. The programs can be adapted to the 1110 EXEC VIII system by making control card changes. The subprograms that were used to complete this multipath analysis

include a plot program, Bessel Function program used to analyze the multipath impact on the sum pattern, a difference pattern function to evaluate multipath impact on the difference channel, and a computer program concerning the reflective effect on a signal in a multi-layer dielectric. The multiple-layer dielectric program was used to study the effect of the TPS on the reflected signal (indirect signal).

The programs developed for this analysis are contained in Appendix B which all use a double precision format to avoid errors due to round-off of the output data. The first two programs listed and flowcharted in the appendix (Figures 18-21) are used to give the results of Earth and Orbiter multipath as a function of either grazing angle or frequency. The remaining two programs (Figures 22-25) are used to show the effect of Earth and Orbiter multipath on the sum and difference channels for multiple offset angles as a function of grazing angle and frequency.

The components previously discussed that make up the multipath programs for this evaluation are incorporated into two general computer programs relative to the Earth and Orbiter. The two programs are then adapted to study the multipath impact on the sum and difference channels of the tracking system of the Ku-Band Communications Antenna.

4.6 Multipath Impact on Radiation Patterns for Sum and Difference Channels

The multipath effect on the sum and difference channels of the Ku-Band tracking system has been evaluated by combining the individual radiation pattern and the multipath factor into their respective electric field equations. The electric field of the direct and indirect signals relative to the sum pattern are written as a function grazing angle, Ψ_1 , frequency, and offset angle, ϕ .

The geometry used to evaluate the impact of multipath on the sum and difference tracking channels is illustrated in Figure 3A. This geometry is utilized for both the Earth and Orbiter related multipath math models. The dotted line illustrates the path of the signal relative to the Earth multipath math model.

In Figure 3A the indirect signal is only illustrated to prevent possible confusion with a line representing the direct signal. The antenna radiation patterns are calculated for offset angles from the horizontal denoted by ϕ in Figure 3B between zero and ten degrees. The negative offset ($-\phi$) would refer to the Ku-Band Communications antenna being pointed towards the Earth or Orbiter surface. The electric field equations for the direct and indirect signals that are used to illustrate the Earth and Orbiter multipath impact on the sum pattern are shown in equations (18) and (19), respectively.

$$E(\Psi_1 - \phi) = \left| \frac{2\lambda}{\pi D} \left(\frac{J_1\left[\left(\frac{\pi D}{\lambda}\right) \sin\left(\Psi_1 - \phi\right)\right]}{\sin\left(\Psi_1 - \phi\right)} \right) \right| \qquad (18)$$

$$E(-\Psi_1 - \phi) = \left| \frac{2\lambda}{\pi D} \left(\frac{J_1\left[\left(\frac{\pi D}{\lambda}\right) \sin(-\Psi_1 - \phi)\right]}{\sin(-\Psi_1 - \phi)} \right) \right| \qquad (19)$$

D	is the diameter of the Ku-Band antenna in meters
Ψ_1	is the grazing angle in radians
ϕ	is the offset with respect to the horizontal of the antenna in radians
J_1	is the first order Bessel function (Reference J)
$J_1\left[\left(\frac{\pi D}{\lambda}\right) \sin(\Psi_1 - \phi)\right]$	is the Bessel function argument for the direct signal
$J_1\left[\left(\frac{\pi D}{\lambda}\right) \sin(-\Psi_1 - \phi)\right]$	is the Bessel function argument for the indirect signal

Equations (18) and (19) are combined with the multipath equations (16) and (17) to evaluate the multipath impact on the sum radiation pattern relative to the Earth and Orbiter. The resultant modified multipath equation for Orbiter multipath is shown in equation (20).

$$L_{MP}' \text{ (dB)} = 20 \log \left| E(\Psi_1-\phi) + E(-\Psi_1-\phi)(\rho_s D_{c\gamma} \left|\hat{R}_c\right| e^{-j\left(\frac{2\pi}{\lambda} \Delta r_o + \phi_c\right)}) \right| \qquad (20)$$

$E(\Psi_1-\phi)$	is the electric field of the direct signal in volts/meter
$E(-\Psi_1-\phi)$	is the electric field of the indirect signal in volts/meter

Equation (20) accounts for the combined effect of the direct and indirect components of the resultant signal received at the Orbiter from the TDRS. The indirect signal field includes the effect of multipath off the Orbiter.

The result of Orbiter multipath impact on the sum radation pattern is shown in Figure 4. This radiation pattern illustrates the results of a signal being received at a grazing angle of 1.5° and the antenna at an offset angle of 1.5° in a multipath environment. The radation pattern is isotropic as all the patterns are in the design note. The error or peak shift of this pattern is shown to be .08° from the 1.5° point on the grazing angle coordinate. Sum channel radation patterns were also evaluated for offset angles between ±5° within a 0-10° grazing angle spectrum.

The Earth multipath impact on the sum radiation pattern is calculated using equation (16). The resultant modified Earth multipath equation relative to the sum channel is shown in equation (21) as

$$L''_{MP}\ (dB) = 20 \log \left| E(\Psi_1-\phi) + E(-\Psi_1-\phi)\left(\rho_s\left(\frac{r}{r_1+r_2}\right) D_e |\hat{R}_c| e^{-j\left(\frac{2\pi}{\lambda}\Delta r + \phi_c\right)}\right)\right| \quad (21)$$

The equations used to calculate the direct and indirect signals in order to show the impact on the difference channel employs a sine function as shown in equations (22-23) which were derived from Reference E.

$$E'\ (\Psi_1 - \phi) = \sin\left(\pi\left(\frac{\Psi_1-\phi}{HPBW}\right) + \pi\right) - \sin\left(\pi\left(\frac{\Psi_1-\phi}{HPBW}\right)\right) \quad (22)$$

$$E''(-\Psi_1 - \phi) = \sin\left(\pi\left(\frac{-\Psi_1 - \phi}{HPBW}\right) + \pi\right) - \sin\left(\pi\left(\frac{-\Psi_1 - \phi}{HPBW}\right)\right) \quad (23)$$

Ψ_1	is the grazing angle in radians
ϕ	is the offset angle with respect to the horizontal of the antenna in radians
π	is 3.14159265358979324
HPBW	is the half-power beamwidth (1.30^{o})

To account for the multipath impact on the difference channel from the Orbiter and Earth, $E(\Psi_1 - \phi)$ and $E(-\Psi_1 - \phi)$ are replaced by $E'(\Psi_1 - \phi)$ and $E''(-\Psi_1 - \phi)$ in equatins (20) and (21). The results from the difference channel function is repetitious which means the graphs are interpreted in a localized manner i.e. for a particular offset angle (grazing angle) on the coordinate axis within $\pm$ X degrees the null shift may be read directly. An example is shown in Figure 5 for the Orbiter multipath impact on the difference channel where the offset is 3.5 degrees having a null shift of .18 degrees. The modified Earth and Orbiter multipath equations (20 and 21) pertaining to the sum and difference channels are incorporated into the multipath programs shown in Appendix B, Figures 44 and 46, as a function of grazing angle and frequency.

4.7 Evaluation of the Multipath Effects

A general computer program has been written to evaluate the impact of multipath on the Ku-Band Communications Antenna performance. The program has many modifications that were written for the

1108 Executive II system. These modifications were written to show the impact of multipath on the received signal from the TDRS to the Orbiter. The different modifications aid the evaluation of multipath from the Earth and Orbiter as a function of grazing angle and frequency. Another modification has been written to evaluate the multipath impact on the sum and difference radiation patterns to determine the antenna limits of the Ku-Band tracking for the communications system.

4.7.1 Evaluation and Recommended Implementation for the Ku-Band Antenna Referenced to Earth Multipath

The five different surfaces chosen to represent the earth's composition are: sandy soil, wet soil, fresh and salt water, and ice. The results showed minimal multipath magnitudes of 10^{-3} and 10^{-13} between 0 and .2 degree grazing as a function of grazing angle. Frequency also shows a minimal effect relative to Earth multipath at a grazing angle of $.2^{o}$ for the five respective Earth surfaces. Figure 6 shows the Earth multipath mangitude from sandy soil which is also representative of the other four Earth surfaces as a function of frequency.

The Earth multipath impact to the sum and difference patterns as a function of grazing angle shows a minimal effect as illustrated in Figures 7-8 from sandy soil. The peak and null shifts are very minimal in the radiation patterns of Figures 7 and 8. This impact is also representative of the other four Earth surfaces.

The Earth multipath impact to the sum and difference pattern as a function of frequency had the same minimal impact for small grazing angles from the five respective surfaces considered on the earth's surface as shown in Figures 9 and 10, respectively. The curves shown in Figures 9-10 show no scalloping of the pattern indicating that there may not be any interference within the frequency bandwidth of the TDRS/Orbiter communications link. Therefore, the impact of Earth multipath as a function of frequency shows that there is no effect as shown in Figures 9 and 10.

The multipath from the earth's surface will have a minimal effect on the signal transmitted from the TDRS at a carrier frequency of 13.775 GHz. Also, the pointing error or peak and null shifts are at a minimum for the sum and difference patterns of the TDRS carrier frequency producing a good tracking signal.

In relation to the Earth multipath, the modulation of the carrier signal from the Tracking Data Relay Satellite (TDRS) may be a despread signal due to the results shown in this paragraph. Recommended implementation of the Ku-Band Antenna is not restricted due to Earth multipath and therefore may function with very little interference from the earth's reflections.

4.7.2 Evaluations and Recommended Implementation for the Ku-Band Antenna Referenced to Orbiter Multipath

The Orbiter multipath factor shown in Figure 11 as a function of grazing angle indicates that it is a cyclic function with increasing magnitude and angle. When integrated with a signal

degradation or enhancement may result. The Orbiter multipath factor as a function of frequency illustrated in Figure 12 shows that the multipath nulls do not occur within the r.f. bandwidth of the TDRS/Orbiter signal for grazing angles less than 3.5 degrees.

The Orbiter multipath math model was used to show the peak and null shifts of the sum and difference patterns for grazing angles between 0° and 10° at offset angles between $\pm 5^o$. Table 2 contains a tabulation of these respective shifts or pointing errors for corresponding offset angles within the grazing angle spectrum. Table 2 shows that minimum pointing error for the sum pattern occurred at 3.5^o offset (grazing angle) and 2.0^o offset (grazing angle) for the difference pattern.

The Orbiter multipath results shown in Figure 13 as a function of grazing angle shows that the minimum peak shift of the sum pattern occurred at a grazing angle of 3.5 degrees. Therefore, it may be concluded that the worst case tracking due to multipath interference will occur when the grazing angle is 0-3.5 degrees in relation to the sum pattern. There are still some minor perturbations in the sidelobes which are at a level of -17 dB down from the main lobe.

The minimum null displacement of the difference pattern was found to be at a grazing angle of two degrees as shown in Figure 14. The difference pattern is the signal from which the elevation and azimuth difference tracking channel is derived. Figure 14 shows that there are possibilities for false lock-on at lower

Offset Angle, ϕ (degrees)	Sum Pattern Pointing Error (degrees)	Difference Pattern (degrees)
-2.0	.18	.185
-1.5	.02	.52
-1.0	.23	.60
- .5	.20	.25
0	.30	.02
.5	.20	.10
1.0	.20	.20
1.5	.08	.15
2.0	.50	.001
2.5	.50	.02
3.0	.50	.20
3.5	0	.18
4.0	. 1	1.10
4.5	.05	.05
5.0	.02	.04

Table 2 Pointing Errors Due To Orbiter Multipath For Sum And Difference Radiation Patterns.

grazing angles shown by the small glich or false null in the pattern just before the main null. There are a number of false nulls in Figure 14 which accounts for the repetitous sine function used to produce this pattern. With this false null being close to the actual null which is characteristic in a multipath environment a spread modulation is recommended to avoid as little power loss as possible in the signal. In a spread spectrum modulation or pseudo noise modulation the power bandwidth is large decreasing the possibility of total signal cancellation.

The impact of Orbiter multipath on the sum and difference pattern as a function of frequency shows a possibility of interference. The center frequency of the carrier, 13.775 GHz, is shifted close to the null between the mainlobe and first sidelobe of the sum pattern for an offset of -2.0° and +3.0° at small grazing angles (0-1.32°) as shown in Figures 15-16. Therefore, the multipath interference may occur at these respective offsets with the center frequency of the carrier being shifted close to the null between the mainlobe and sidelobe of the sum pattern.

The difference channel is affected by multipath in relation to frequency in that the TDRS carrier frequency bandwidth is at the top of the difference lobe for offset angles greater than 2.5 degrees and lower in the null for offset angles of less than 2.5° at small grazing angles (0-1.32°). Therefore, tracking of an object would be better at +2.5° off the horizontal of the beam. This result is shown in Figures 17 for offset angles of +2.5° relative to the difference pattern.

In relation to Orbiter multipath, there is a possibility for cancellation of the TDRS signal as explained in this paragraph. Therefore the recommended modulation to use is pseudo noise (PN) for the orbiter multipath environment.

5.0 RESULTS

The purpose of this section is to summarize the factors from the previous disussion to define the rationale for pertinent recommendations for operation of the Ku-Band tracking in a multipath environment.

The first three discussion sections (4.1-4.3) reviewed the factors and geometries used to build the math models to analyze multipath relative to either the Earth or Orbiter. The r.f. bandwidth (13.75-13.80 GHz) analyzed was the Ku-Band TDRS/Orbiter communications link which operates at a center frequency of 13.775 GHz. The calculations performed considered the geometrical shapes of a sphere and cylinder for the Earth and Orbiter. The factors that are considered in these math models are grouped into three areas which include: the electrical characteristics of the reflecting surfaces, reflective surface characteristics, and the path differences between the direct and indirect signal from the TDRS. Equations 16-17 represent the multipath factor relative to the Earth and Orbiter, respectively. These equations may be adaptable to numerous surface conditions on the Earth or Orbiter.

Multipath at small grazing angles can have an impact on the operation of the Ku-Band tracking system. The multipath phenomena may impact the system by shifting and scalloping of the sum and difference signals which could result in a false lock-on of the TDRS signal as shown in Figure 37, and also a r.f. phase variation which could result in partial or total cancellation within the spectrum of the TDRS signal.

The received signal on the TDRS/Orbiter link (Forward Link) may be enhanced or degraded by the multipath factor dependent on the r.f. phase variation between the direct and indirect signal, and also the electrical characteristics of the reflecting surface. The sum and difference curves shown in Figures 37 and 38 show a minimum peak shift of zero degrees for an offset of 3.5^{o} and a minimum null shift of $.001^{o}$. The sum pattern will not have maximum tracking for grazing angles of 3.5^{o} or less. The difference pattern showed a minimum shift for grazing angles of 2 degrees or less. The difference between the peak shift and null shift which has the maximum difference will yield the best tracking signal.

The most favorable modulation for a multipath environment is considered to be a spread spectrum or pseudo noise type of modulation. This fact has been shown to be true in past history. The spread spectrum spacing for Ku-Band is 2.9599 kHz over a 6.056 MHz bandwidth. The spread spectrum requires a small beamwidth, as is baselined, in order to operate properly. The spread spectrum has a very good advantage over other modulations such as the despread modulation where, if cancellation does occur, the cancellation may be very slight in comparison with the despread modulation.

6.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of this multipath study relative to the Earth and Orbiter, the following communication oriented recommendations are made for the Ku-Band Communications Antenna tracking system.

(1) The multipath effects from the earth's surface will have a very minimal impact on the TDRS/Orbiter communications link (13.75-13.80 GHz). As a result communication may be maintained when the TDRS is within the line of site of the Orbiter.

(2) The Orbiter reflections will impact the sum and difference patterns limiting the antenna scan of the Ku-Band tracking system. Grazing angles of 3.5 degrees or less will generate an impact on the received signal by scalloping of the radiation patterns and may also result in a false lock-on. The recommended scan limit for Orbiter multipath corresponds to a minimum grazing angle of 3.5 degrees.

(3) Use of the spread spectrum (pseudo noise modulation) is recommended to create minimum cancellation impact and may be used during acquisition if the signal-to-noise ratio is adequate.

(4) Further use of this math tool may be applied to radar problems and changes in the baseline antenna patterns.

7.0 REFERENCES

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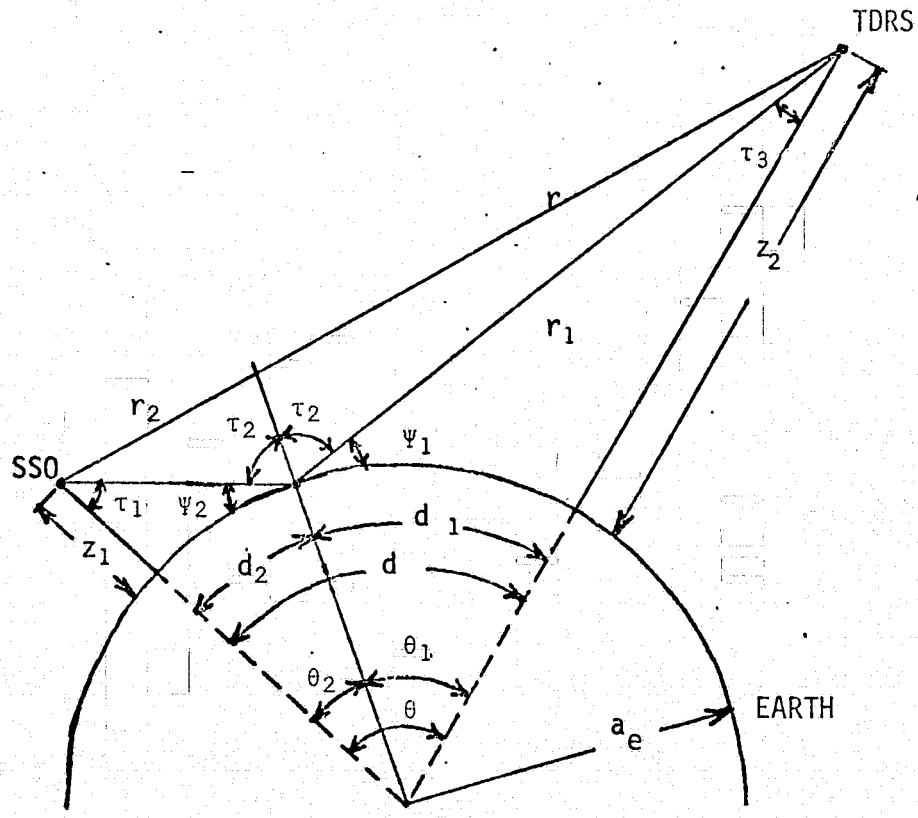
APPENDIX A
FIGURES



$$\tau_1 = \sin^{-1}\left(\frac{a_e \sin\left(\frac{d_2}{a_e}\right)}{r_2}\right) \quad \text{(radians)}$$

$$\tau_2 = \cos^{-1}\left(\frac{(a_e + z_2)\cos\tau_3 - r_1}{a_e}\right) \quad \text{(radians)}$$

$$\tau_3 = \sin^{-1}\left(\frac{a_e \sin\left(\frac{d_1}{a_e}\right)}{r_1}\right) \quad \text{(radians)}$$

$$\Psi_1 = 90^o - \tau_2 \quad \text{(radians)}$$

$$\Psi_2 \simeq \Psi_1 \quad \text{(radians)}$$

WHERE:

$$d = \frac{\pi a_e \theta}{180^o} \quad \text{(meters)}$$

$$d_1 = d/2 + p\cos\left(\frac{\Phi + \pi}{3}\right) \quad \text{(meters)}$$

$$p = \frac{2}{\sqrt{3}}\sqrt{a_e\,(z_1 + z_2) + \left(\frac{d}{2}\right)^2} \quad \text{(meters)}$$

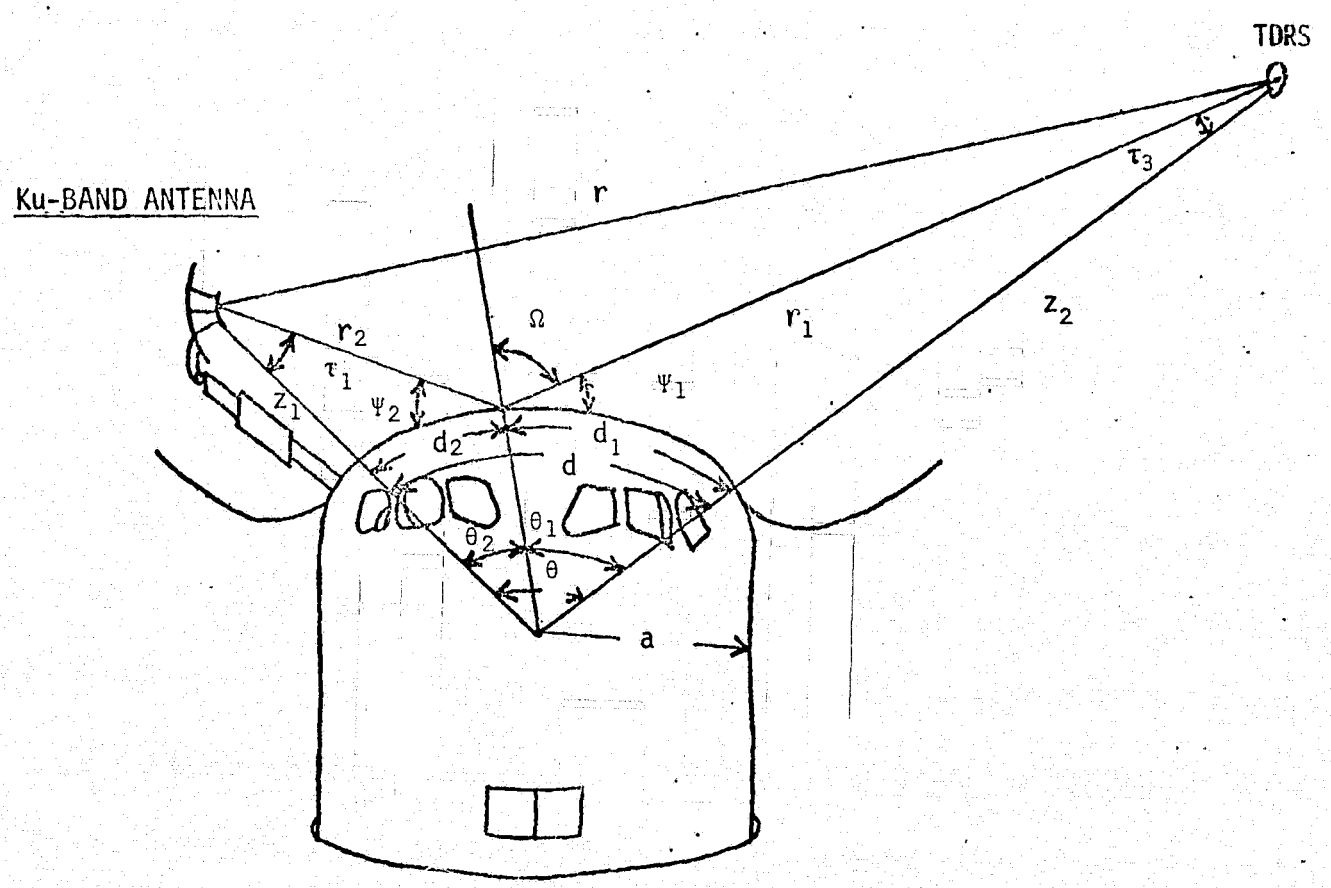
$$\Phi = \cos^{-1}\left(\frac{2a_e\,(z_1 - z_2)\,d}{p^3}\right) \quad \text{(meters)}$$

$$d_2 = d - d_1 \quad \text{(meters)}$$

$$\theta\ \text{max.} = \cos^{-1}\left(\frac{a_e}{z_1 + a_e}\right) + \cos^{-1}\left(\frac{a_e}{z_2 + a}\right) \quad \text{(radians)}$$

$$\theta = \cos^{-1}\left(\frac{(z_1 + a_e)^2 + (z_2 + a_e)^2 - r^2}{2\,(z_1 + a_e)\,(z_2 + a_e)}\right) \quad \text{(radians)}$$

FIGURE 1 EARTH MULTIPATH GEOMETRY



SHUTTLE ORBITER (FRONT VIEW)

$\theta' = \Omega + \frac{\pi}{2}$ (radians)

$\Psi_2 = \Psi_1$(radians)

$r_1 = \sqrt{a^2 + (a + z_2)^2 - 2\,a\,(a + z_2)\,\cos\frac{d_1}{a}}$ (meters) (Reference I)

$r_2 = \sqrt{a^2 + (a + z_1)^2 - 2\,a\,(a + z_1)\,\cos\frac{d_2}{a}}$ (meters) (References I)

WHERE:

$d = \frac{\pi\,a\,\theta}{180^o}$ (meters)

$d_2^1 = a\,\theta_2$ (0° grazing) (meters)

$d_2 = d_2' - 1.1 \times 10^{-4}$(meters)

$d_1 = d - d_2$ (meters)

$\theta = \cos^{-1}\left(\frac{(z_1 + a)^2 + (z_2 + a)^2 - r^2}{2\,(z_1 + a)\,(z_2 + a)}\right)$

FIGURE 2 ORBITER MULTIPATH GEOMETRY

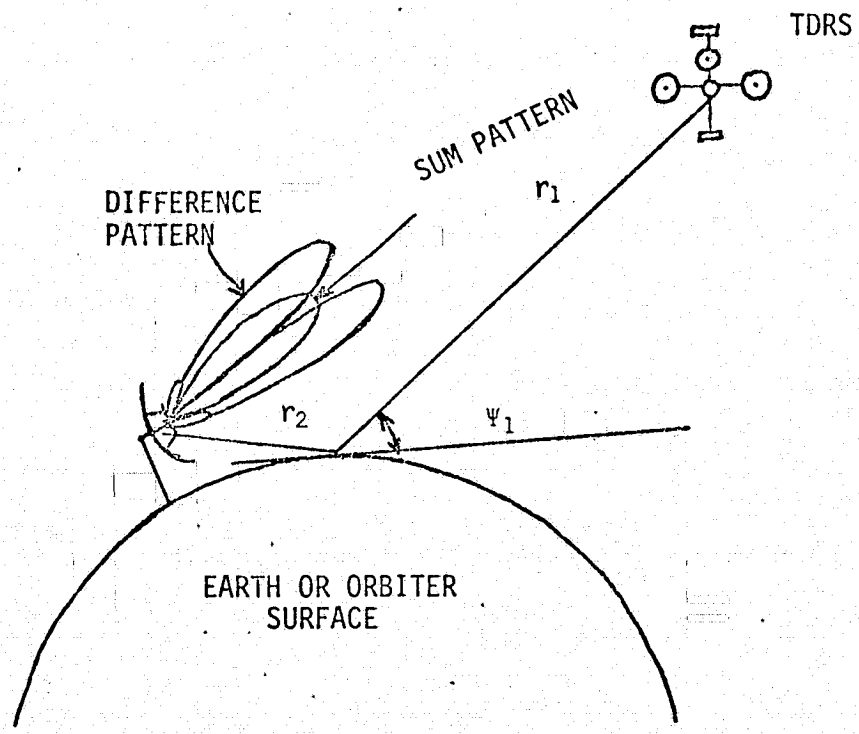


FIGURE 3A GENERAL RADIATION PATTERN GEOMETRY

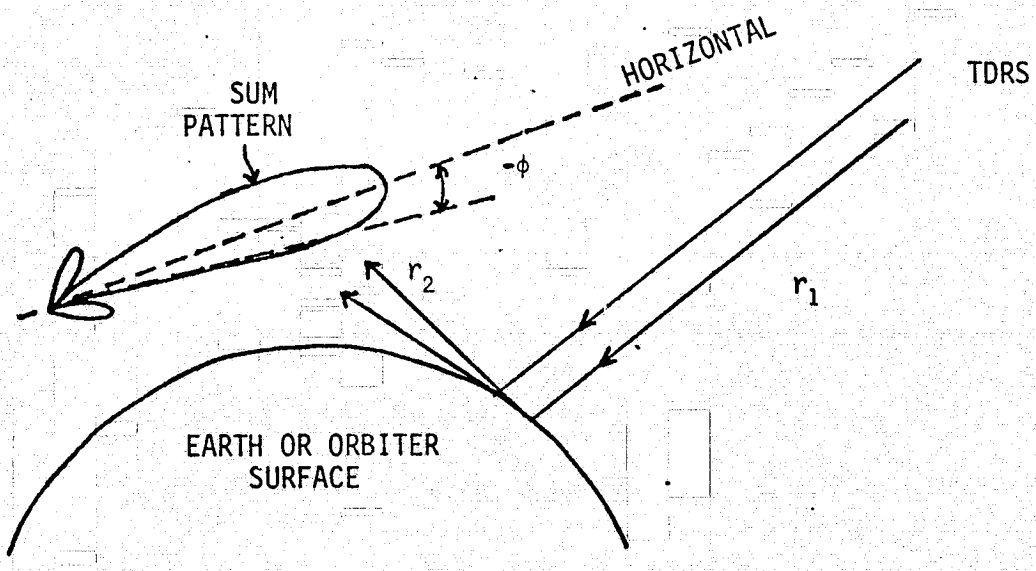


FIGURE 3B SUM RADIATION PATTERN GEOMETRY

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

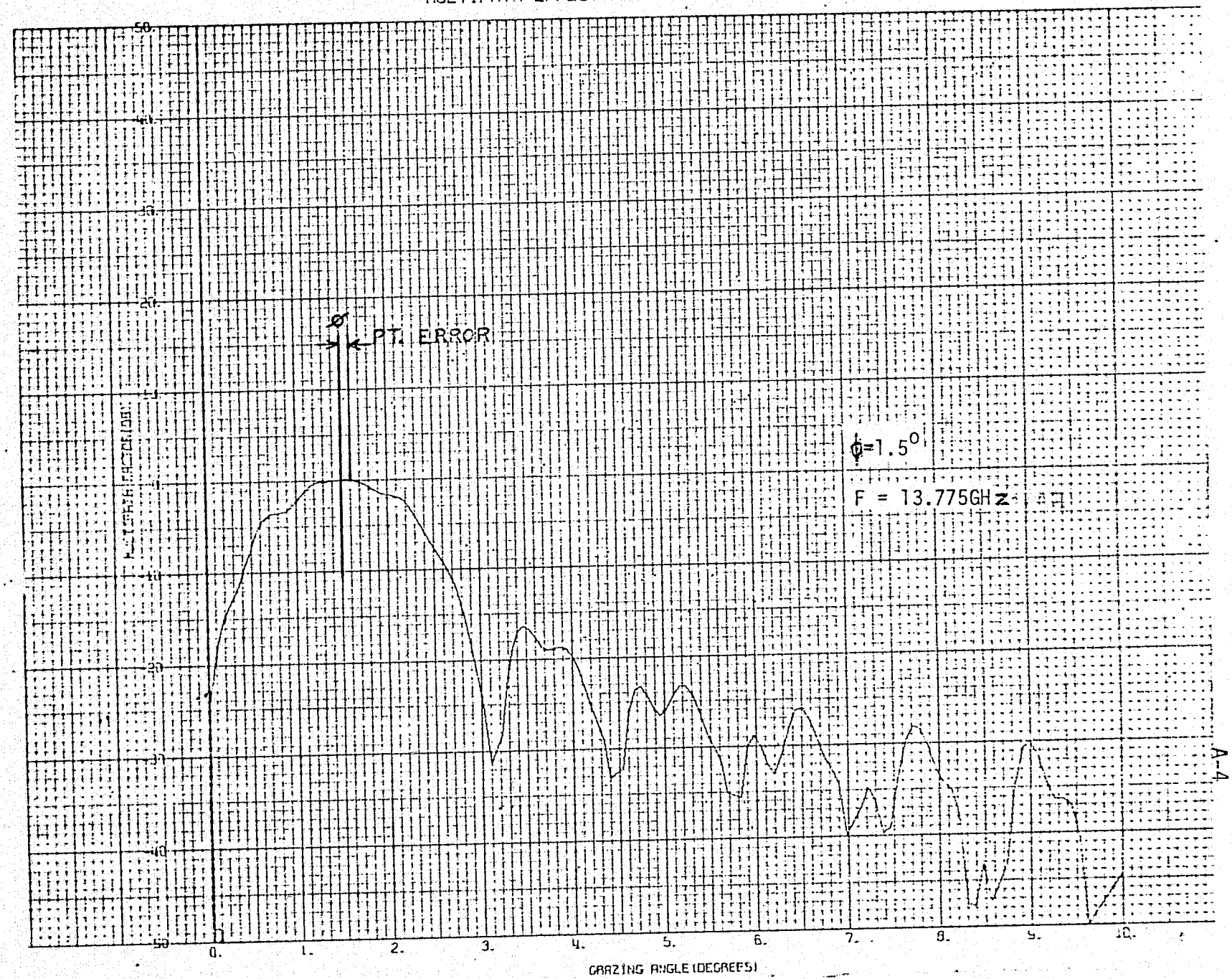


FIGURE 4 MULTIPLE EFFECT FROM THE ORBITER VEHICLE (SUM PATTERN IMPACT)

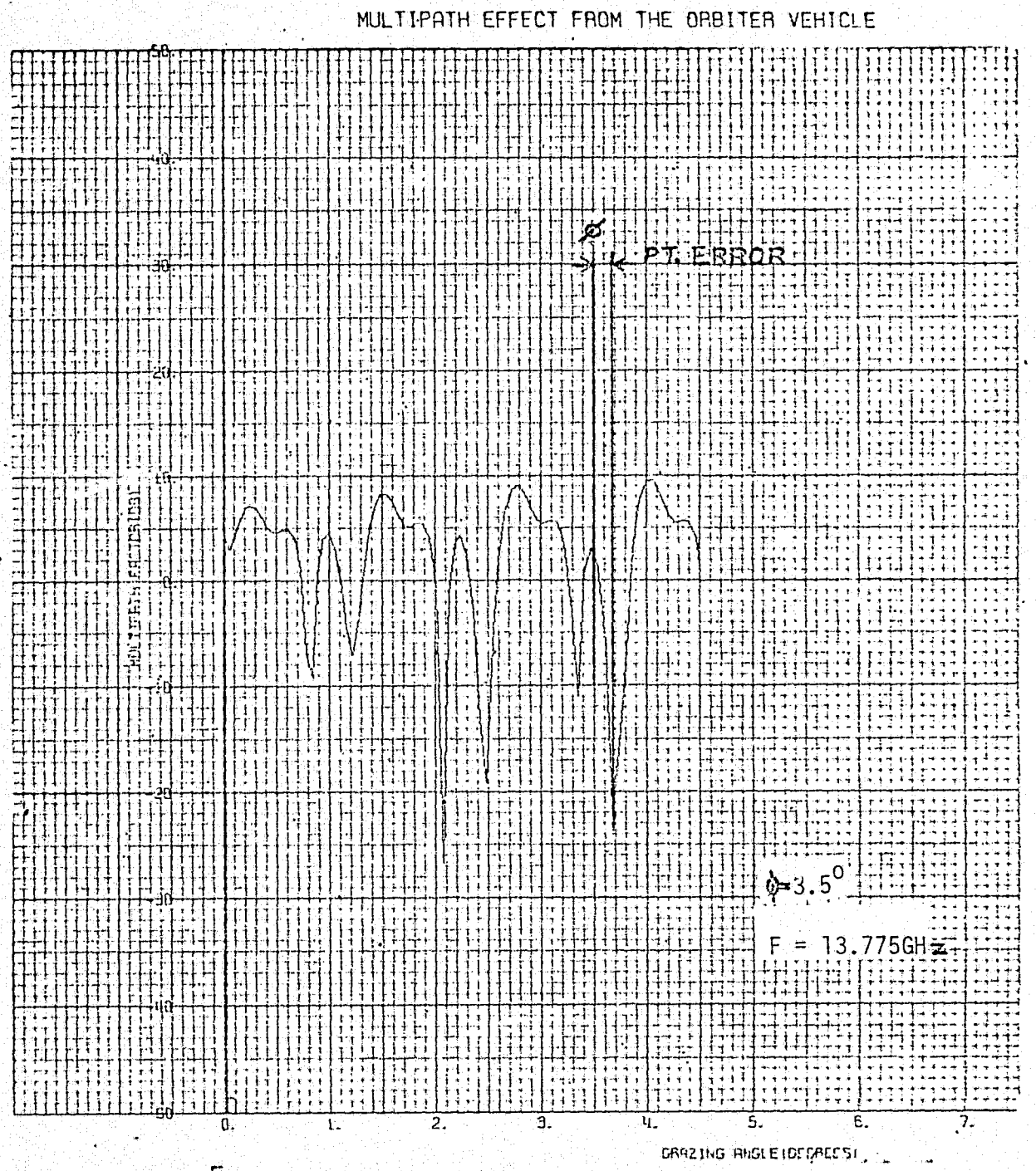


FIGURE 5 MULTIPATH EFFECT FROM THE ORBITER VEHICLE

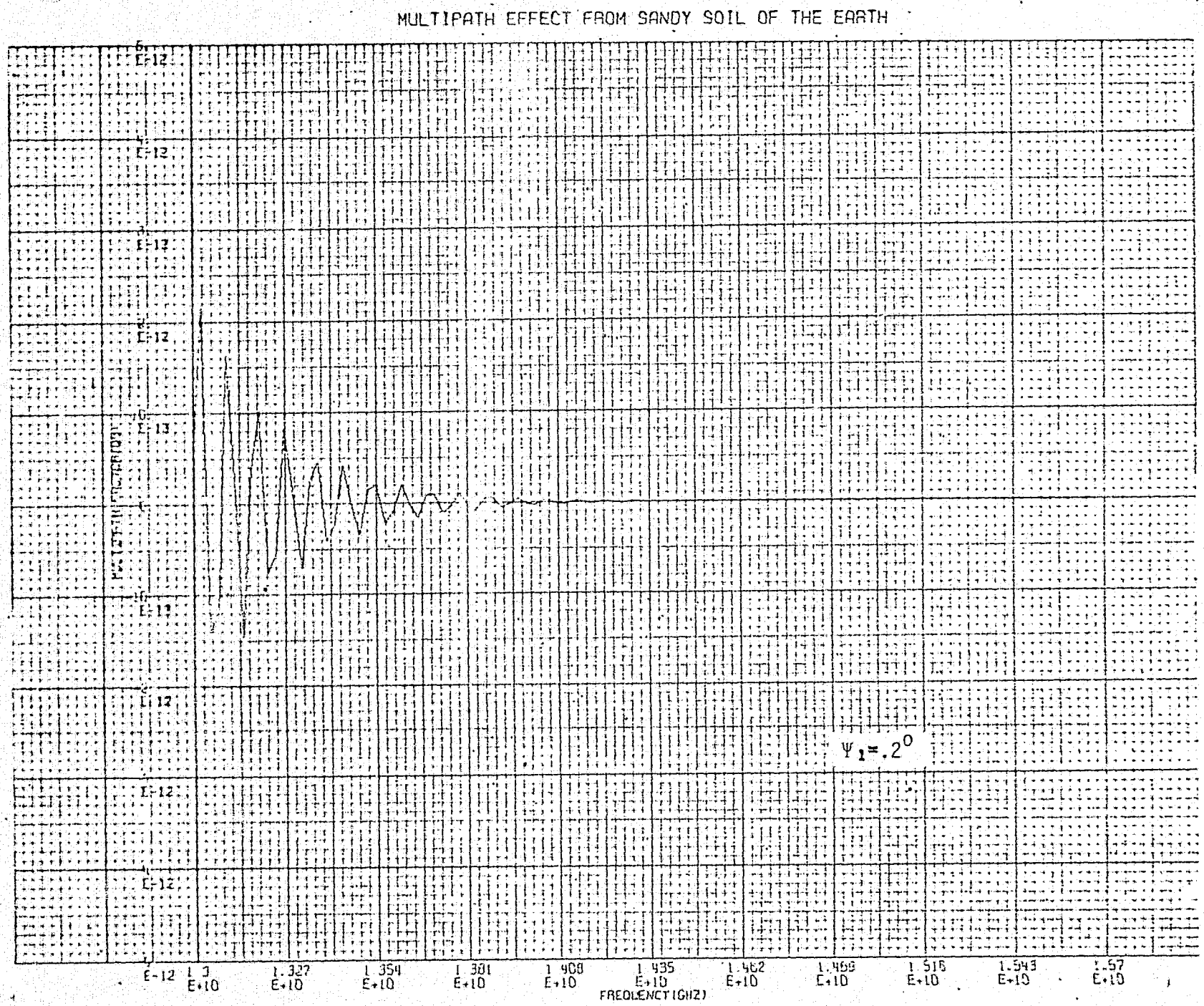


FIGURE 6 MULTIPATH EFFECT FROM SANDY SOIL OF THE EARTH'S SURFACE (FREQUENCY)

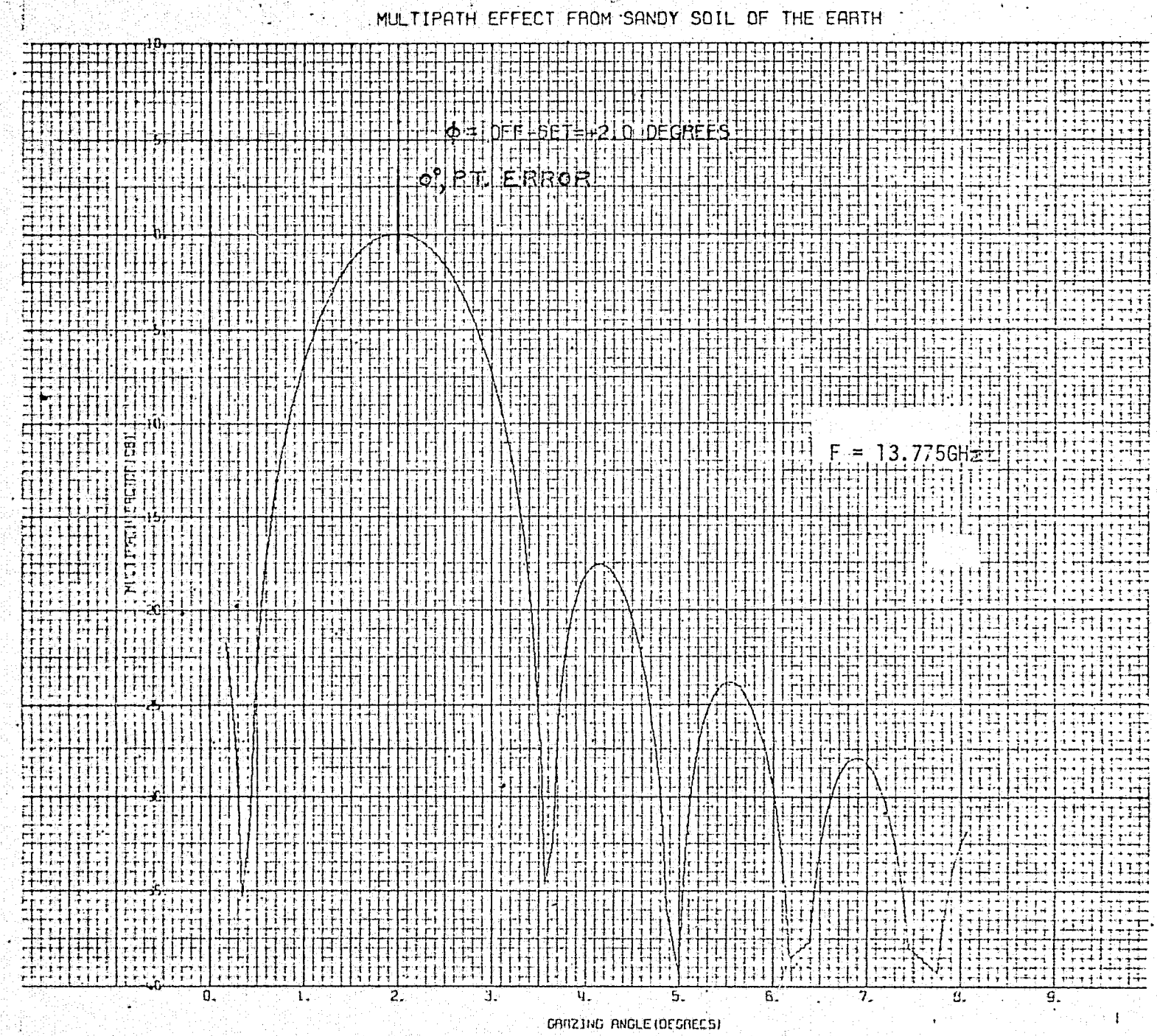


FIGURE 7 MULTIPATH EFFECT FROM SANDY SOIL OF THE EARTH'S SURFACE (SUM PATTERN IMPACT, GRAZING ANGLE)

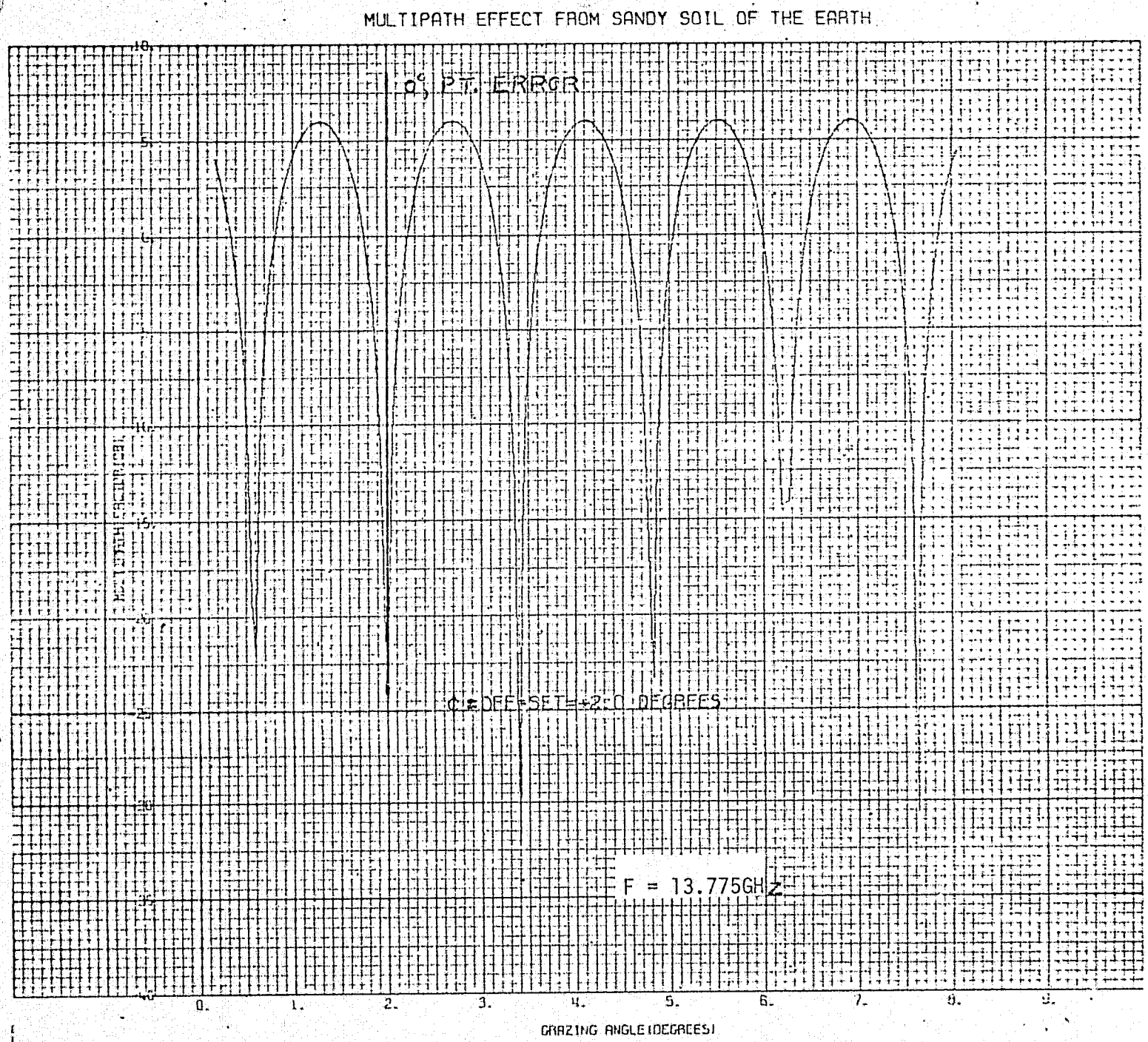


FIGURE 8 MULTIPATH EFFECT FROM SANDY SOIL OF THE EARTH'S SURFACE (DIFFERENCE PATTERN IMPACT, GRAZING ANGLE)

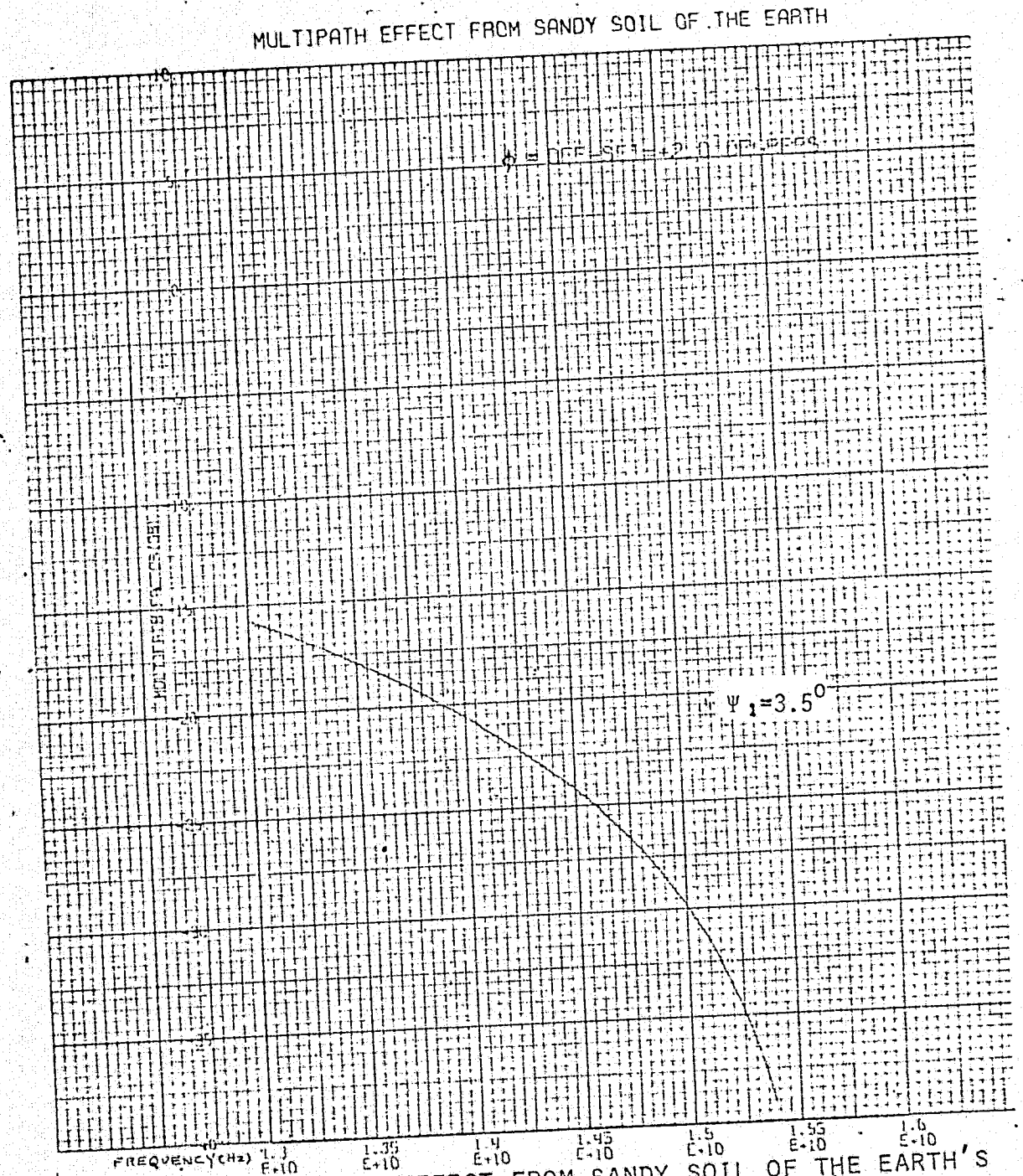


FIGURE 9 MULTIPATH EFFECT FROM SANDY SOIL OF THE EARTH'S SURFACE (SUM PATTERN IMPACT FREQUENCY)

MULTIPATH EFFECT FROM SANDY SOIL OF THE EARTH

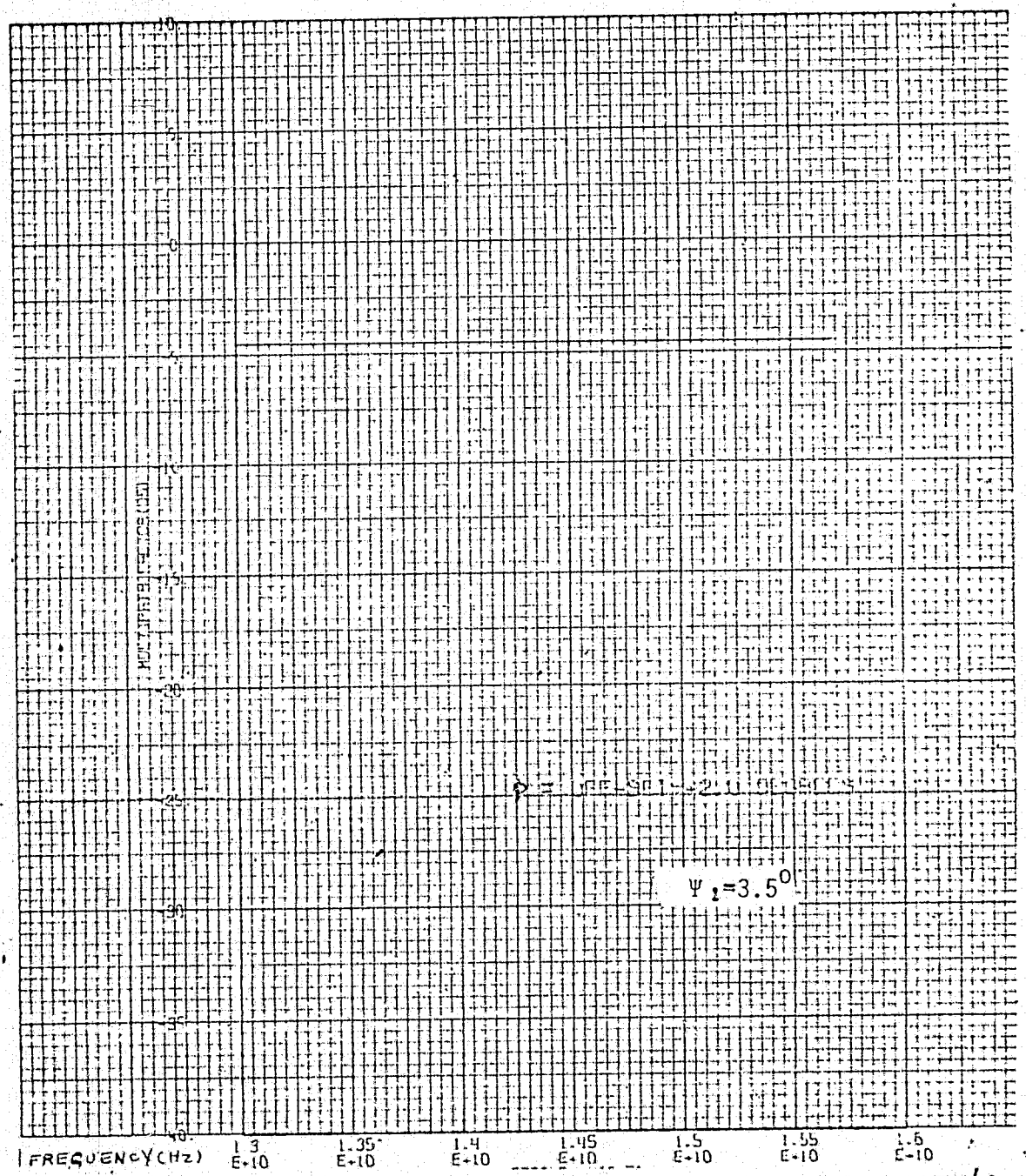


FIGURE 10 MULTIPATH EFFECT FROM SANDY SOIL OF THE EARTH'S SURFACE (DIFFERENCE PATTERN IMPACT FREQUENCY)

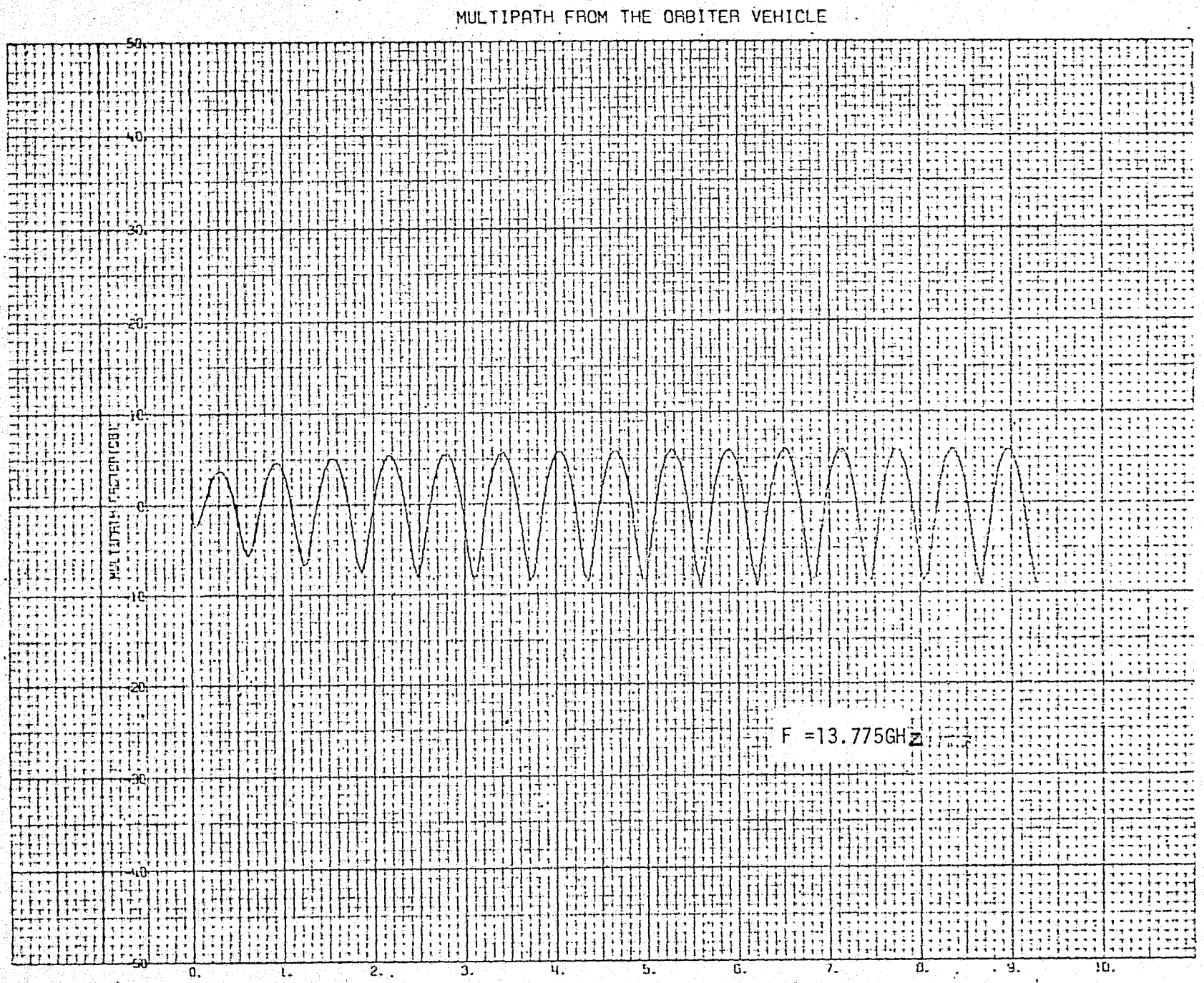


FIGURE 11 MULTIPATH EFFECT FROM THE ORBITER VEHICLE (GRAZING ANGLE)

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

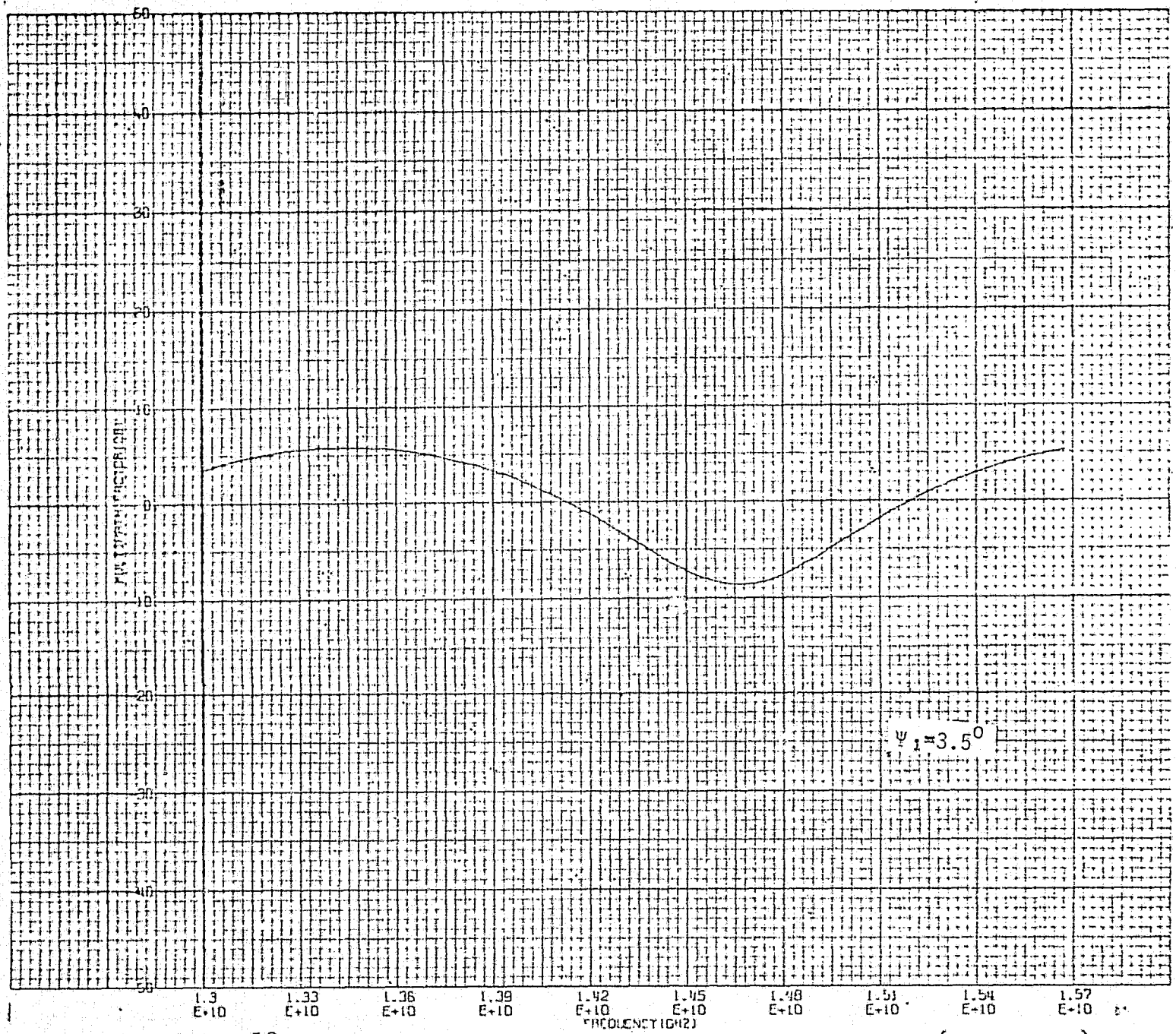


FIGURE 12 MULTIPATH EFFECT FROM THE ORBITER VEHICLE (FREQUENCY)

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

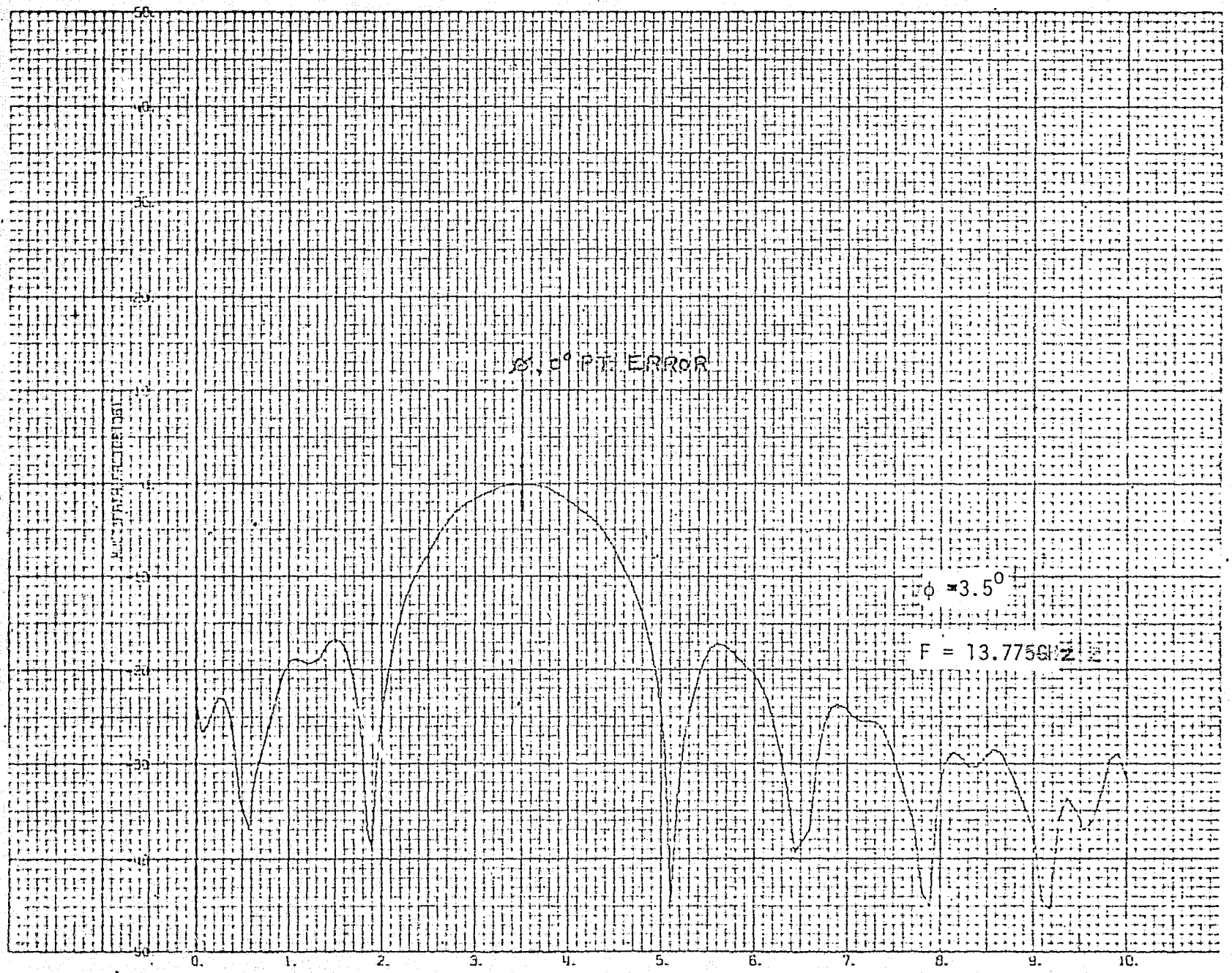


FIGURE 13 MULTIPATH EFFECT FROM THE ORBITER VEHICLE (SUM PATTERN IMPACT, GRAZING ANGLE)

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

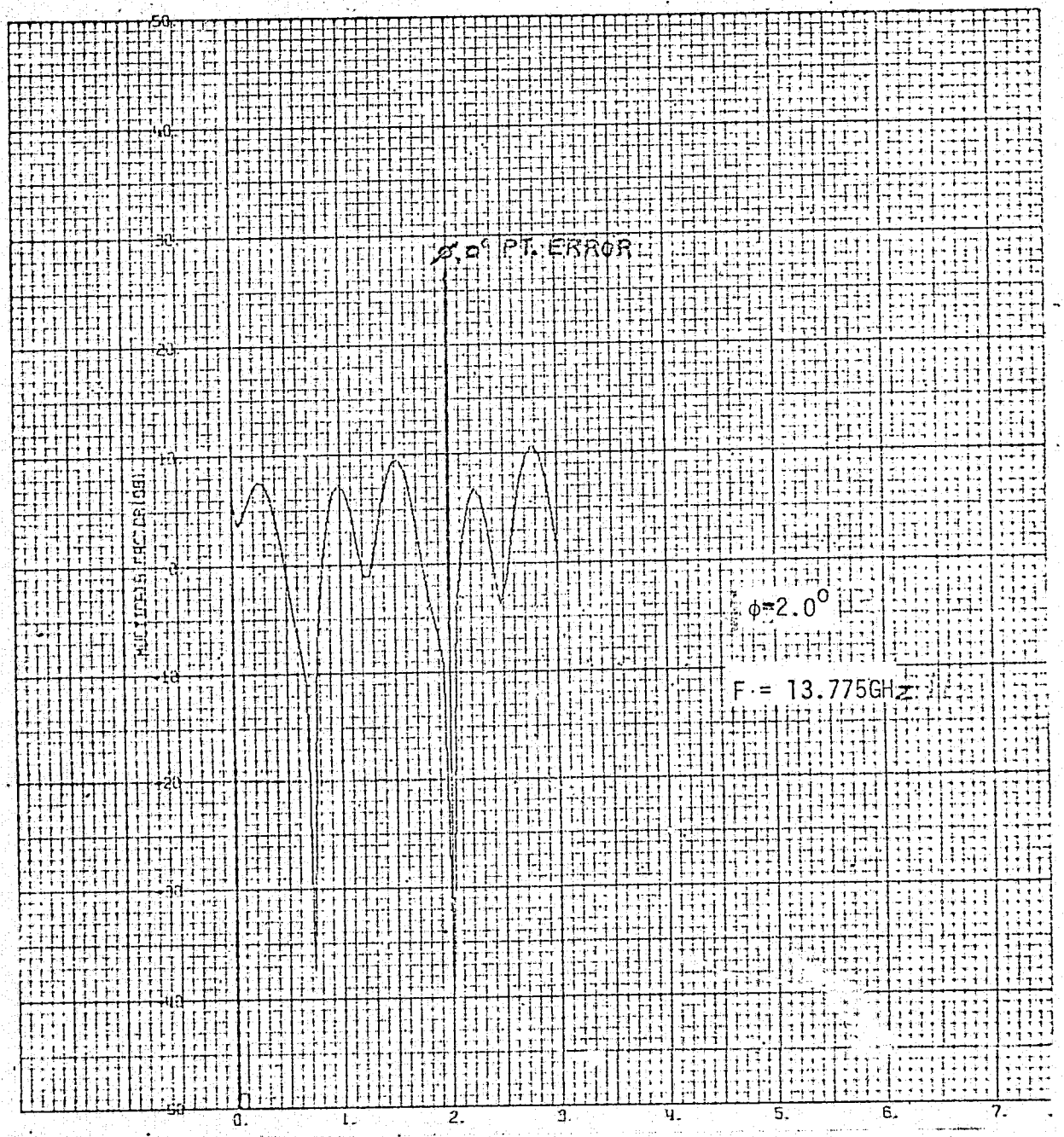


FIGURE 14 MULTIPATH EFFECT FROM THE ORBITER VEHICLE (DIFFERENCE PATTERN IMPACT, GRAZING ANGLE)

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

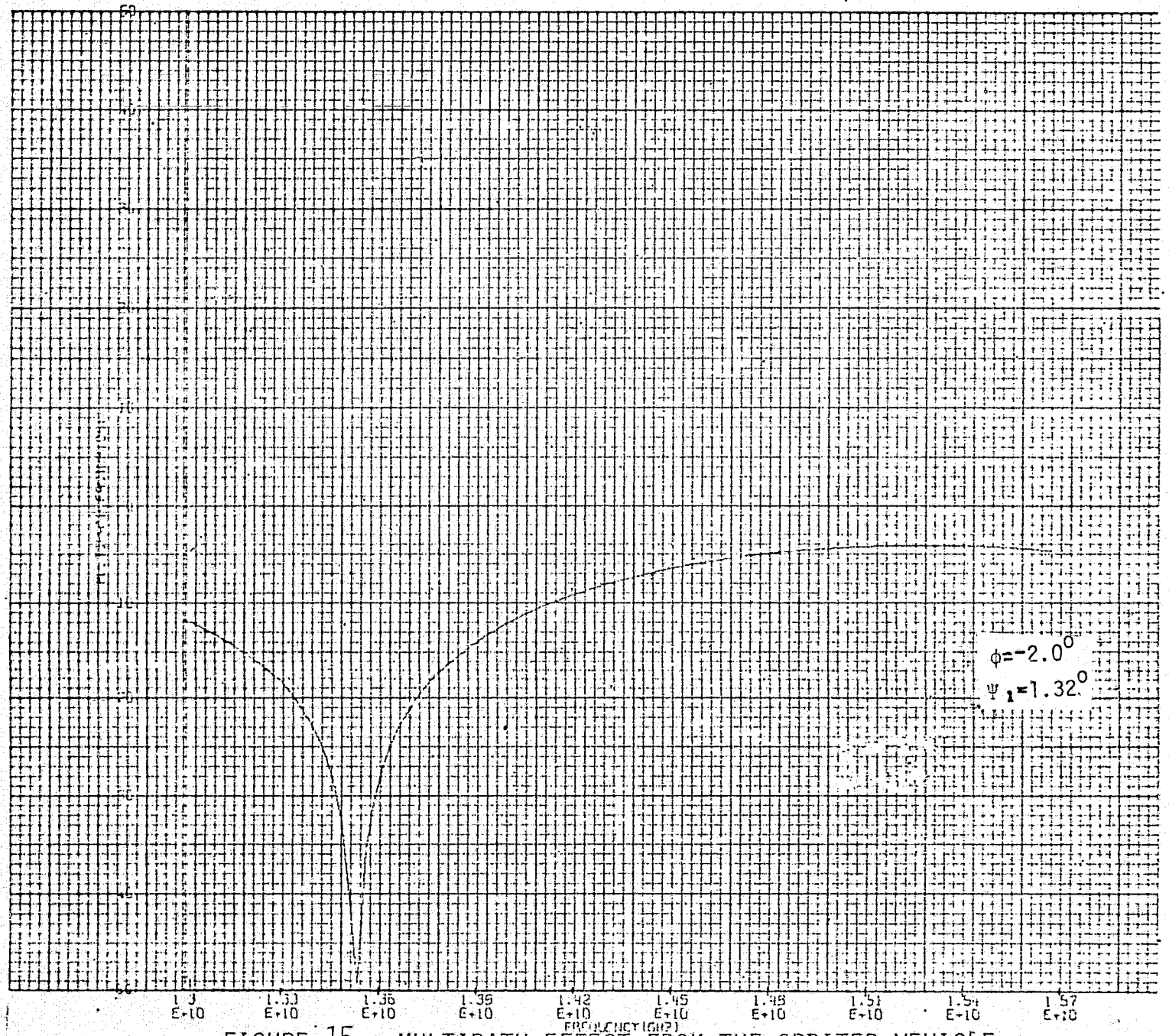


FIGURE 15 MULTIPATH EFFECT FROM THE ORBITER VEHICLE
(DIM [illegible] FREQUENCY)

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

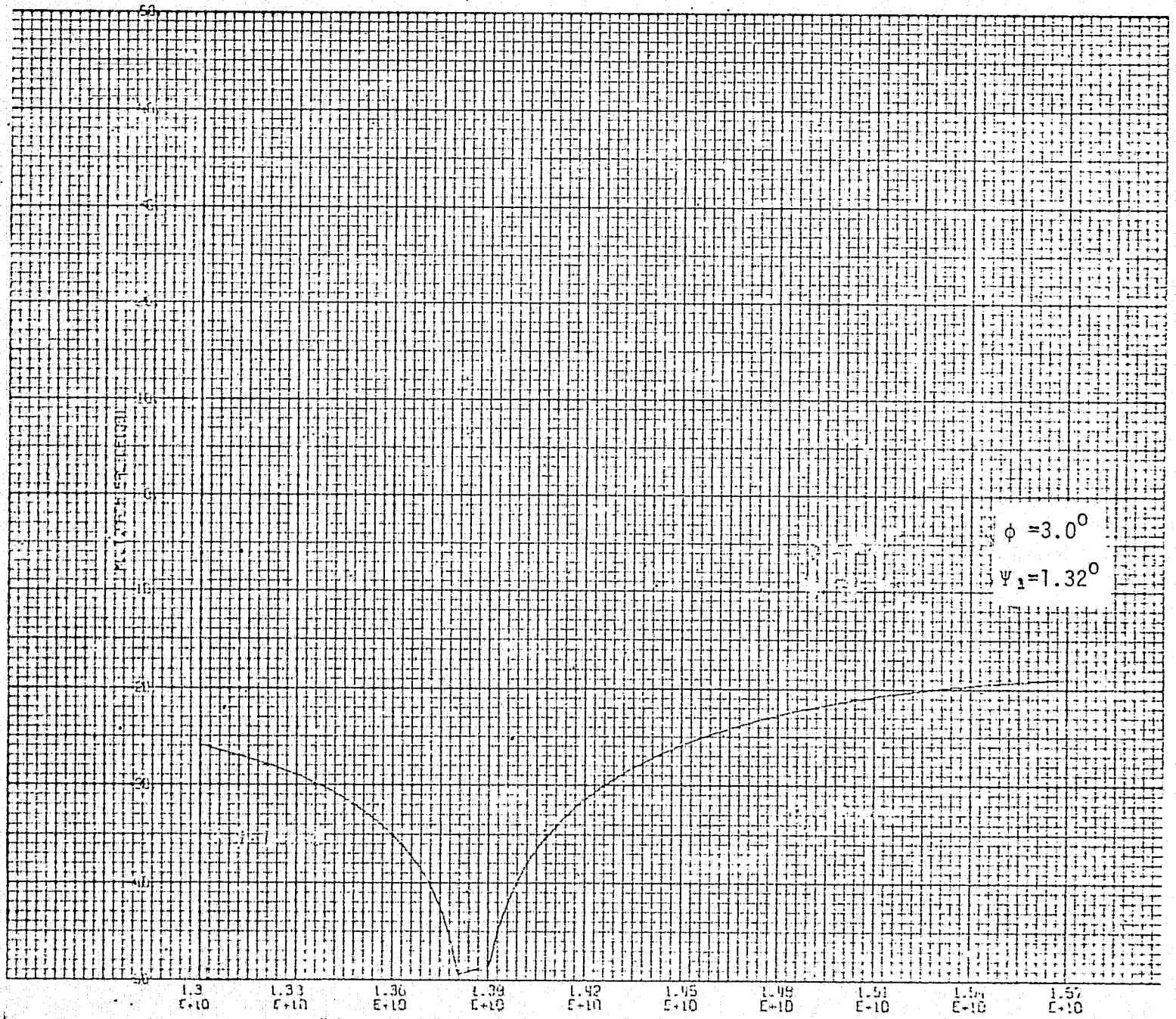


FIGURE 16 MULTIPATH EFFECT FROM THE ORBITER VEHICLE (SUM PATTERN IMPACT, FREQUENCY)

MULTIPATH EFFECT FROM THE ORBITER VEHICLE

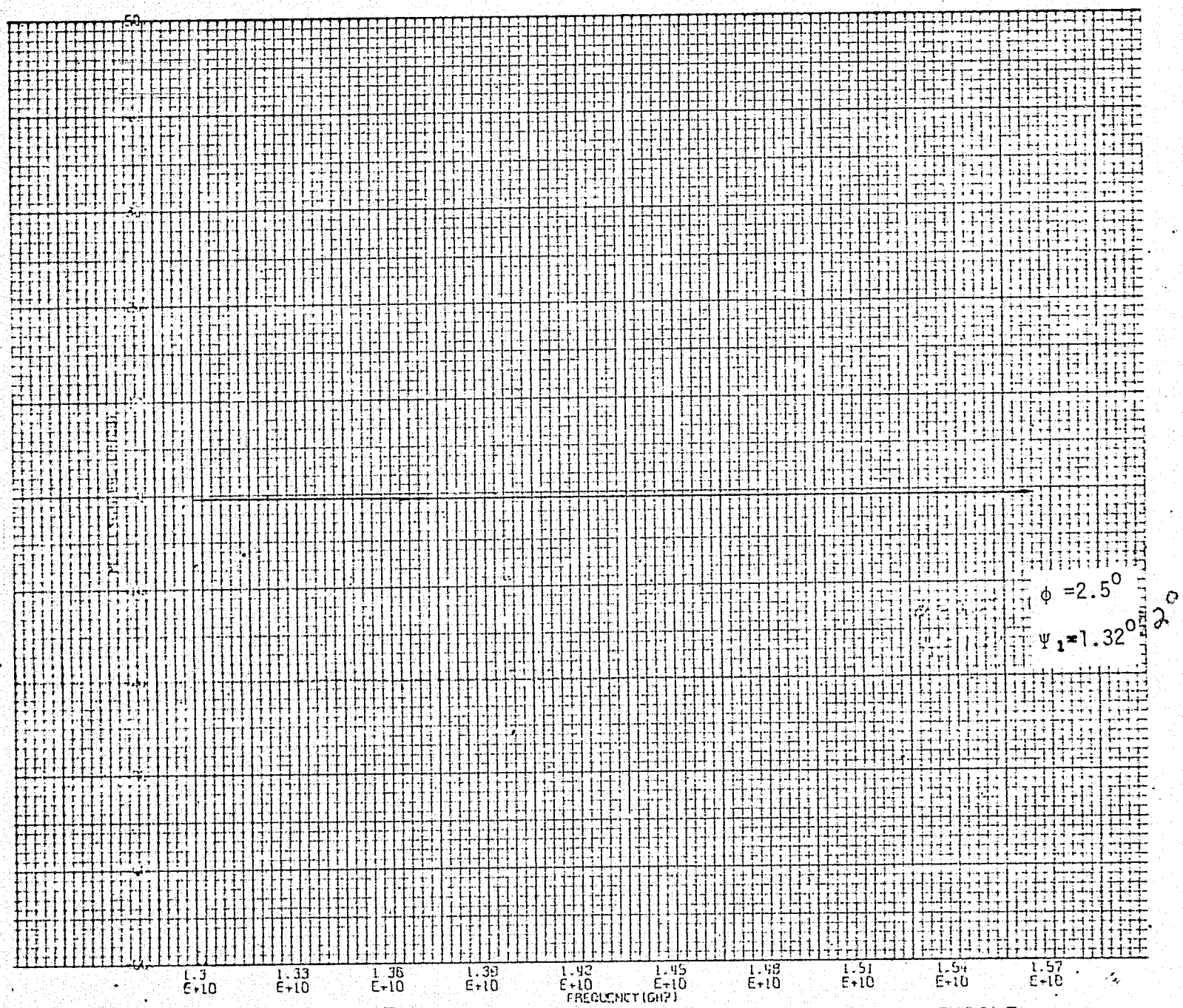


FIGURE 17 MULTIPATH EFFECT FROM THE ORBITER VEHICLE (DIFFERENCE PATTERN IMPACT, FREQUENCY)

APPENDIX B
MULTIPATH PROGRAMS (FORTRAN)

```
@ FOR EARFE,EARFE                                                                    29 JUL 77          1:38:45.873
UNIVAC 1108 FORTRAN V EXEC II LEVEL 25A  -(EXEC8 LEVEL E1201001DA)
THIS COMPILATION WAS DONE ON 29 JUL 77 AT 01:38:46

   MAIN PROGRAM

   STORAGE USED: CODE(1) 001060; DATA(0) 000621; BLANK COMMON(2) 000670

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NRDU$
    0004   NIO2$
    0005   DACOS
    0006   DSQRT
    0007   SQRT
    0010   DCOS
    0011   DSIN
    0012   DASIN
    0013   DATAN
    0014   DEXP
    0015   DLOG10
    0016   NWBU$
    0017   NWNL$
    0020   NREF$
    0021   NSTOP$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000531 171G     0001   000537 177G     0001   001022 226G     0001   000350 23L      0001   000057 24L
    0000   000474 26F      0001   000000 30L      0001   001056 41L      0000 D 000360 A        0000 D 000372 BH
    0000 D 000452 BTHET    0000 D 000370 BV       0000 D 000336 COMP     0000 D 000346 CON      0000 D 000462 D
    0000 D 000444 DIV      0000 D 000362 DIV1     0000 D 000364 DIV2     0000 D 000416 D1       0000 D 000424 D2
    0000 D 000342 FIELD    0002 D 000000 FREQ     0000 D 000420 GAMA1    0000 D 000334 H        0000 I 000471 I
    0000 I 000473 J        0000 I 000470 M        0000 I 000472 N        0000 D 000420 P        0000 D 000434 PADIF
    0000   000476 PATH2    0000   000506 PATI1    0000 D 000450 PH       0000 D 000404 PHAC     0000 D 000406 PHAH
    0000 D 000402 PHAV     0000 D 000422 PHI      0000 D 000344 PI       0000 D 000374 PV       0000 D 000466 Q
    0000 R 000000 QFREQ    0000 D 000410 RANG     0000 D 000412 RANG1    0000 D 000414 RANG2    0000 D 000356 RC
    0000 D 000350 RDIE     0002 D 000334 RELP     0000 D 000400 RH       0000 R 000156 RMP      0000 D 000376 RV
    0000 D 000166 S        0000 D 000340 SCAT     0000 D 000454 ST       0000 D 000432 STHET    0000 D 000442 TAU1
    0000 D 000436 TAU2     0000 D 000440 TAU3     0000 D 000430 THET1    0000 D 000456 T1       0000 D 000464 WAVE
    0000 D 000460 X        0000 D 000446 Y        0000 D 000352 Z1       0000 D 000354 Z2

00101      1.          COMMON FREQ(110),RELP(110)
00103      2.          DIMENSION QFREQ(110),RMP(110)
00104      3.          DOUBLE PRECISION H,COMP
00105      4.          DOUBLE PRECISION SCAT,FIELD,PI,CON,RDIE,FREQ,Z1,Z2,RC,A,DIV1,DIV2
00106      5.          DOUBLE PRECISION S,BV,BH,PV,RV,RH,PHAV,PHAC,PHAH,RELP
00107      6.          DOUBLE PRECISION RANG,RANG1,RANG2,D1,P,PHI,D2,GAMA1,THET1
00110      7.          DOUBLE PRECISION STHET,PADIF,TAU2,TAU3,TAU1,DIV,Y,PH,BTHET
00111      8.          DOUBLE PRECISION ST,T1,X,D,WAVE,Q
00111      9.    C     CONDUCTIVITY OF TYPE OF EARTH SURFACE
00111     10.    C     RELATIVE DIELECTRIC CONSTANT OF TYPE OF EARTH SURFACE
00111     11.    C     COMPLEMENT OF GRAZING ANGLE
```

FIGURE 13 EARTH MULTIPATH AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

ORIGINAL PAGE IS
OF POOR QUALITY

```
00111          C      DO LOOP MAXIMUM LIMIT
00112             30 READ(5,26,END=41)CON,RDIE,COMP,M
00120             26 FORMAT(3D16.9,I3)
00120          C      ROUGHNESS FACTOR
00121                 H=2.
00121          C      DISTANCE FROM EARTH'S SURFACE TO ORBITER
00122                 Z1=4.399798405
00122          C      DISTANCE FROM EARTH'S SURFACE TO TDRS
00123                 Z2=3.578607
00124                 PI=3.141592653589793238
00124          C      DEGREE TO RADIAN CONVERSION
00125                 X=PI/180.
00125          C      RADIUS OF THE EARTH
00126                 A=.866933333307
00126          C      ANGLE BETWEEN LINE FROM ORBITER AND NORMAL TO EARTH'S TANGENT RELA
00126          C      TIVE TO THE CENTER OF THE EARTH
00127                 THET1=DACOS(A/(Z2+A))
00127          C      ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO EARTH'S TANGENT RELATIV
00127          C      E TO THE CENTER OF THE EARTH
00130                 STHET=DACOS(A/(Z1+A))
00131                 T1=THET1*(1./X)
00132                 ST=STHET*(1./X)
00132          C      MAXIMUM ANGLE THETA AT GRAZING
00133                 BTHET=T1*5)
00134             24 CONTINUE
00134          C      TOTAL ARC DISTANCE BETWEEN TDRS AND ORBITER
00135                 D=(PI*A*BTHET)/180.
00136                 P=(2./DSQRT(3.))*(DSQRT(A*(Z1+Z2)+(D/2.)**2.))
00137                 PHI=DACOS(((2.*A)*(Z1-Z2)*D)/P**3.)
00137          C      ARC DISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE
00137          C      EARTH AND THE ORBITER
00140                 D2=D/2.+P*DCOS((PHI+PI)/3.)
00140          C      ARC DISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
00140          C      THE EARTH
00141                 D1=D-D2
00141          C      TWO DISTANCE COMPONENTS OF INDIRECT SIGNAL
00142                 RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
00143                 RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
00143          C      DISTANCE TRAVELED BY DIRECT SIGNAL
00144                 RANG=A*DSQRT((Z1/A)**2.+(Z2/A)**2.-2.*(Z1/A)*(Z2/A)+2.*(1.+(Z1/A)+
00144                1(Z2/A)+(Z1/A)*(Z2/A))*(1.-DCOS(D/A)))
00144          C      PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
00145                 RADIF=RANG1+RANG2-RANG
00145          C      ANGLE BETWEEN REFLECTED SIGNAL PATH AND LINE FROM EARTH'S CENTER
00145          C      TO THE ORBITER
00146                 TAU1=DASIN((A*DSIN(D2/A))/RANG2)
00146          C      ANGLE BETWEEN SIGNAL PATH OF INDIRECT SIGNAL FROM THE TDRS AND LIN
00146          C      E FROM THE CENTER OF THE EARTH TO THE TDRS
00147                 TAU3=DASIN((A*DSIN(D1/A))/RANG1)
00147          C      COMPLEMENT OF GRAZING ANGLE
00150                 TAU2=DACOS(((A+Z2)*DCOS(TAU3)-RANG1)/A)
00151                 IF(TAU2-COMP)23,23,22
00154             22 BTHET=BTHET-.1
00155                 IF(TAU2-COMP)23,23,24
00160             23 CONTINUE
00160          C      GRAZING ANGLE
00161                 GAMA1=PI/2.-TAU2
00161          C      DIVERGENCE FACTOR
```

ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 18 CONTINUED

```
00162          DIV1=A*(RANG1+RANG2)*DSQRT(DSIN(TAU2)+DCOS(TAU2))
00163          DIV2=DSQRT(((A+Z2)*RANG1*DCOS(TAU3)+(A+Z1)*RANG2*DCOS(TAU1))*(A+Z1
00163         1)*(A+Z2)*DSIN(BTHET*X))
00164          DIV=DIV1/DIV2
00164    C     FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
00165          I=1
00166          FREQ(I)=13.00000009
00167          N=M-1
00170          DO 50 I=1,N
00173          FREQ(I+1)=FREQ(I)+24.545406
00174       50 CONTINUE
00176          DO 40 I=1,M,1
00176    C     WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
00201          WAVE=3.006/FREQ(I)
00201    C     FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
00201    C     FICIENT
00202          Y=1.80010*(CON/FREQ(I))
00202    C     PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
00203          S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1)))**2.+Y**2.)*(RDIE
00203         1-(1./2.)*(1.+DCOS(2.*GAMA1))))/2.)
00203    C     FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTING REFLEC
00203    C     TION COEFFICIENT
00204          Q=Y/(2.*S)
00204    C     PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
00204    C     FICIENT
00205          BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
00206          PV=(2.*(S*RDIE*Q*Y))/(S**2.+Q**2.)
00206    C     VERTICAL POLARIZATION REFLECTION COEFFICIENT
00207          RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1))-PV*DSIN(GAMA1))/(1.+(BV/2
00207         1.)*(1.-DCOS(2.*GAMA1))+PV*DSIN(GAMA1)))
00207    C     PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE
00210          PHAV=DATAN((Y*DSIN(GAMA1)-Q)/(RDIE*DSIN(GAMA1)-S))-DATAN((Y*DSIN(G
00210         1AMA1)+Q)/(RDIE*DSIN(GAMA1)+S))+PI
00210    C     PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
00210    C     EFFICIENT
00211          BH=1./(S**2.+Q**2.)
00212          PH=(2.*S)/(S**2.+Q**2.)
00212    C     HORIZONTAL REFLECTION COEFFICIENT
00213          RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMA1))-PH*DSIN(GAMA1))/(1.+(BH/2
00213         1.)*(1.-DCOS(2.*GAMA1))+PH*DSIN(GAMA1)))
00213    C     PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
00214          PHAH=DATAN(-Q/(DSIN(GAMA1)-S))-DATAN(Q/(DSIN(GAMA1)+S))+PI
00214    C     CIRCULAR REFLECTION COEFFICIENT
00215          RC=DABS((RV+RH)/2.)
00215    C     PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
00216          PHAC=(PHAV+PHAH)/2.
00216    C     SCATTERING REFLECTION COEFFICIENT
00217          SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMA1))**2))
00217    C     MULTIPATH FIELD STRENGTH
00220          FIELD=1.+((RANG/(RANG1+RANG2))*DIV*DABS(RC)*SCAT)**2.+2.*((RANG/(R
00220         1ANG1+RANG2))*DIV*DABS(RC)*SCAT)*(DCOS((((2.*PI)/WAVE)*PADIF)+PHAC)
00220         2)
00220    C     MULTIPATH FACTOR
00221          HELP(I)=20.*DLOG10(DABS(FIELD))
00222       40 CONTINUE
00224          J=1
00225          DO 51 I=1,M
00230          QFREQ(I)=SNGL(FREQ(J))
```

ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 18 CONTINUED

```
00231    128•          RMP(I)=SNGL(RELP(J))
00232    129•          WRITE(8)RMP(I),QFREQ(I)
00236    130•          J=J+1
00237    131•       51 CONTINUE
00241    132•          NAMELIST/PATH2/RELP,FREQ
00242    133•          WRITE(6,PATH2)
00246    134•          NAMELIST/PATH1/RMP,QFREQ
00246    135•          WRITE(6,PATH1)
00251    136•          ENDFILE8
00252    137•          GO TO 30
00253    138•       41 CONTINUE
00254    139•          END

END OF COMPILATION:      NO DIAGNOSTICS.
```

FIGURE 18 CONTINUED

```
C       CONDUCTIVITY OF TYPE OF EARTH SURFACE
C       RELATIVE DIELECTRIC CONSTANT OF TYPE OF EARTH SURFACE
C       ARCDISTANCE INCREMENT
C       FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
```

AO 6

30 READ(5,26,END=41)CON,RDIE,INC,FREQ

26 FORMAT(4D16.9)

```
C       ARCDISTANCE LIMITATION
```

READ(5,67)K

67 FORMAT(1D16.9)

```
C       ROUGHNESS FACTOR
```

H=2.

```
C       DISTANCE FROM EARTH'S SURFACE TO ORBITER
```

Z1=4.399796405

```
C       DISTANCE FROM EARTH'S SURFACE TO TDRS
```

```
Z2=3.578607
I=1
J=1
PI=3.14159265358979323 8
```

```
C       DEGREE TO RADIAN CONVERSION
```

X=PI/180.

```
C       RADIUS OF THE EARTH
```

A=.848933333307

```
C       ANGLE BETWEEN LINE FROM ORBITER AND NORMAL TO EARTH.S TANGENT RELA
C       TIVE TO THE CENTER OF THE EARTH
```

CONT. ON PG. 2

EARMU
PG 1 OF 6

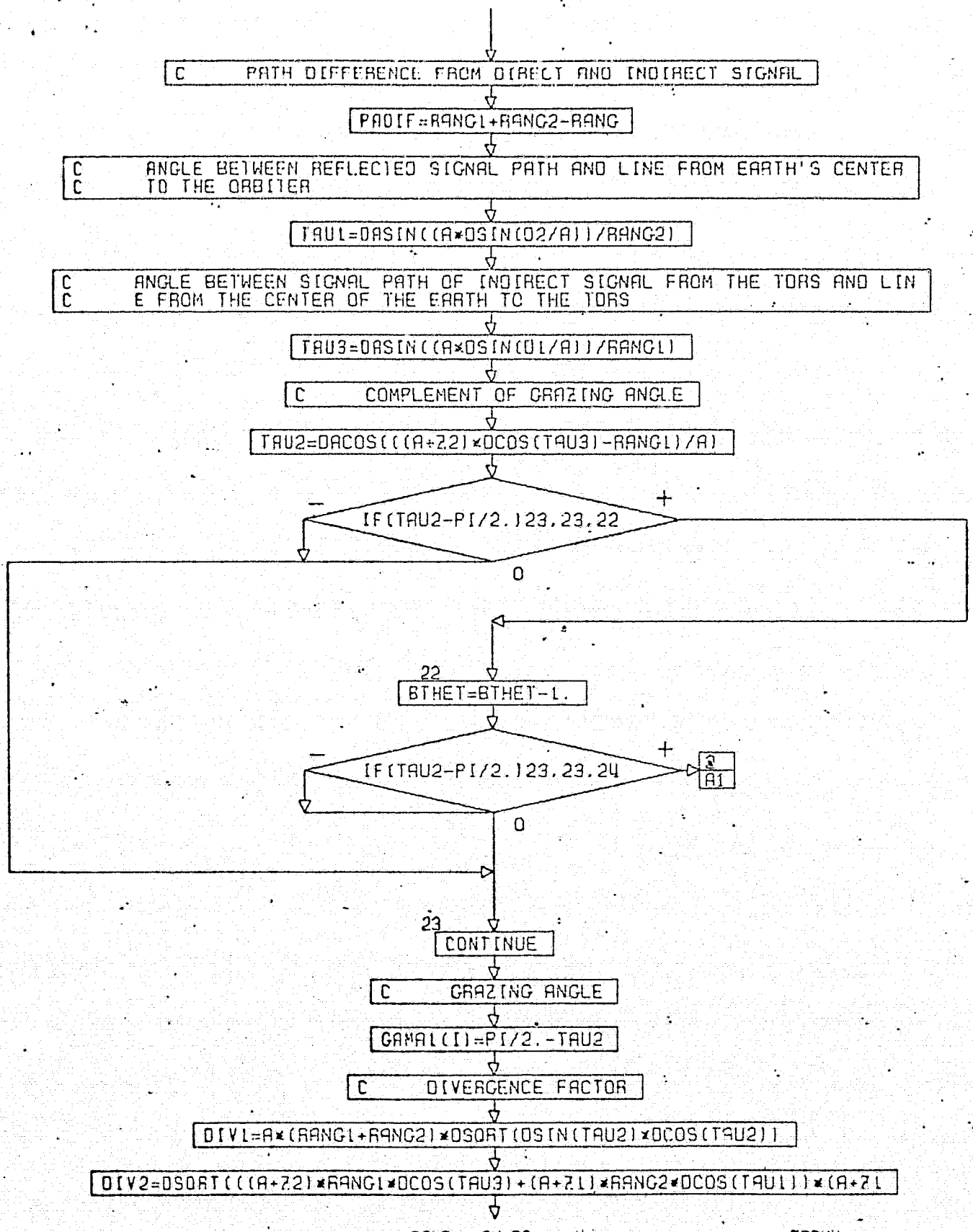
FIGURE 19 FLOWCHART FOR EARTH MULTIPATH AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

```
THETL=DACOS(A/(Z2+A))

C     ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO EARTH'S TANGENT RELATIV
C     E TO THE CENTER OF THE EARTH

STHET=DACOS(A/(Z1+A))
TL=THETL*(1./X)
ST=STHET*(1./X)

C     MAXIMUM ANGLE THETA AT GRAZING

BTHET=TL+ST

A1 [3]

24 CONTINUE

BTHETL=BTHET

A2 [5]

21 CONTINUE

C     TOTAL ARC DISTANCE BETWEEN TDRS AND ORBITER

D=(PI*A*BTHET)/180.
P=(2./DSQRT(3.))*(DSQRT(A*(Z1+Z2)+(D/2.)**2.))
PHI=DACOS((2.*A*(Z1-Z2)*D)/P**3)

C     ARC DISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE
C     EARTH AND THE ORBITER

D2=D/2.+P*DCOS((PHI+PI)/3.)

C     ARC DISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
C     THE EARTH

D1=D-D2

C     TWO DISTANCE COMPONENTS OF INDIRECT SIGNAL

RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))

C     DISTANCE TRAVELED BY DIRECT SIGNAL

RANG=A*DSQRT((Z1/A)**2.+(Z2/A)**2.-2.*(Z1/A)*(Z2/A)+2.*(1.+(Z1/A)+
(Z2/A)+(Z1/A)*(Z2/A))*(1.-DCOS(D/A)))
```

CONT. ON PG 3

EARMU
PG 2 OF

FIGURE 19 CONTINUED



CONT. ON PG 4

ERRMU
PG 3 OF 6

FIGURE 19 CONTINUED

```
I*(A+Z2)*DSIN(BTHEL*X))
DIV=DIV1/DIV2
C     WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
WAVE=3.008/FREQ
C     FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
C     FICIENT
Y=1.80010*(CON/FREQ)
C     PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1([I])))**2.+Y**2.)+(R
DIE-(1./2.)*(1.+DCOS(2.*GAMA1([I]))))/2.)
C     FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTING REFLEC
C     TION COEFFICIENT
Q=Y/(2.*S)
C     PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
C     FICIENT
BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)
C     VERTICAL POLARIZATION REFLECTION COEFFICIENT
RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1([I])))-PV*DSIN(GAMA1([I])))/(1.
+(BV/2.)*(1.-DCOS(2.*GAMA1([I])))+PV*DSIN(GAMA1([I]))))
C     PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED
PHAV=DATAN((Y*DSIN(GAMA1([I]))-Q)/(RDIE*DSIN(GAMA1([I]))-S))-DATAN((Y*
DSIN(GAMA1([I]))+Q)/(RDIE*DSIN(GAMA1([I]))+S))+PI
C     PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
C     EFFICIENT
BH=1./(S**2.+Q**2.)
PH=(2.*S)/(S**2.+Q**2.)
C     HORIZONTAL REFLECTION COEFFICIENT
RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMA1([I])))-PH*DSIN(GAMA1([I])))/(1.
+(BH/2.)*(1.-DCOS(2.*GAMA1([I])))+PH*DSIN(GAMA1([I]))))
```

CONT. ON PG 5

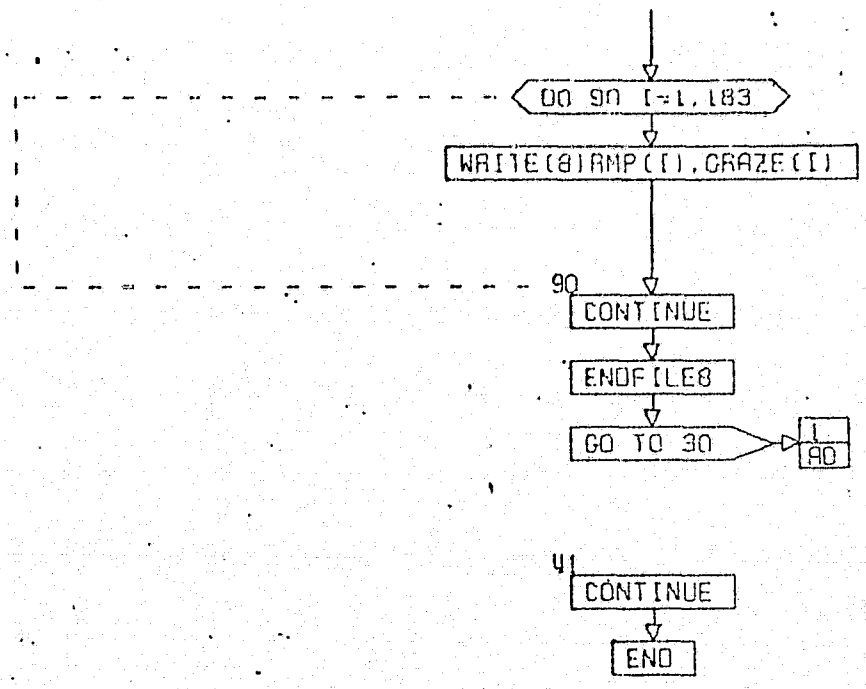
FIGURE 19 CONTINUED

```
C      PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
PHAH=DATAN(-Q/(DSIN(GAMA1(I))-S))-DATAN(Q/(DSIN(GAMA1(I))+S))+PI
C      CIRCULAR REFLECTION COEFFICIENT
RC=DABS((RV+RH)/2.)
C      PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
PHAC=(PHAV+PHAH)/2.
C      SCATTERING REFLECTION COEFFICIENT
SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMA1(I)))**2))
C      MULTIPATH FIELD STRENGTH
FIELD=1.+((RANG/(RANG1+RANG2))*DIV*DABS(RC)*SCAT)**2.+2.*((RANG/(R
ANG1+RANG2))*DIV*DABS(RC)*SCAT)*(DCOS(((2.*PI)/WAVE)*PADIF)+PHAC)
)
C      MULTIPATH FACTOR
RELP(I)=20.*DLOG10(DABS(FIELD))
GAMA1(I)=GAMA1(I)*(1./X)
GRAZE(I)=SNGL(GAMA1(J))
RMP(I)=SNGL(RELP(J))
U=BTHET1-K
I=I+1
J=J+1
BTHET=BTHET-INC
IF(BTHET.GT.U)
F
T
GO TO 21
2
A2
NAMELIST/PAT15/RELP,GAMA1
WRITE(6,PAT15)
NAMELIST/PATH3/RMP,GRAZE
WRITE(6,PATH3)
```

CONT. ON PG 6

EARMU
PG 5 OF 6

FIGURE 19 CONTINUED



EARMU
PG 6 FINAL

FIGURE 19 CONTINUED

```
@ FOR ORBMU,ORBMU                                                                  22 JUL 77          13: 6:58.119
UNIVAC 1108 FORTRAN V EXEC 11 LEVEL 25A  -(EXEC8 LEVEL E12010010A)
THIS COMPILATION WAS DONE ON 22 JUL 77 AT 13:06:58

   MAIN PROGRAM

   STORAGE USED: CODE(1) 000714; DATA(0) 000776; BLANK COMMON(2) 001334

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NRDU$
    0004   NIO2$
    0005   DACOS
    0006   DATAN
    0007   DCOS
    0010   DSQRT
    0011   DTAN
    0012   DSIN
    0013   DEXP
    0014   NANL$
    0015   DLOG10
    0016   NWBU$
    0017   NWEF$
    0020   NSTOP$

   STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000074 21L      0000    000701 26F      0001    000000 30L      0001    000676 36L      0001    000712 41L
    0000 D  000632 A        0000 D  000564 BH       0000 D  000666 BTHET    0000 D  000670 BTHET1   0000 D  000576 BV
    0000 D  000600 CON      0000 D  000606 D        0000 D  000556 DIS      0000 D  000634 DIV      0000 D  000654 D1
    0000 D  000674 D2       0000 D  000620 FIELD    0000 D  000612 FREQ     0002 D  000556 GAMA1    0000 R  000267 GRAZE
    0000 D  000614 H        0000 I  000677 I        0000 D  000562 INC      0000 I  000700 J        0000 I  000676 K
    0000 D  000664 PADIF    0000    000710 PATH1    0000    000720 PATH2    0000    000703 PATH6    0000 D  000602 PH
    0000 D  000644 PHAC     0000 D  000646 PHAH     0000 D  000642 PHAV     0000 D  000656 PHI      0000 D  000622 PI
    0000 D  000566 PV       0000 D  000574 Q        0000 D  000650 RANG1    0000 D  000652 RANG2    0000 D  000630 RC
    0000 D  000570 RDIE     0002 D  000000 RELP     0000 D  000640 RH       0000 R  000000 RHP      0000 D  000636 RV
    0000 D  000572 S        0000 D  000616 SCAT     0000 D  000560 SICK     0000 D  000662 STHET    0000 D  000660 THET1
    0000 D  000610 WAVE     0000 D  000672 X        0000 D  000604 Y        0000 D  000624 Z1       0000 D  000626 Z2

00101      1.          COMMON RELP(183),GAMA1(183)
00103      2.          DIMENSION RHP(183),GRAZE(183)
00104      3.          DOUBLE PRECISION DIS,SICK,INC
00105      4.          DOUBLE PRECISION BH,PV,RDIE,S,Q,BV,CON,PH,Y
00106      5.          DOUBLE PRECISION D,WAVE,FREQ,H
00107      6.          DOUBLE PRECISION SCAT,FIELD,PI,Z1,Z2,RC,A,DIV
00110      7.          DOUBLE PRECISION RV,RH,PHAV,PHAC,PHAH,RELP
00111      8.          DOUBLE PRECISION RANG1,RANG2,D1,PHI,GAMA1,THET1
00112      9.          DOUBLE PRECISION STHET,PADIF,BTHET,BTHET1,X,D2
00112     10.    C     CONDUCTIVITY OF THE ORBITER SKIN
00112     11.    C     RELATIVE DIELECTRIC CONSTANT OF THE ORBITER SKIN
00112     12.    C     FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
00112     13.    C     ARCDISTANCE INCREMENT
00112     14.    C     LOOP DIMENSION
```

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FIGURE 20 ORBITER MULTIPATH AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

```
00113          30 READ(5,26,END=41)CON,RDIE,INC,FREQ,K
00122          26 FORMAT(4D16.9,I3)
00122      C      DISTANCE BETWEEN TDRS AND ORBITER
00123             Z2=3.534602036D7
00123      C      DISTANCE BETWEEN ORBITER SKIN AND KU-BAND ANTENNA
00124             Z1=1.0
00124      C      RMS ROUGHNESS IN METERS
00125             H=0.0
00126             I=1
00127             J=1
00130             PI=3.14159265358979
00130      C      DEGREE TO RADIAN CONVERSION
00131             X=PI/180.
00131      C RADIUS OF THE ORBITER FUSELAGE
00132             A=2.992100584328168
00132      C      ANGLE BETWEEN LINE FROM ANTENNA AND NORMAL TO ORBITER'S TANGENT
00132      C      RELATIVE TO ORBITER'S CENTER
00133             STHET=DACOS(A/(Z1+A))
00133      C      ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO ORBITER'S TANGENT RELAT
00133      C      IVE TO THE ORBITER'S CENTER
00134             THET1=DACOS(A/(Z2+A))
00134      C      ARCDISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE ORB
00134      C      ITER AND THE KU-BAND ANTENNA
00135             D2=A*STHET
00135      C      TOTAL ARCDISTANCE BETWEEN ANTENNA AND TDRS
00136             D=A*(THET1+STHET)
00137             BTHET=DATAN(Z1/D2)
00137      C      GRAZING ANGLE
00140             GAMA1(I)=BTHET-DATAN(Z1/D2)
00141          21 CONTINUE
00141      C      ARCDISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
00141      C      THE ORBITER
00142             D1=D-D2
00142      C      COMPLEMENT OF GRAZING ANGLE
00143             PHI=(PI/2.)-GAMA1(I)
00144             BTHET1=PI/2.*PHI
00144      C      TWO DISTANCE COMPONENTS OF INDIRICT SIGNAL
00145             RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
00146             RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
00146      C      PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
00147             PADIF=2.*Z1*DTAN(GAMA1(I))
00147      C      DIVERGENCE FACTOR
00150             SICK=DACOS((A**2+(A+Z1)**2-RANG2**2)/(2.*A*(A+Z1)))
00151             DIS=DSQRT((A*DSIN(GAMA1(I)))/((A*DSIN(GAMA1(I))+(2.*RANG2))*(1.+(Z
00151            11/A))*DSIN(SICK)))
00152             DIV=DSQRT(DIS)
00152      C      WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
00153             WAVE=3.0D8/FREQ
00153      C      FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
00153      C      FICIENT
00154             Y=1.80D10*(CON/FREQ)
00154      C      PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
00155             S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1(I))))**2.+Y**2.)+(R
00155            1DIE-(1./2.)*(1.+DCOS(2.*GAMA1(I)))))/2.)
00155      C      FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTATION OF R
00156      C      EFLECTION COEFFICIENT
00156             Q=Y/(2.*S)
00156      C      PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
```

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FIGURE 20 CONTINUED

1.2-DN-B0703-008
B-13

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```
00156      C     FICIENT
00157            BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
00160            PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)
00160      C     VERTICAL POLARIZATION REFLECTION COEFFICIENT
00161            RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))-PV*DSIN(GAMA1(I)))/(1.
00161           1+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))+PV*DSIN(GAMA1(I))))
00161      C     PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE
00162            PHAV=DATAN((Y*DSIN(GAMA1(I))-Q)/(RDIE*DSIN(GAMA1(I))-S))-DATAN((Y*
00162           1DSIN(GAMA1(I))+Q)/(RDIE*DSIN(GAMA1(I))+S))
00163            PHAV=PHAV+PI
00163      C     PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
00163      C     EFFICIENT
00164            BH=1./(S**2.+Q**2.)
00165            PH=(2.*S)/(S**2.+Q**2.)
00165      C     HORIZONTAL REFLECTION COEFFICIENT
00166            RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))-PH*DSIN(GAMA1(I)))/(1.
00166           1+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))+PH*DSIN(GAMA1(I))))
00166      C     PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
00167            PHAH=DATAN(-Q/(DSIN(GAMA1(I))-S))-DATAN(Q/(DSIN(GAMA1(I))+S))
00170            PHAH=PHAH+PI
00170      C     CIRCULAR REFLECTION COEFFICIENT
00171            RC=DABS((RV+RH)/2.)
00171      C     PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
00172            PHAC=(PHAV+PHAH)/2.
00172      C     SCATTERING REFLECTION COEFFICIENT
00173            SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMA1(I)))**2))
00173      C     MULTIPATH FIELD STRENGTH
00174            FIELD=1.+(DIV*DABS(RC)*SCAT)**2+2.*(DIV*DABS(RC)*SCAT)*(DCOS((((2.
00174           1*PI)/WAVE)*PADIF)+PHAC))
00175            NAMELIST/PATH6/FIELD
00176            WRITE(6,PATH6)
00176      C     MULTIPATH FACTOR
00201            RELP(I)=20.*DLOG10(DABS(FIELD))
00202            GAMA1(I)=GAMA1(I)*(1./X)
00203            RMP(I)=SNGL(RELP(J))
00204            GRAZE(I)=SNGL(GAMA1(J))
00205            WRITE(8)RMP(I),GRAZE(I)
00211            IF(I.EQ.K)GO TO 36
00213            I=I+1
00214            J=J+1
00215            D2=D2-INC
00216            GAMA1(I)=DATAN(Z1/D2)-BTHET
00217            IF(I.LE.K)GO TO 21
00221         36 CONTINUE
00222            NAMELIST/PATH1/RELP,GAMA1
00223            WRITE(6,PATH1)
00226            NAMELIST/PATH2/RMP,GRAZE
00227            WRITE(6,PATH2)
00232            ENDFILE8
00233            GO TO 30
00234         41 CONTINUE
00235            END

      END OF COMPILATION:        NO  DIAGNOSTICS.
```

FIGURE 20 CONTINUED

```
C       CONDUCTIVITY OF THE ORBITER SKIN
C       RELATIVE DIELECTRIC CONSTANT OF THE ORBITER SKIN
C       FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
C       ARCDISTANCE INCREMENT
C       LOOP DIMENSION
```

AO 5

30 READ(5,26,END=41)CON,RDIE,INC,FREQ,K

26 FORMAT(4D16.9,I3)

```
C       DISTANCE BETWEEN TDRS AND ORBITER
```

Z2=3.53460203607

```
C       DISTANCE BETWEEN ORBITER SKIN AND KU-BAND ANTENNA
```

Z1=1.0

```
C       RMS ROUGHNESS IN METERS
```

```
H=0.0
I=1
J=1
PI=3.14159265358979
```

```
C       DEGREE TO RADIAN CONVERSION
```

X=PI/180.

```
C RADIUS OF THE ORBITER FUSELAGE
```

A=2.992100584328168

```
C       ANGLE BETWEEN LINE FROM ANTENNA AND NORMAL TO ORBITER'S TANGENT
C       RELATIVE TO ORBITER'S CENTER
```

STHET=DACOS(A/(Z1+A))

```
C       ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO ORBITER'S TANGENT RELAT
C       IVE TO THE ORBITER'S CENTER
```

THET1=DACOS(A/(Z2+A))

```
C       ARCDISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE ORB
C       ITER AND THE KU-BAND ANTENNA
```

CONT. ON PG 2

ORBMU
PG 1 OF 5

FIGURE 21 FLOWCHART FOR ORBITER MULTIPATH AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

```
D2=A*STHET
C     TOTAL ARCDISTANCE BETWEEN ANTENNA AND TDRS
D=A*(THET1+STHET)
BTHET=DATAN(Z1/D2)
C     GRAZING ANGLE
GAMA1(I)=BTHET-DATAN(Z1/D2)
A1 5
2 CONTINUE
C     ARCDISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
C     THE ORBITER
D1=D-D2
C     COMPLEMENT OF GRAZING ANGLE
PHI=(PI/2.)-GAMA1(I)
BTHET1=PI/2.+PHI
C     TWO DISTANCE COMPONENTS OF INDIRICT SIGNAL
RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
C     PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
PADIF=2.*Z1*DTAN(GAMA1(I))
C     DIVERGENCE
ACOS((A**2+(A+Z1)**2-RANG2**2)/(2.*A*(A+Z1)))
DIS=DSQRT((A*DSIN(GAMA1(I)))/((A*DSIN(GAMA1(I))+(2.*RANG2))*(1.+(Z
1/A))*DSIN(SICK)))
DIV=DSQRT(DIS)
C     WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
WAVE=3.008/FREQ
C     FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
```

CONT. ON PG 3

ORBMU
PG 2 OF 5

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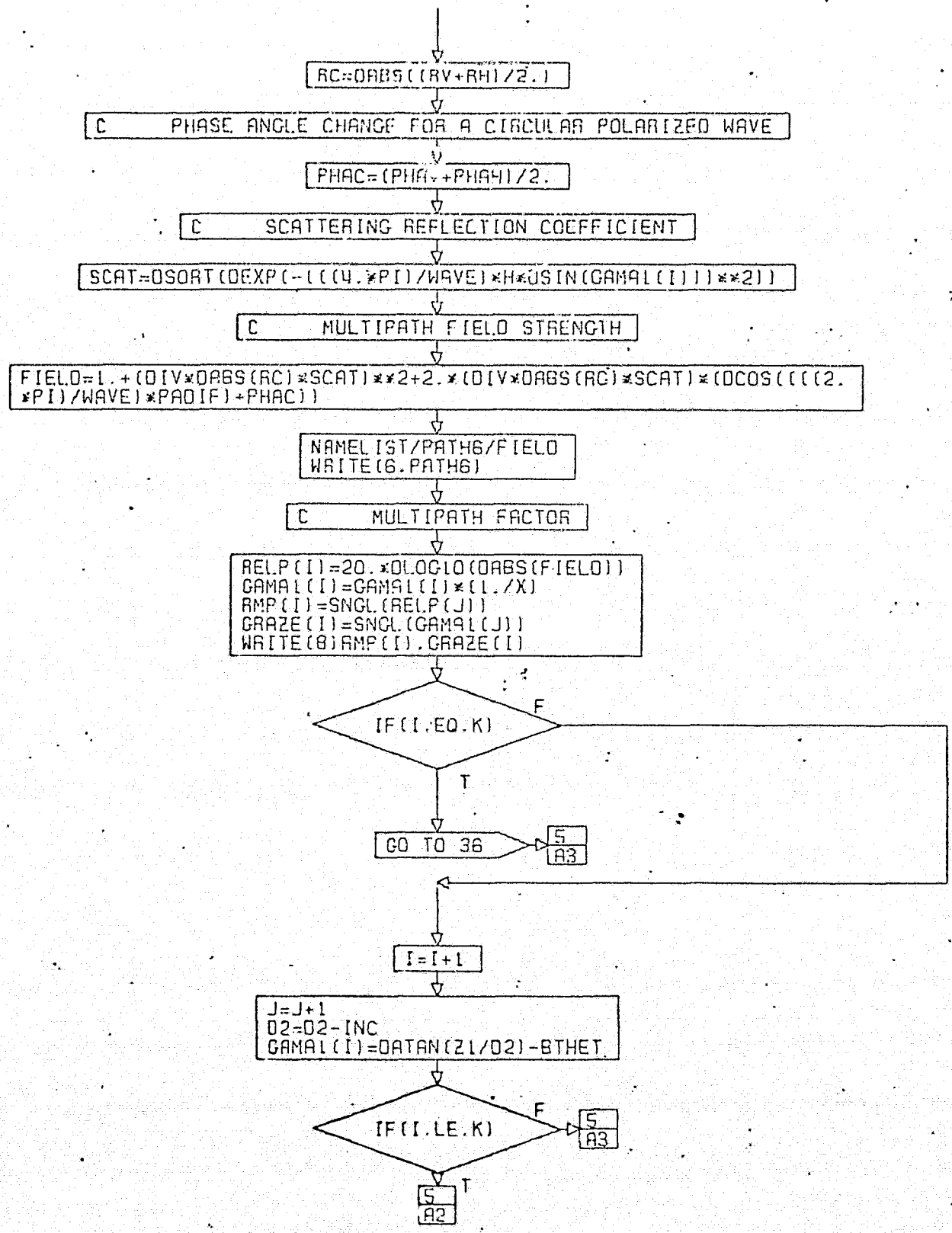
FIGURE 21 CONTINUED

```
C       FICIENT

Y=1.80010*(CON/FREQ)

C       PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT

S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1(I))))**2.+Y**2.)+(R
DIE-(1./2.)*(1.+DCOS(2.*GAMA1(I))))))/2.)

C       FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTATION OF R
C       EFLECTION COEFFICIENT

Q=Y/(2.*S)

C       PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
C       FICIENT

BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)

C       VERTICAL POLARIZATION REFLECTION COEFFICIENT

RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))-PV*DSIN(GAMA1(I)))/(1.
+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))+PV*DSIN(GAMA1(I))))

C       PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE

PHAV=DATAN((Y*DSIN(GAMA1(I))-Q)/(RDIE*DSIN(GAMA1(I))-S))-DATAN((Y*
DSIN(GAMA1(I))+Q)/(RDIE*DSIN(GAMA1(I))+S))

PHAV=PHAV+PI

C       PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
C       EFFICIENT

BH=1./(S**2.+Q**2.)
PH=(2.*S)/(S**2.+Q**2.)

C       HORIZONTAL REFLECTION COEFFICIENT

RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))-PH*DSIN(GAMA1(I)))/(1.
+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))+PH*DSIN(GAMA1(I))))

C       PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE

PHAH=DATAN(-Q/(DSIN(GAMA1(I))-S))-DATAN(Q/(DSIN(GAMA1(I))+S))
PHAH=PHAH+PI

C       CIRCULAR REFLECTION COEFFICIENT
```

CONT. ON PG 4

ORBMU
PG 3 OF 5

FIGURE 21 CONTINUED



CONT. ON PG 5

ORGMU
PG 4 OF 5

FIGURE 21 CONTINUED

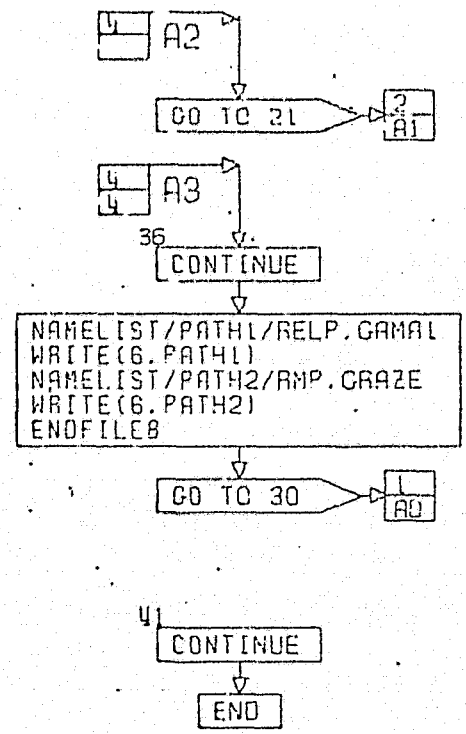


FIGURE 21 CONTINUED

```
@ FOR EARGR,EARGR                                                                    19 JUL 77          19:53:40.167
UNIVAC 1108 FORTRAN V EXEC II LEVEL 25A  -(EXEC8 LEVEL E12010010A)
THIS COMPILATION WAS DONE ON 19 JUL 77 AT 19:53:40

   MAIN PROGRAM

   STORAGE USED: CODE(1) 001660; DATA(0) 003017; BLANK COMMON(2) 00[illegible]

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003    NRDU$
    0004    NIO2$
    0005    DACOS
    0006    DSQRT
    0007    SQRT
    0010    DCOS
    0011    DSIN
    0012    DASIN
    0013    DATAN
    0014    DEXP
    0015    DLOG10
    0016    NWNL$
    0017    NWRU$
    0020    NWEF$
    0021    NSTOP$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000102 21L      0001    000376 23L      0001    000100 24L      0000    002671 26F      0001    000000 30L
    0001    001656 41L      0001    001630 41LG     0001    001135 60L      0001    001202 62L      0001    001152 64L
    0001    001154 65L      0001    001130 66L      0000    002673 67F      0001    001341 70L      0001    001346 72L
    0001    001363 75L      0001    001365 76L      0001    001413 77L      0001    000031 80L      0000 D  002510 A
    0000 D  002622 AFLG     0000 D  002630 BETA     0000 D  002632 BFLG     0000 D  002522 BH       0000 D  002602 BTHET
    0000 D  002600 BTHET1   0000 D  002520 BV       0000 D  002634 CFLG     0000 D  002474 CON      0000 D  002614 D
    0000 D  002636 DFLG     0000 D  002646 DIA      0000 D  002644 DIFF     0000 D  002654 DIFF1    0000 D  002572 DIV
    0000 D  002512 DIV1     0000 D  002514 DIV2     0002 D  001334 DP       0000 D  002546 DI       0000 D  002554 D2
    0000 D  002640 EFLG     0000 D  002642 FFLG     0000 D  002470 FIELD    0000 D  002500 FREQ     0002 D  000000 GAMA1
    0000 R  002167 GRAZE    0000 D  002456 H        0000 D  002650 HPBW     0000 I  002665 I        0000 I  002670 IBETA
    0000 D  002462 INC      0000 D  002660 IND      0000 I  000000 INT      0000 I  002666 J        0000 D  002460 K
    0000 I  002464 L        0002 D  002670 LDP      0002 D  002112 LSP      0000 I  002667 M        0000 R  000055 MLSP
    0000 R  000344 NLDP     0000 D  002550 P        0000 D  002562 PADIF    0000    002707 PATH2    0000    002702 PATH3
    0000    002475 PATIS    0000 D  002576 PH       0000 D  002534 PHAC     0000 D  002536 PHAH     0000 D  002532 PHAV
    0000 D  002552 PHI      0000 D  002472 PI       0000 D  000001 PT       0000 D  002524 PV       0000 D  002620 Q
    0000 D  002540 RANG     0000 D  002542 RANG1    0000 D  002544 RANG2    0000 D  002506 RC       0000 D  002476 RDIE
    0000 D  002530 RH       0000 D  002526 RV       0000 D  002516 S        0000 D  002466 SCAT     0000 D  002652 SMP
    0000 D  002662 SMP1     0002 D  000556 SP       0000 D  002604 ST       0000 D  002560 STHET    0000 D  002570 TAU1
    0000 D  002564 TAU2     0000 D  002566 TAU3     0000 D  002556 THET1    0000 D  002606 T1       0000 D  002610 U
    0000 D  002616 WAVE     0000 D  002612 X        0000 D  000633 XLMP     0000 D  002626 X2       0000 D  002656 X3
    0000 D  002574 Y        0000 D  001411 YLMP     0000 D  002464 YI       0000 D  002624 Z        0000 D  002502 Z1
    0000 D  002504 Z2

00101      1*          COMMON GAMA1(183)
00103      2*          COMMON SP(183),DP(183)
```

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FIGURE 22 EARTH MULTIPATH IMPACT ON SUM AND DIFFERENCE CHANNEL AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

```
      COMMON LSP(183),LDP(183)
      DIMENSION PT(22)
      DIMENSION MLSP(183),MLDP(183)
      DIMENSION XLMP(183),YLMP(183)
      DIMENSION GRAZE(183)
      REAL MLDP,MLSP
      DOUBLE PRECISION M,K,INC,Y1
      DOUBLE PRECISION SCAT,FIELD,PI,CON,RDIE,FREQ,Z1,Z2,RC,A,DIV1,DIV2
      DOUBLE PRECISION SHV,BH,PV,HV,RH,PHAV,PHAC,PHAH
      DOUBLE PRECISION RANG,RANG1,RANG2,D1,P,PHI,DZ,GAMA1,THETB
      DOUBLE PRECISION STHET,PADIF,TAU2,TAU3,TAU1,DIV,Y,PH,BTHETI,BTHET
      DOUBLE PRECISION ST,T1,U,X,D,HAVE,Q
      DOUBLE PRECISION AFLG,Z,A2,BETA,BFLG,CFLG,DFLG,EFLG,FFLG
      DOUBLE PRECISION PT,DIFF,DP,DIA,HPBW,SMP,SP
      DOUBLE PRECISION DIFF1,X3,IND,SMP1
      DOUBLE PRECISION XLMP,YLMP,LSP,LDP
C     CONDUCTIVITY OF TYPE OF EARTH SURFACE
C     RELATIVE DIELECTRIC CONSTANT OF TYPE OF EARTH SURFACE
C     ARCDISTANCE INCREMENT
C     FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
   30 READ(5,26,END=41)CON,RDIE,INC,FREQ
   26 FORMAT(4D16.9)
C     HALF-POWER BEAMWIDTH
C     DIAMETER OF ANTENNA
C     ARCDISTANCE LIMITATION
      READ(5,67)HPBW,DIA,K
   67 FORMAT(3D16.9)
      L=1
C     OFFSET ANGLE
      PT(L)=.349065850E-1
C     ROUGHNESS FACTOR
      M=2.
   60 CONTINUE
C     DISTANCE FROM EARTH'S SURFACE TO ORBITER
      Z1=4.399796405
C     DISTANCE FROM EARTH'S SURFACE TO TDRS
      Z2=3.578607
      I=1
      J=1
C     BESSEL FUNCTION CONSTANT
      N=1
      PI=3.141592653589793238
C     DEGREE TO RADIAN CONVERSION
      X=PI/180.
C     RADIUS OF THE EARTH
      A=.6378333307
C     ANGLE BETWEEN LINE FROM ORBITER AND NORMAL TO EARTH'S TANGENT REL.
C     TIVE TO THE CENTER OF THE EARTH
      THETI=DACOS(A/(Z2+A))
C     ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO EARTH'S TANGENT RELATIV
C     E TO THE CENTER OF THE EARTH
      STHET=DACOS(A/(Z1+A))
      T1=THETI*(1./X)
      ST=STHET*(1./X)
C     MAXIMUM ANGLE THETA AT GRAZING
      BTHET=T1+ST
   24 CONTINUE
      BTHETI=BTHET
```

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FIGURE 22 CONTINUED

```
   21 CONTINUE
C     TOTAL ARC DISTANCE BETWEEN TDRS AND ORBITER
      D=(PI*A*BTHET)/180.
      P=(2./DSQRT(3.))*(DSQRT(A*(Z1+Z2)+(D/2.)**2.))
      PHI=DACOS((2.*A*(Z1-Z2)*D)/P**3)
C     ARC DISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE
C     EARTH AND THE ORBITER
      D2=D/2.+P*DCOS((PHI+PI)/3.)
C     ARC DISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
C     THE EARTH
      D1=D-D2
C     TWO DISTANCE COMPONENTS OF INDIRECT SIGNAL
      RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
      RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
C     DISTANCE TRAVELED BY DIRECT SIGNAL
      RANG=A*DSQRT((Z1/A)**2.+(Z2/A)**2.-2.*(Z1/A)*(Z2/A)+2.*(1.+(Z1/A)*
     1(Z2/A)+(Z1/A)-(Z2/A))*(1.-DCOS(D/A)))
C     PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
      PADIF=RANG1+RANG2-RANG
C     ANGLE BETWEEN REFLECTED SIGNAL PATH AND LINE FROM EARTH'S CENTER
C     TO THE ORBITER
      TAU1=DASIN((A*DSIN(D2/A))/RANG2)
C     ANGLE BETWEEN SIGNAL PATH OF INDIRECT SIGNAL FROM THE TDRS AND LIN
C     E FROM THE CENTER OF THE EARTH TO THE TDRS
      TAU3=DASIN((A*DSIN(D1/A))/RANG1)
C     COMPLEMENT OF GRAZING ANGLE
      TAU2=DACOS(((A+Z2)*DCOS(TAU3)-RANG1)/A)
      IF(TAU2-PI/2.)23,23,22
   22 BTHET=BTHET-1.
      IF(TAU2-PI/2.)23,23,24
   23 CONTINUE
C     GRAZING ANGLE
      GAMA1(I)=PI/2.-TAU2
C     DIVERGENCE FACTOR
      DIV1=A*(RANG1+RANG2)*DSQRT(DSIN(TAU2)*DCOS(TAU2))
      DIV2=DSQRT(((A+Z2)*RANG1*DCOS(TAU3)+(A+Z1)*RANG2*DCOS(TAU1))*(A+Z1
     1)*(A+Z2)*DSIN(BTHET*X))
      DIV=DIV1/DIV2
C     WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER.
      WAVE=3.009/FREQ
C     FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
C     FICIENT
      Y=1.80010*(CON/FREQ)
C     PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
      S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1(I))))**2.+Y**2.)+(R
     1DIE-(1./2.)*(1.+DCOS(2.*GAMA1(I)))))/2.)
C     FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTING REFLEC
C     TION COEFFICIENT
      Q=Y/(2.*S)
C     PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
C     FICIENT
      BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
      PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)
C     VERTICAL POLARIZATION REFLECTION COEFFICIENT
      RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))-PV*DSIN(GAMA1(I)))/(1.
     1+(BV/2.)*(1.-DCOS(2.*GAMA1(I))))+PV*DSIN(GAMA1(I))))
C     PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE
      PHAV=DATAN((Y*DSIN(GAMA1(I))-Q)/(RDIE*DSIN(GAMA1(I))-S))-DATAN((Y*
```

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FIGURE 22 CONTINUED

```
00224          IDSIN(GAMA1(I))*Q)/(RDIE*DSIN(GAMA1(I))+S))+PI
00224    C     PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
00224    C     EFFICIENT
00225          BH=1./(S**2.+Q**2.)
00226          PH=(2.*S)/(S**2.+Q**2.)
00226    C     HORIZONTAL REFLECTION COEFFICIENT
00227          RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))-PH*DSIN(GAMA1(I)))/(1.
00227         1+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))+PH*DSIN(GAMA1(I))))
00227    C     PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
00230          PHAH=DATAN(-Q/(DSIN(GAMA1(I))-S))-DATAN(Q/(DSIN(GAMA1(I))+S))+PI
00230    C     CIRCULAR REFLECTION COEFFICIENT
00231          RC=DABS((RV-RH)/2.)
00231    C     PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
00232          PHAC=(PHAV+PHAH)/2.
00232    C     SCATTERING REFLECTION COEFFICIENT
00233          SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMA1(I)))**2))
00233    C     MULTIPATH FIELD STRENGTH (INDIRECT FIELD)
00234          FIELD=((RANG/(RANG1+RANG2))*DIV*DABS(RC)*SCAT)**2.+2.*((RANG/(RANG
00234         1+RANG2))*DIV*DABS(RC)*SCAT)*(DCOS(((2.*PI)/WAVE)*PADIF)+PHAC))
00234    C     BESSEL FUNCTION ARGUMENT
00235          X2=((PI*DIA)/WAVE)*DSIN(GAMA1(I)-PT(L))
00235    C     BESSEL FUNCTION SUBPROGRAM
00236          Y1=40.
00237          Z=0.0
00240          Y1=Y1+Z
00241          INT=(M+X2)/2.
00242          BETA=2.0*INT+Y1
00243          IBETA=BETA+.001
00244          AFLG=0.0
00245          BFLG=0.0
00246          CFLG=0.0
00247          DFLG=0.0
00250          EFLG=1.0
00251          Z=1.0
00252          FFLG=DCOS((IBETA-2.)*(PI/2.))
00253       66 CONTINUE
00254          IF(IBETA-H)60,61,60
00257       61 CFLG=EFLG
00260       60 CONTINUE
00261          IF(IBETA.EQ.0)GO TO 62
00263          IF(BFLG.GT..0000001)GO TO 64
00265          BFLG=1.0
00266          AFLG=AFLG+EFLG
00267          GO TO 65
00270       64 BFLG=0.0
00271       65 CONTINUE
00272          Z=((2.*IBETA)*(EFLG+((-1.)*DFLG*X2)/(2.*IBETA)))/X2
00273          DFLG=EFLG
00274          EFLG=Z
00275          IBETA=IBETA-1
00276          GO TO 66
00277       62 Z=(2.*AFLG)+EFLG
00300          AFLG=CFLG/Z
00300    C     DIRECT SIGNAL FIELD (SUM PATTERN)
00301          SMP=(2.*WAVE*AFLG)/(PI*DIA*DSIN(GAMA1(I)-PT(L)))
00301    C     BESSEL FUNCTION ARGUMENT
00302          X3=((PI*DIA)/WAVE)*DSIN(-GAMA1(I)-PT(L))
00302    C     BESSEL FUNCTION SUBPROGRAM
```

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FIGURE 22 CONTINUED

```
      Y1=50.
      Z=0.0
      Y1=Y1+Z
      INT=(M+X3)/2.
      BETA=2.0*INT+Y1
      IBETA=BETA+.001
      AFLG=0.0
      BFLG=0.0
      CFLG=0.0
      DFLG=0.0
      EFLG=1.0
      Z=1.0
      FFLG=DCOS((IBETA-2.)*(PI/2.))
   70 CONTINUE
      IF(IBETA-M)72,71,72
   71 CFLG=EFLG
   72 CONTINUE
      IF(IBETA.EQ.0)GO TO 77
      IF(BFLG.GT..0000001)GO TO 75
      BFLG=1.0
      AFLG=AFLG+EFLG
      GO TO 76
   75 BFLG=0.0
   76 CONTINUE
      Z=((2.*IBETA)*(EFLG+((-1.)*DFLG*X3)/(2.*IBETA)))/X3
      DFLG=EFLG
      EFLG=Z
      IBETA=IBETA-1
      GO TO 70
   77 Z=(2.*AFLG)+EFLG
      AFLG=CFLG/Z
C     INDIRECT SIGNAL FIELD (SUM PATTERN)
      SMPI=(2.*WAVE*AFLG)/(PI*DIA*DSIN(-GAMA1(I)-PT(L)))
      IND=SMPI
      XLMP(I)=DABS(SMP+(IND*FIELD))
C     SUM PATTERN FIELD
      SP(I)=20.*DLOG10(XLMP(I))
C     DIFFERENCE PATTERN FUNCTION
C     DIRECT SIGNAL
      DIFF=DSIN(PI*((GAMA1(I)-PT(L))/HPBW)+PI)-DSIN(PI*((GAMA1(I)-PT(L))
     1/HPBW))
C     INDIRECT SIGNAL
      DIFFI=DSIN(PI*((-GAMA1(I)-PT(L))/HPBW)+PI)-DSIN(PI*((-GAMA1(I)-PT(
     1L))/HPBW))
      YLMP(I)=DABS(DIFF+(DIFFI*FIELD))
C     DIFFERENCE PATTERN FIELD
      DP(I)=20.*DLOG10(YLMP(I))
      GAMA1(I)=GAMA1(I)*(1./X)
      PT(L)=PT(L)*(1./X)
      LSP(I)=SP(I)
      LDP(I)=DP(I)
      HLSP(I)=SNGL(LSP(I))
      HLDP(I)=SNGL(LDP(I))
      GRAZE(I)=SNGL(GAMA1(J))
      PT(L)=PT(L)*X
      U=BTHETI-K
      I=I+1
      J=J+1
```

FIGURE 22 CONTINUED

```
00371   235*          BTHET=BTHET-INC
00372   236*          IF(BTHET.GT.0)GO TO 21
00374   237*          NAMELIST/PATH5/PT
00375   238*          WRITE(6,PATH5)
00400   239*          NAMELIST/PATH3/GRAZE
00401   240*          WRITE(6,PATH3)
00404   241*          NAMELIST/PATH2/LSP,LDP
00405   242*          WRITE(6,PATH2)
00410   243*          DO 90 I=1,180
00413   244*          WRITE(8)HLSP(I),GRAZE(I),NLDP(I)
00420   245*       90 CONTINUE
00422   246*          ENDFILE8
00422   247*    C     OFFSET INCREMENT
00423   248*          PT(L+1)=PT(L)+.872222222D-2
00424   249*          L=L+1
00425   250*          IF(L.LT.1)GO TO 80
00427   251*          GO TO 30
00430   252*       41 CONTINUE
00431   253*          END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

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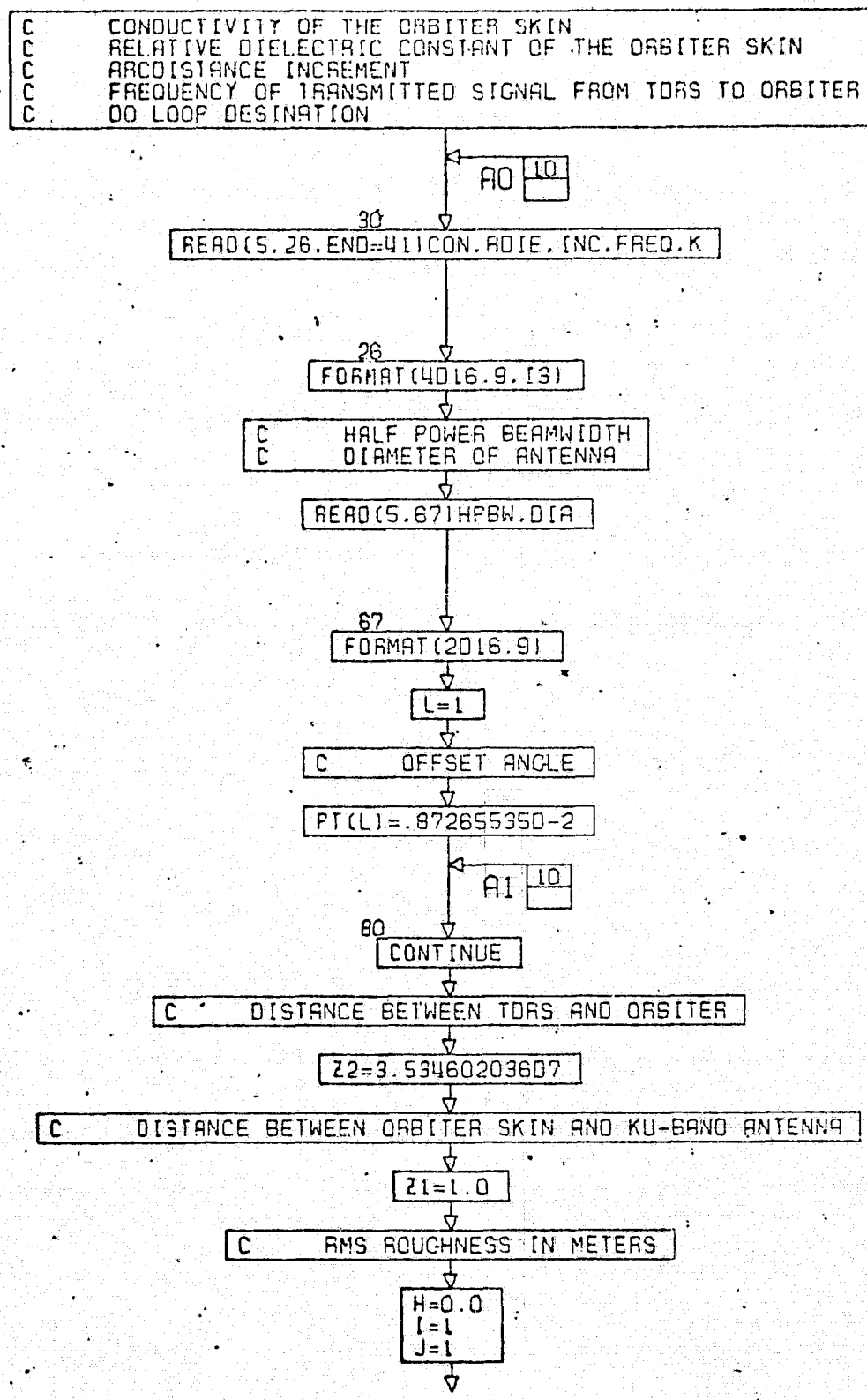
FIGURE 22 CONTINUED



CONT. ON PG 2

ORBSD
PG 1 OF 10

FIGURE 23 FLOWCHART FOR ORBITER MULTIPATH IMPACT ON SUM AND DIFFERENCE CHANNELS AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

```
C       BESSEL FUNCTION CONSTANT
M=1
PI=3.14159265358979
C       DEGREE TO RADIAN CONVERSION
X=PI/180.
C RADIUS OF THE ORBITER FUSELAGE
A=2.9921005843281 68
C       ANGLE BETWEEN LINE FROM ANTENNA AND NORMAL TO ORBITER'S TANGENT
C       RELATIVE TO ORBITER'S CENTER
STHET=DACOS(A/(Z1+A))
C       ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO ORBITER'S TANGENT RELAT
C       IVE TO THE ORBITER'S CENTER
THET1=DACOS(A/(Z2+A))
C       ARCDISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE ORB
C       ITER AND THE KU-BAND ANTENNA
D2=A*STHET
C       TOTAL ARCDISTANCE BETWEEN ANTENNA AND TDRS
D=A*(THET1+STHET)
BTHET=DATAN(Z1/D2)
C       GRAZING ANGLE
GAMA1(I)=BTHET-DATAN(Z1/D2)
A2 9
2 CONTINUE
C       ARCDISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
C       THE ORBITER
D1=D-D2
C       COMPLEMENT OF GRAZING ANGLE
```

CONT. ON PG 3

ORBSO
PG 2 OF 10

FIGURE 23 CONTINUED

```
PHI=(PI/2.-GAMA1(I)
BTHET1=PI/2.+PHI
```

```
C      TWO DISTANCE COMPONENTS OF INDIRICT SIGNAL
```

```
RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
```

```
C      PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
```

```
PADIF=2.*Z1*DTAN(GAMA1(I))
```

```
C      DIVERGENCE FACTOR
```

```
SICK=DACOS((A**2+(A+Z1)**2-RANG2**2)/(2.*A*(A+Z1)))
```

```
DIS=DSQRT((A*DSIN(GAMA1(I)))/((A*DSIN(GAMA1(I))+(2.*RANG2))*(1.+(Z
1/A))*DSIN(SICK)))
```

```
DIV=DSQRT(DIS)
```

```
C      WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
```

```
WAVE=3.008/FREQ
```

```
C      FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
C      FICIENT
```

```
Y=1.80010*(CON/FREQ)
```

```
C      PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
```

```
S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1(I))))**2.+Y**2.)+(R
DIE-(1./2.)*(1.+DCOS(2.*GAMA1(I)))))/2.)
```

```
C      FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTATION OF R
C      EFLECTION COEFFICIENT
```

```
Q=Y/(2.*S)
```

```
C      PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
C      FICIENT
```

```
BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)
```

```
C      VERTICAL POLARIZATION REFLECTION COEFFICIENT
```

```
AV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))-PV*DSIN(GAMA1(I)))/(1.
```

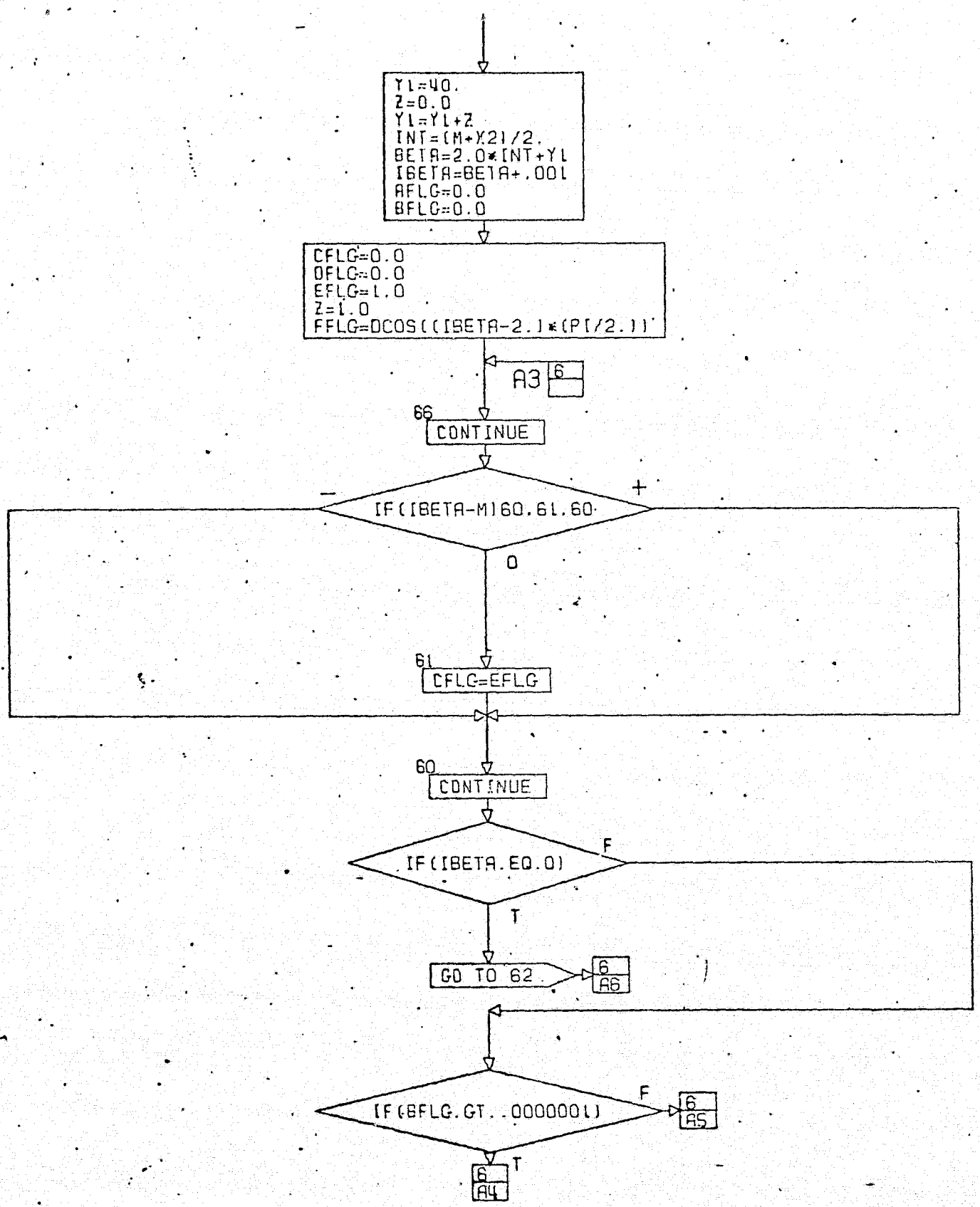
CONT. ON PG 4

FIGURE 23 CONTINUED

```
+(BV/2.)*(L.-DCOS(2.*GAMAL(I)))+PV*DSIN(GAMAL(I))))
C     PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE
PHAV=DATAN((Y*DSIN(GAMAL(I))-Q)/(RDIE*DSIN(GAMAL(I))-S))-DATAN((Y*
DSIN(GAMAL(I))+Q)/(RDIE*DSIN(GAMAL(I))+S))
PHAV=PHAV+PI
C     PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
C     EFFICIENT
BH=1./(S**2.+Q**2.)
PH=(2.*S)/(S**2.+Q**2.)
C     HORIZONTAL REFLECTION COEFFICIENT
RH=DSQRT(((L.+(BH/2.)*(L.-DCOS(2.*GAMAL(I)))-PH*DSIN(GAMAL(I)))/(L.
+(BH/2.)*(L.-DCOS(2.*GAMAL(I)))+PH*DSIN(GAMAL(I))))
C     PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
PHAH=DATAN(-Q/(DSIN(GAMAL(I))-S))-DATAN(Q/(DSIN(GAMAL(I))+S))
PHAH=PHAH+PI
C     CIRCULAR REFLECTION COEFFICIENT
RC=DABS((RV+RH)/2.)
C     PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
PHAC=(PHAV+PHAH)/2.
C     SCATTERING REFLECTION COEFFICIENT
SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMAL(I)))**2))
C     MULTIPATH FIELD STRENGT (INDIRECT SIGNAL)
FIELD=(DIV*DABS(RC)*SCAT)**2+2.*(DIV*DABS(RC)*SCAT)*(DCOS((((2.*PI
)/WAVE)*PAD(F)+PHAC))
C     BESSEL FUNCTION SUBPROGRAM (SUM PATTERN)
C     BESSEL FUNCTION ARGUMENT
X2=((PI*D(A)/WAVE)*DSIN(GAMAL(I)-PT(L))
C     BESSEL FUNCTION LIMITATION
```

CONT. ON PG 5

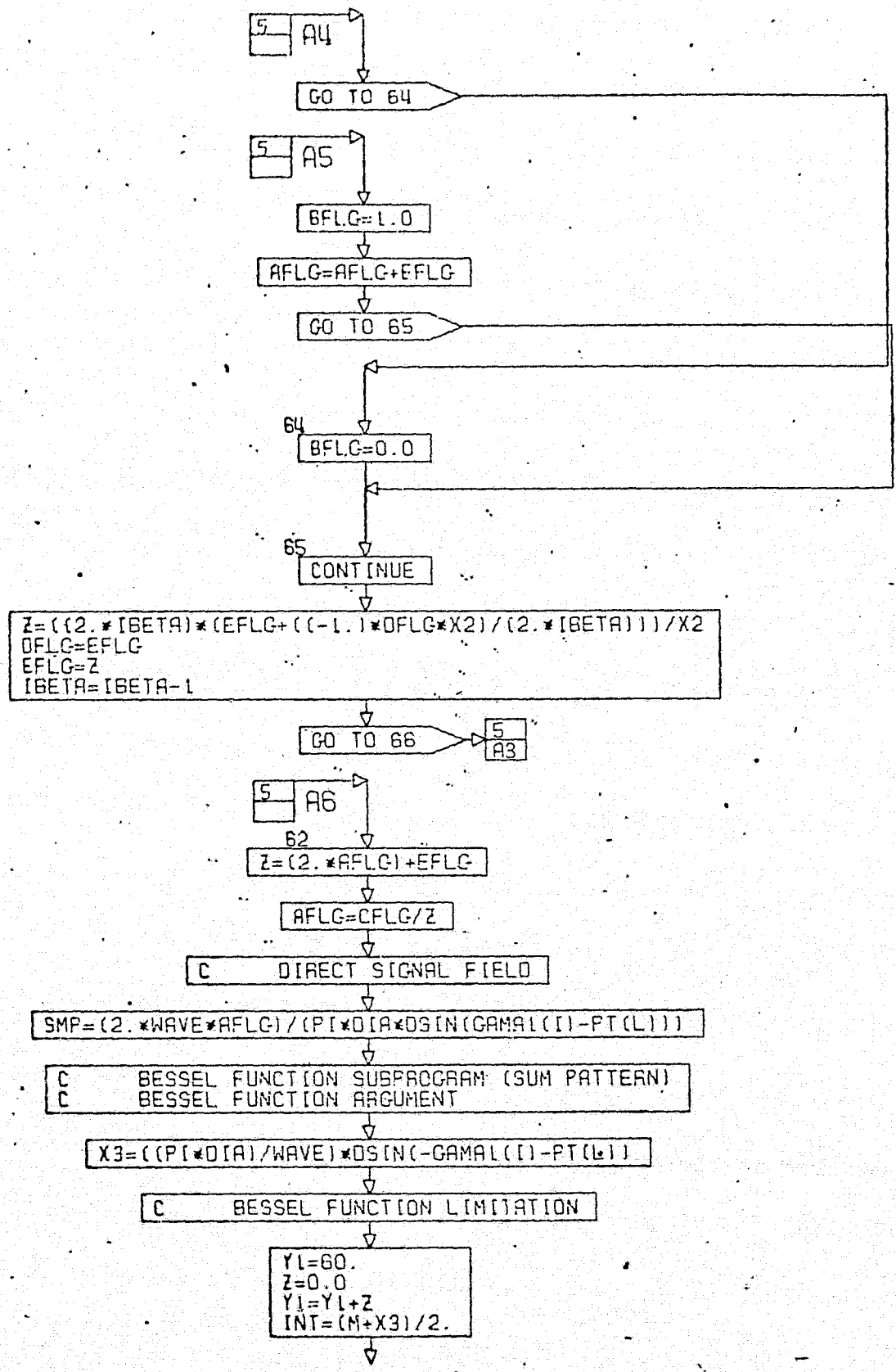
FIGURE 23 CONTINUED



CONT. ON PG 6

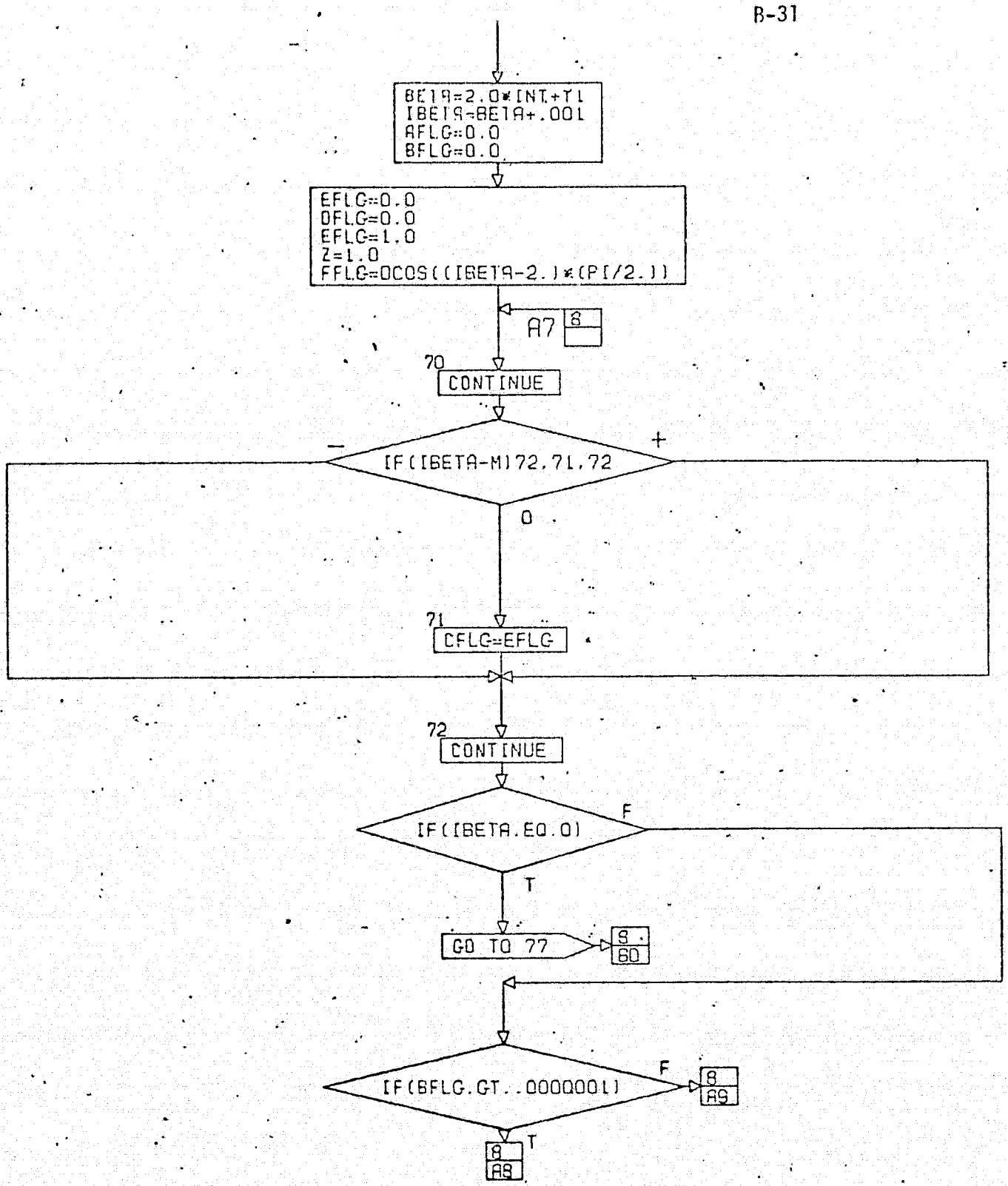
ORBSO
PG 5 OF 10

FIGURE 23 CONTINUED



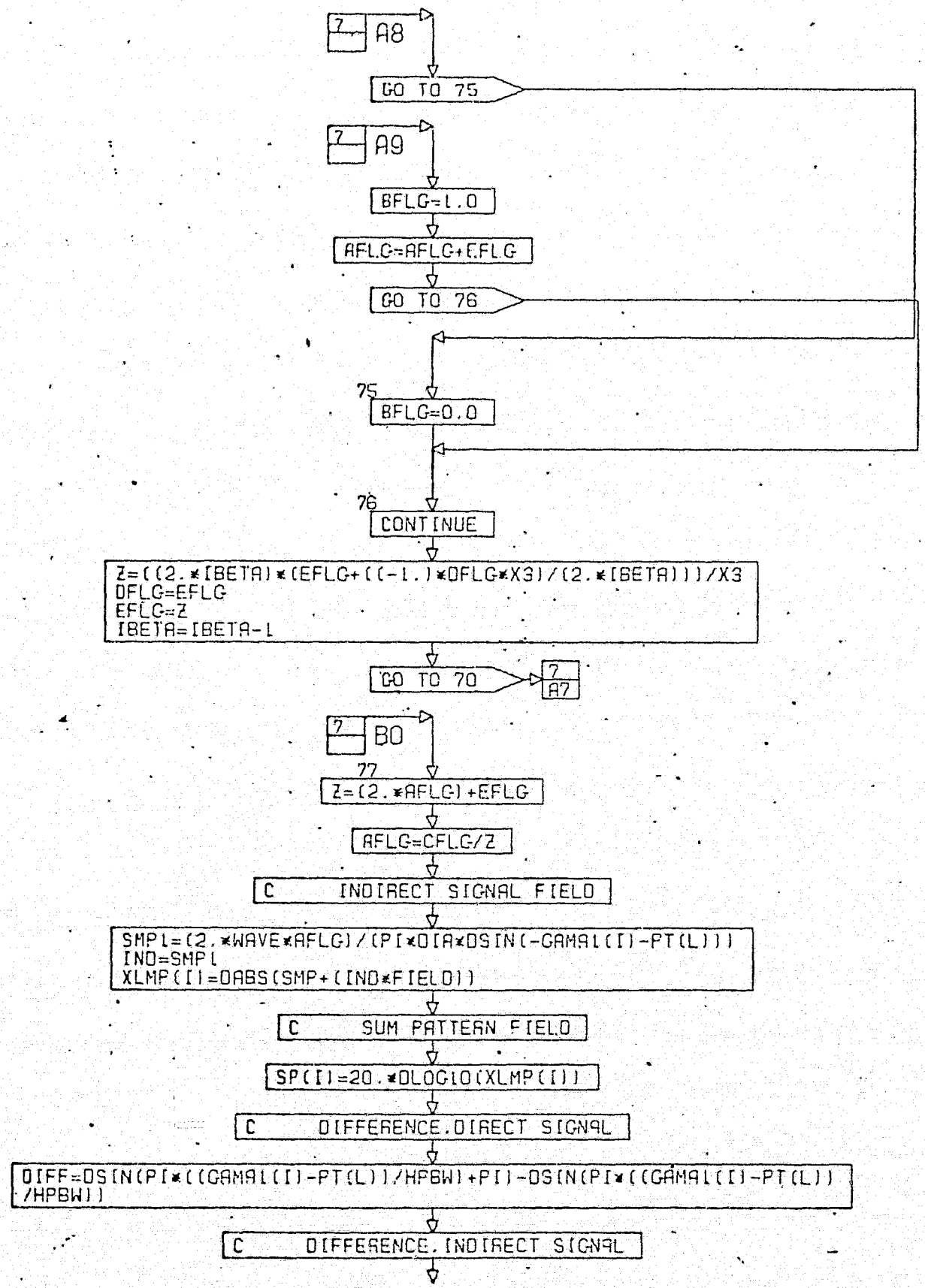
CONT. ON PG 7

FIGURE 23 CONTINUED



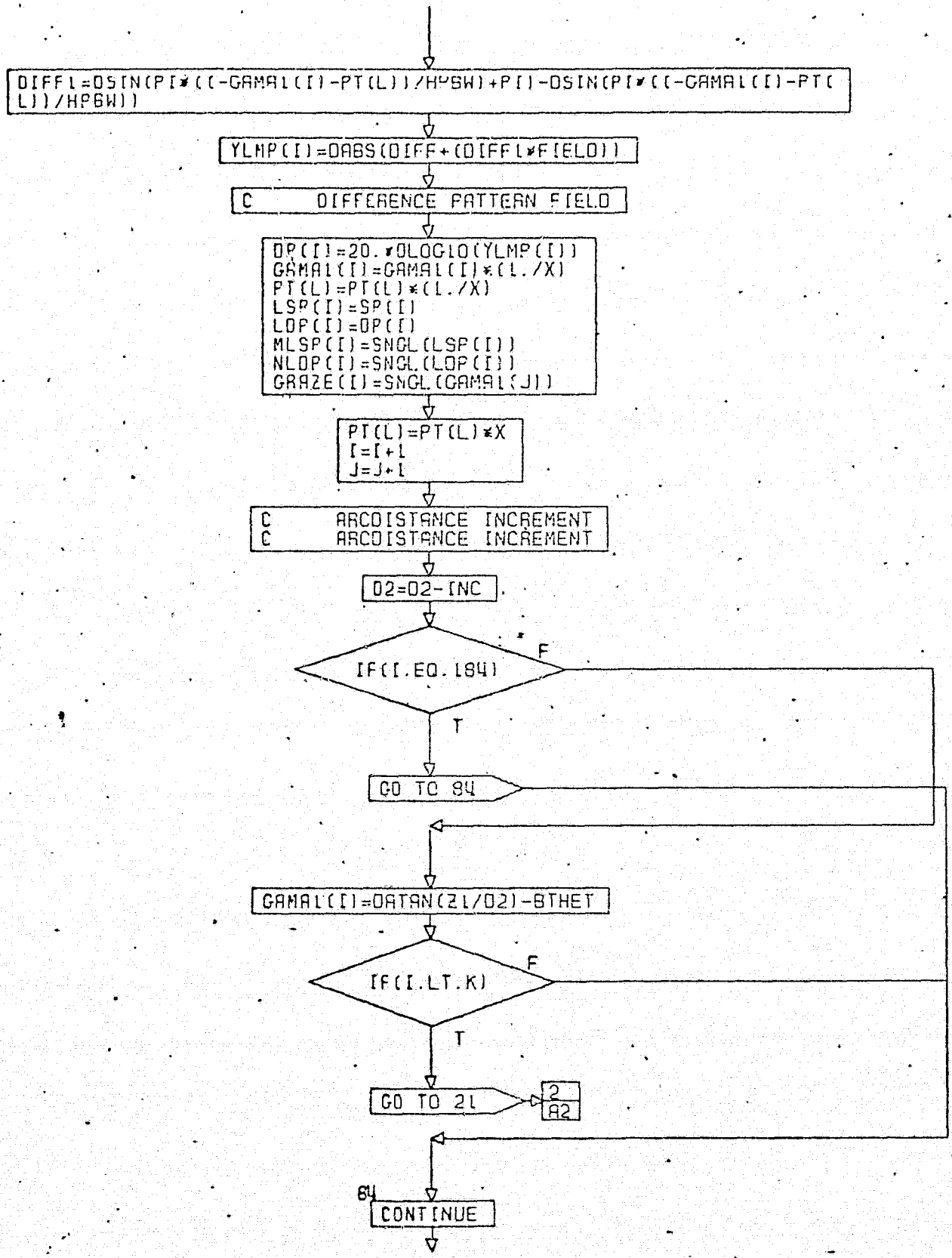
CONT. ON PG 8

FIGURE 23 CONTINUED



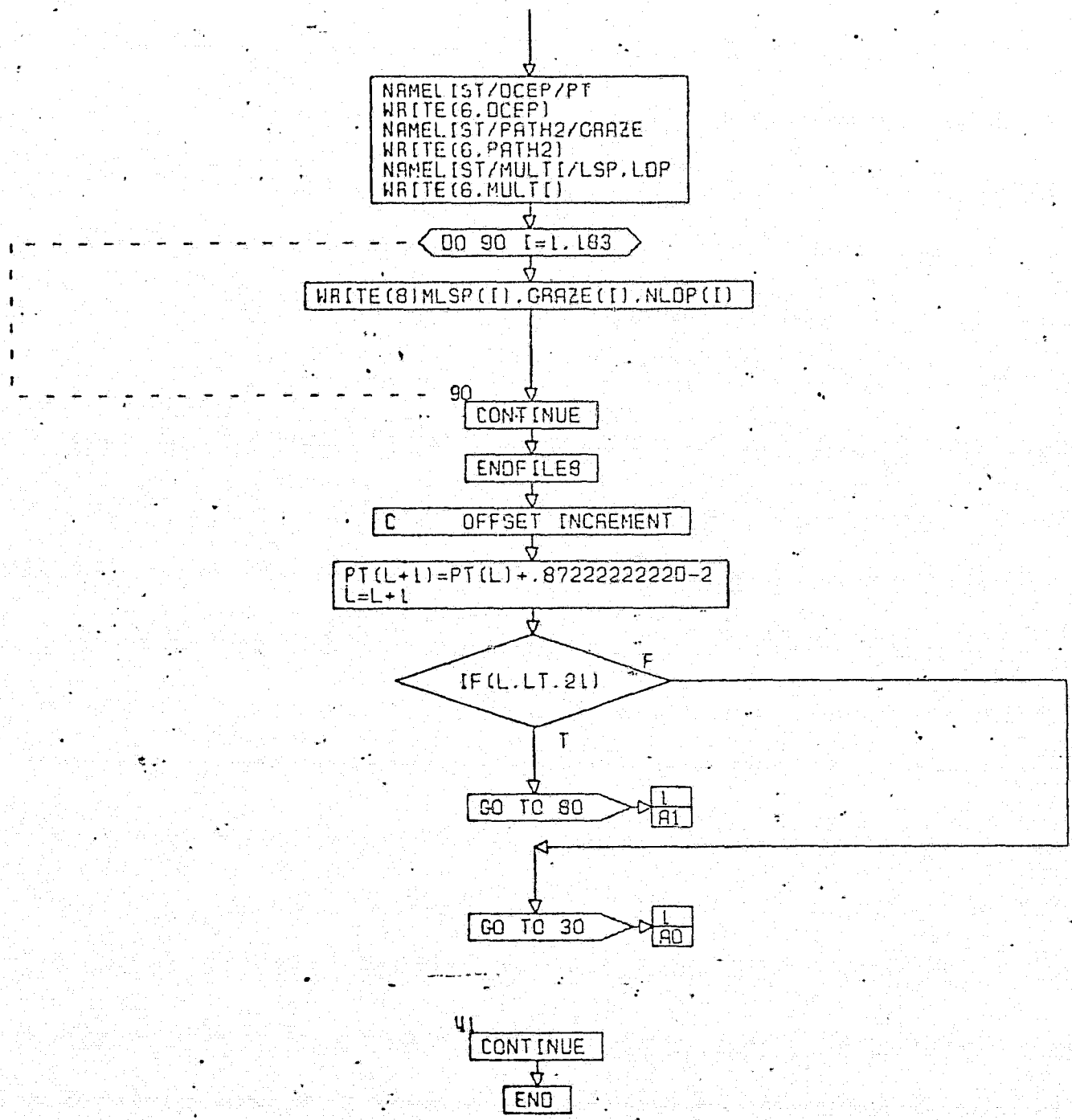
CONT. ON PG 9

FIGURE 23 CONTINUED



CONT. ON PG 10

FIGURE 23 CONTINUED



ORBSO
PG 10 FINAL

FIGURE 23 CONTINUED

```
@ FOR ORBGR,ORBGR                                                                    22 JUL 77          11:13:21.622
UNIVAC 1108 FORTRAN V EXEC II LEVEL 25A  -(EXEC8 LEVEL E12010010A)
THIS COMPILATION WAS DONE ON 22 JUL 77 AT 11:13:21

   MAIN PROGRAM

   STORAGE USED: CODE(1) 001473; DATA(0) 002773; BLANK COMMON(2) 003446

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003    NRDU$
    0004    NIO2$
    0005    DACOS
    0006    DATAN
    0007    DCOS
    0010    DSQRT
    0011    DTAN
    0012    DSIN
    0013    DEXP
    0014    DLOG10
    0015    NANL$
    0016    NWBU$
    0017    NAEF$
    0020    NSTOP$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000111 21L      0000    002656 26F      0001    000000 30L      0001    001442 400G     0001    001471 41L
    0001    000727 60L      0001    000774 62L      0001    000744 64L      0001    000746 65L      0001    000722 66L
    0000    002660 67F      0001    001134 70L      0001    001141 72L      0001    001156 75L      0001    001160 76L
    0001    001206 77L      0001    000027 80L      0001    001421 84L      0000 D  002610 A        0000 D  002464 AFLG
    0000 D  002472 BETA     0000 D  002474 BFLG     0000 D  002552 BH       0000 D  002626 BTHET    0000 D  002630 BTHET1
    0000 D  002564 BV       0000 D  002476 CFLG     0000 D  002566 CON      0000 D  002636 D        0000    002662 DCEP
    0000 D  002500 DFLG     0000 D  002510 DIA      0000 D  002506 DIFF     0000 D  002516 DIFF1    0000 D  002544 DIS
    0000 D  002612 DIV      0002 D  000556 DP       0000 D  002614 D1       0000 D  002634 D2       0000 D  002502 EFLG
    0000 D  002504 FFLG     0000 D  002576 FIELD    0000 D  002642 FREQ     0002 D  002670 GAMA1    0000 R  002175 GRAZE
    0000 D  002646 H        0000 D  002512 HPBW     0000 I  002652 I        0000 I  002655 IBETA    0000 D  002550 INC
    0000 D  002522 IND      0000 I  000000 INT      0000 I  002653 J        0000 I  002650 K        0000 I  002651 L
    0002 D  002112 LOP      0002 D  001334 LSP      0000 I  002654 M        0000 R  000063 MLSP     0000    002674 MULTI
    0000 R  000352 NLOP     0000 D  002624 PADIF    0000    002667 PATH2    0000 D  002570 PH       0000 D  002534 PMAC
    0000 D  002536 PHAM     0000 D  002532 PHAV     0000 D  002616 PHI      0000 D  002600 PI       0000 D  000001 PT
    0000 D  002554 PV       0000 D  002562 Q        0000 D  002540 RANG1    0000 D  002542 RANG2    0000 D  002606 RC
    0000 D  002556 RDIE     0000 D  002530 RH       0000 D  002526 RV       0000 D  002560 S        0000 D  002574 SCAT
    0000 D  002546 SICK     0000 D  002514 SHP      0000 D  002524 SHP1     0002 D  000000 SP       0000 D  002622 STHET
    0000 D  002620 THET1    0000 D  002640 WAVE     0000 D  002632 X        0000 D  000641 XLMP     0000 D  002470 X2
    0000 D  002520 X3       0000 D  002572 Y        0000 D  001417 YLMP     0000 D  002644 Y1       0000 D  002466 Z
    0000 D  002602 Z1       0000 D  002604 Z2

00101     1*          COMMON SP(183),DP(183)
00103     2*          COMMON LSP(183),LOP(183)
00104     3*          COMMON GAMA1(183)
00105     4*          DIMENSION PT(25)
00106     5*          DIMENSION MLSP(183),NLOP(183)
```

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FIGURE 24 ORBITER MULTIPATH IMPACT ON SUM AND DIFFERENCE CHANNELS AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

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```
      DIMENSION XLMP(183),YLMP(183)
      DIMENSION GRAZE(183)
      REAL NLDP,NLSP
      DOUBLE PRECISION AFLG,Z,X2,BETA,BFLG,CFLG,DFLG,EFLG,FFLG
      DOUBLE PRECISION PT,DIFF,DP,DIA,HPBW,SMP,SP
      DOUBLE PRECISION DIFF1,X3,IND,SMP1
      DOUBLE PRECISION XLMP,YLMP,LSP,LOP
      DOUBLE PRECISION RV,RH,PHAV,PHAC,PHAH
      DOUBLE PRECISION RANG1,RANG2
      DOUBLE PRECISION DIS,SICK,INC
      DOUBLE PRECISION BH,PV,RDIE,S,Q,BV,CON,PH,Y
      DOUBLE PRECISION SCAT,FIELD,PI,Z1,Z2,RC,A,DIV
      DOUBLE PRECISION D1,PHI,GAMA1,THET1
      DOUBLE PRECISION STHET,PADIF,BTHET,BTHET1,X,D2
      DOUBLE PRECISION D,WAVE,FREQ,Y1,H
C     CONDUCTIVITY OF THE ORBITER SKIN
C     RELATIVE DIELECTRIC CONSTANT OF THE ORBITER SKIN
C     ARCDISTANCE INCREMENT
C     FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
C     DO LOOP DESINATION
   30 READ(5,26,END=41)CON,RDIE,INC,FREQ,K
   26 FORMAT(4D16.9,I3)
C     HALF POWER BEAMWIDTH
C     DIAMETER OF ANTENNA
      READ(5,67)HPBW,DIA
   67 FORMAT(2D16.9)
      L=1
C     OFFSET ANGLE
      PT(L)=.87265535D-2
   80 CONTINUE
C     DISTANCE BETWEEN TDRS AND ORBITER
      Z2=3.53460203607
C     DISTANCE BETWEEN ORBITER SKIN AND KU-BAND ANTENNA
      Z1=1.0
C     RMS ROUGHNESS IN METERS
      H=0.0
      I=1
      J=1
C     BESSEL FUNCTION CONSTANT
      M=1
      PI=3.14159265358979
C     DEGREE TO RADIAN CONVERSION
      X=PI/180.
C RADIUS OF THE ORBITER FUSELAGE
      A=2.99210058432816B
C     ANGLE BETWEEN LINE FROM ANTENNA AND NORMAL TO ORBITER'S TANGENT
C     RELATIVE TO ORBITER'S CENTER
      STHET=DACOS(A/(Z1+A))
C     ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO ORBITER'S TANGENT RELAT
C     IVE TO THE ORBITER'S CENTER
      THET1=DACOS(A/(Z2+A))
C     ARCDISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE ORB
C     ITER AND THE KU-BAND ANTENNA
      D2=A*STHET
C     TOTAL ARCDISTANCE BETWEEN ANTENNA AND TDRS
      D=A*(THET1+STHET)
      BTHET=DATAN(Z1/D2)
C     GRAZING ANGLE
```

FIGURE 24 CONTINUED

```
00164      GAMA1(I)=BTHET-DATAN(Z1/D2)
00165   21 CONTINUE
00165 C    ARCDISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
00165 C    THE ORBITER
00166      D1=D-D2
00166 C    COMPLEMENT OF GRAZING ANGLE
00167      PHI=(PI/2.)-GAMA1(I)
00170      BTHET1=PI/2.+PHI
00170 C    TWO DISTANCE COMPONENTS OF INDIRECT SIGNAL
00171      RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
00172      RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
00172 C    PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
00173      PADIF=2.*Z1*DTAN(GAMA1(I))
00173 C    DIVERGENCE FACTOR
00174      SICK=DACOS((A**2+(A+Z1)**2-RANG2**2)/(2.*A*(A+Z1)))
00175      DIS=DSQRT((A*DSIN(GAMA1(I)))/((A*DSIN(GAMA1(I))+(2.*RANG2))*(1.+(Z
     1/A))*DSIN(SICK)))
00176      DIV=DSQRT(DIS)
00176 C    WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
00177      WAVE=3.0D8/FREQ
00177 C    FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
00177 C    FICIENT
00200      Y=1.8D10*(CON/FREQ)
00200 C    PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
00201      S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1(I)))**2.+Y**2.)+(R
     1DIE-(1./2.)*(1.+DCOS(2.*GAMA1(I))))))/2.)
00201 C    FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTATION OF R
00201 C    EFLECTION COEFFICIENT
00202      Q=Y/(2.*S)
00202 C    PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
00202 C    FICIENT
00203      BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
00203      PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)
00204 C    VERTICAL POLARIZATION REFLECTION COEFFICIENT
00205      RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMA1(I)))-PV*DSIN(GAMA1(I)))/(1.
     1+(BV/2.)*(1.-DCOS(2.*GAMA1(I))))+PV*DSIN(GAMA1(I))))
00205 C    PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE
00206      PHAV=DATAN((Y*DSIN(GAMA1(I))-Q)/(RDIE*DSIN(GAMA1(I))-S))-DATAN((Y*
     1DSIN(GAMA1(I))+Q)/(RDIE*DSIN(GAMA1(I))+S))
00207      PHAV=PHAV*PI
00207 C    PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
00207 C    EFFICIENT
00210      BH=1./(S**2.+Q**2.)
00211      PH=(2.*S)/(S**2.+Q**2.)
00211 C    HORIZONTAL REFLECTION COEFFICIENT
00212      RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))-PH*DSIN(GAMA1(I)))/(1.
     1+(BH/2.)*(1.-DCOS(2.*GAMA1(I)))+PH*DSIN(GAMA1(I))))
00212 C    PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
00213      PHAH=DATAN(-Q/(DSIN(GAMA1(I))-S))-DATAN(Q/(DSIN(GAMA1(I))+S))
00214      PHAH=PHAH*PI
00214 C    CIRCULAR REFLECTION COEFFICIENT
00215      RC=DABS(RV*RH)/2.)
00215 C    PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
00216      PHAC=(PHAV+PHAH)/2.
00216 C    SCATTERING REFLECTION COEFFICIENT
00217      SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMA1(I)))**2))
00217 C    MULTIPATH FIELD STRENGT (INDIRECT SIGNAL)
00220      FIELD=(DIV*DABS(RC)*SCAT)**2+2.*(DIV*DABS(RC)*SCAT)*(DCOS(((2.*PI
```

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FIGURE 24 CONTINUED

1.2-DN-B0703-008
B-38

C-2

```
00220          1)/WAVE)*PAD(F)+PHAC))
00220     C     BESSEL FUNCTION SUBPROGRAM (SUM PATTERN)
00220     C     BESSEL FUNCTION ARGUMENT
00221           X2=((PI*DIA)/WAVE)*DSIN(GAMA1(I)-PT(L))
00221     C     BESSEL FUNCTION LIMITATION
00222           Y1=40.
00223           Z=0.0
00224           Y1=Y1+Z
00225           INT=(M+X2)/2.
00226           BETA=2.0*INT+Y1
00227           IBETA=BETA+.001
00230           AFLG=0.0
00231           BFLG=0.0
00232           CFLG=0.0
00233           DFLG=0.0
00234           EFLG=1.0
00235           Z=1.0
00236           FFLG=DCOS((IBETA-2.)*(PI/2.))
00237        66 CONTINUE
00240           IF(IBETA-M)60,61,60
00243        61 CFLG=CFLG
00244        60 CONTINUE
00245           IF(IBETA.EQ.0)GO TO 62
00247           IF(BFLG.GT..0000001)GO TO 64
00251           BFLG=1.0
00252           AFLG=AFLG+EFLG
00253           GO TO 65
00254        64 BFLG=0.0
00255        65 CONTINUE
00256           Z=((2.*IBETA)*(EFLG+((-1.)*DFLG*X2)/(2.*IBETA)))/X2
00257           DFLG=EFLG
00260           EFLG=Z
00261           IBETA=IBETA-1
00262           GO TO 66
00263        62 Z=(2.*AFLG)+EFLG
00264           AFLG=CFLG/Z
00264     C     DIRECT SIGNAL FIELD
00265           SMP=(2.*WAVE*AFLG)/(PI*DIA*DSIN(GAMA1(I)-PT(L)))
00265     C     BESSEL FUNCTION SUBPROGRAM (SUM PATTERN)
00265     C     BESSEL FUNCTION ARGUMENT
00266           X3=((PI*DIA)/WAVE)*DSIN(-GAMA1(I)-PT(L))
00266     C     BESSEL FUNCTION LIMITATION
00267           Y1=60.
00270           Z=0.0
00271           Y1=Y1+Z
00272           INT=(M+X3)/2.
00273           BETA=2.0*INT+Y1
00274           IBETA=BETA+.001
00275           AFLG=0.0
00276           BFLG=0.0
00277           EFLG=0.0
00300           DFLG=0.0
00301           EFLG=1.0
00302           Z=1.0
00303           FFLG=DCOS((IBETA-2.)*(PI/2.))
00304        70 CONTINUE
00305           IF(IBETA-M)72,71,72
00310        71 CFLG=EFLG
```

FIGURE 24 CONTINUED

```
00311      72 CONTINUE
00312         IF(IBETA.EQ.0)GO TO 77
00314         IF(BFLG.GT..0000001)GO TO 75
00316         BFLG=1.0
00317         AFLG=AFLG+EFLG
00320         GO TO 76
00321      75 BFLG=0.0
00322      76 CONTINUE
00323         Z=((2.*IBETA)*(EFLG*(1-1.)*DFLG*X3)/(2.*IBETA)))/X3
00324         DFLG=EFLG
00325         EFLG=Z
00326         IBETA=IBETA-1
00327         GO TO 70
00330      77 Z=(2.*AFLG)+EFLG
00331         AFLG=EFLG/Z
00331   C     INDIRECT SIGNAL FIELD
00332         SMPI=(2.*WAVE*AFLG)/(PI*DIA*DSIN(-GAMA1(I)-PT(L)))
00333         IND=SMPI
00334         XLMP(I)=DABS(SMP+(IND*FIELD))
00334   C     SUM PATTERN FIELD
00335         SP(I)=20.*DLOG10(XLMP(I))
00335   C     DIFFERENCE,DIRECT SIGNAL
00336         DIFF=DSIN(PI*((GAMA1(I)-PT(L))/HPBW)+PI)-DSIN(PI*((GAMA1(I)-PT(L))
00336        1/HPBW))
00336   C     DIFFERENCE,INDIRECT SIGNAL
00337         DIFFI=DSIN(PI*((-GAMA1(I)-PT(L))/HPBW)+PI)-DSIN(PI*((-GAMA1(I)-PT(
00337        1L))/HPBW))
00340         YLMP(I)=DABS(DIFF+(DIFFI*FIELD))
00340   C     DIFFERENCE PATTERN FIELD
00341         DP(I)=20.*DLOG10(YLMP(I))
00342         GAMA1(I)=GAMA1(I)*(1./X)
00343         PT(L)=PT(L)*(1./A)
00344         LSP(I)=SP(I)
00345         LDP(I)=DP(I)
00346         MLSP(I)=SNGL(LSP(I))
00347         MLDP(I)=SNGL(LDP(I))
00350         GRAZE(I)=SNGL(GAMA1(J))
00351         PT(L)=PT(L)*X
00352         I=I+1
00353         J=J+1
00353   C     ARCDISTANCE INCREMENT
00353   C     ARCDISTANCE INCREMENT
00354         D2=D2-INC
00355         IF(I.EQ.184)GO TO 84
00357         GAMA1(I)=DATAN(Z1/D2)-BTHET
00360         IF(I.LT.K)GO TO 21
00362      84 CONTINUE
00363         NAMELIST/DCEP/PT
00364         WRITE(6,DCEP)
00367         NAMELIST/PATH2/GRAZE
00370         WRITE(6,PATH2)
00373         NAMELIST/MULTI/LSP,LDP
00374         WRITE(6,MULTI)
00377         DO 90 I=1,183
00402         WRITE(8)MLSP(I),GRAZE(I),MLDP(I)
00407      90 CONTINUE
00411         ENDFILE8
00411   C     OFFSET INCREMENT
```

FIGURE 24 CONTINUED

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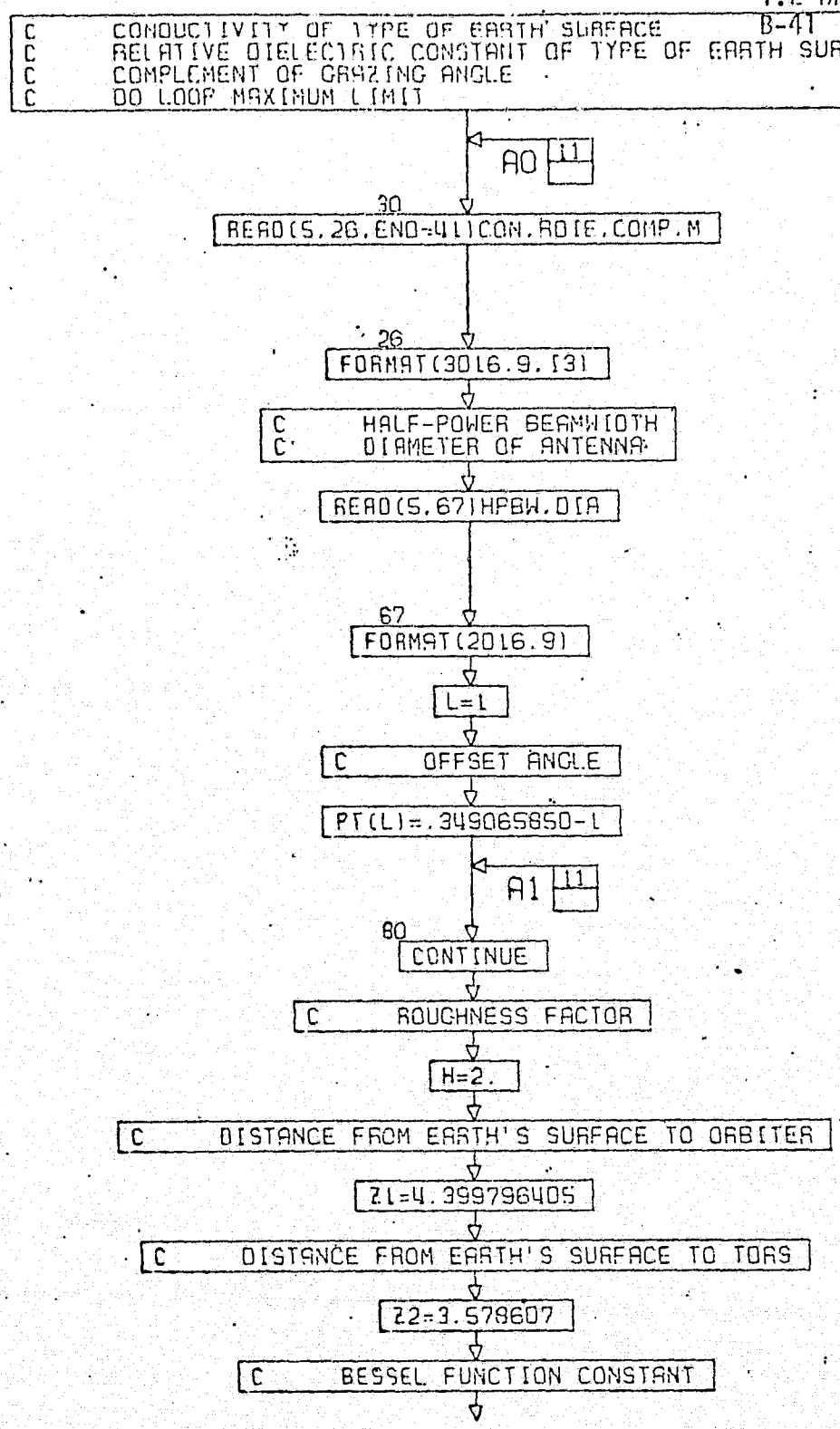
```
00412    238*          PT(L+1)=PT(L)+.87222222220-2
00413    239*          L=L+1
00414    240*          IF(L.LT.21)GO TO 80
00416    241*          GO TO 30
00417    242*       41 CONTINUE
00420    243*          END

     END OF COMPILATION:        NO  DIAGNOSTICS.
```

FIGURE 24 CONTINUED



CONT. ON PG 2

EARSD
PG 1 OF 11

FIGURE 25 FLOWCHART FOR EARTH MULTIPATH IMPACT ON SUM AND DIFFERENCE CHANNELS AS A FUNCTION OF GRAZING ANGLE OR FREQUENCY

```
K=1
PI=3.141592653589793238
C     DEGREE TO RADIAN CONVERSION
X=PI/180.
C     RADIUS OF THE EARTH
A=.868933333307
C     ANGLE BETWEEN LINE FROM ORBITER AND NORMAL TO EARTH.S TANGENT RELA
C     TIVE TO THE CENTER OF THE EARTH
THET1=DACOS(A/(Z2+A))
C     ANGLE BETWEEN LINE FROM TDRS AND NORMAL TO EARTH'S TANGENT RELATIV
C     E TO THE CENTER OF THE EARTH
STHET=DACOS(A/(Z1+A))
T1=THET1*(1./X)
ST=STHET*(1./X)
C     MAXIMUM ANGLE THETA AT GRAZING
BTHET=T1+ST
A2 3
24 CONTINUE
C     TOTAL ARC DISTANCE BETWEEN TDRS AND ORBITER
D=(PI*A*BTHET)/180.
P=(2./DSQRT(3.))*(DSQRT(A*(Z1+Z2)+(D/2.)**2.))
PHI=DACOS(((2.*A)*(Z1-Z2)*D)/P**3.)
C     ARC DISTANCE BETWEEN THE REFLECTION POINT ON THE SURFACE OF THE
C     EARTH AND THE ORBITER
D2=D/2.+P*DCOS((PHI+PI)/3.)
C     ARC DISTANCE BETWEEN TDRS AND REFLECTION POINT OFF THE SURFACE OF
C     THE EARTH
D1=D-D2
C     TWO DISTANCE COMPONENTS OF INDIRECT SIGNAL
```

CONT. ON PG 3

FIGURE 25 CONTINUED

```
RANG1=DSQRT(A**2+(A+Z2)**2-((2.*A)*(A+Z2)*DCOS(D1/A)))
RANG2=DSQRT(A**2+(A+Z1)**2-((2.*A)*(A+Z1)*DCOS(D2/A)))
```

```
C       DISTANCE TRAVELED BY DIRECT SIGNAL
```

```
RANG=A*DSQRT((Z1/A)**2.+(Z2/A)**2.-2.*(Z1/A)*(Z2/A)+2.*(1.+(Z1/A)+
(Z2/A)+(Z1/A)*(Z2/A))*(1.-DCOS(D/A)))
```

```
C       PATH DIFFERENCE FROM DIRECT AND INDIRECT SIGNAL
```

```
PADIF=RANG1+RANG2-RANG
```

```
C       ANGLE BETWEEN REFLECTED SIGNAL PATH AND LINE FROM EARTH'S CENTER
C       TO THE ORBITER
```

```
TAU1=DASIN((A*DSIN(D2/A))/RANG2)
```

```
C       ANGLE BETWEEN SIGNAL PATH OF INDIRECT SIGNAL FROM THE TDRS AND LIN
C       E FROM THE CENTER OF THE EARTH TO THE TDRS
```

```
TAU3=DASIN((A*DSIN(D1/A))/RANG1)
```

```
C       COMPLEMENT OF GRAZING ANGLE
```

```
TAU2=DACOS(((A+Z2)*DCOS(TAU3)-RANG1)/A)
```

```
IF(TAU2-COMP)23,23,22
```

(− → 23, + → 22, 0 → 23)

```
22
BTHET=BTHET-.1
```

```
IF(TAU2-COMP)23,23,24
```

(− → 23, + → 2 / A2, 0 → 23)

```
23
CONTINUE
```

```
C       GRAZING ANGLE
```

CONT. ON PG 4

FIGURE 25 CONTINUED

```
GAMA1=PI/2.-TAU2
C      DIVERGENCE FACTOR
DIV1=A*(RANG1+RANG2)*DSQRT(DSIN(TAU2)*DCOS(TAU2))
DIV2=DSQRT(((A+Z2)*RANG1*DCOS(TAU3)+(A+Z1)*RANG2*DCOS(TAU1))*(A+Z1
)*(A+Z2)*DSIN(BTHET*X))
DIV=DIV1/DIV2
C      FREQUENCY OF TRANSMITTED SIGNAL FROM TDRS TO ORBITER
I=1
FREQ(I)=13.000000009
N=M-1
DO 50 I=1,N
FREQ(I+1)=FREQ(I)+24.545406
50
CONTINUE
DO 40 I=1,M,1
C      WAVELENGTH OF TRANSMITTED SIGNAL FROM THE TDRS TO THE ORBITER
WAVE=3.008/FREQ(I)
C      FUNCTION OF DIELECTRIC CONSTANT USED FOR COMPUTING REFLECTION COEF
C      FICIENT
Y=1.80010*(CON/FREQ(I))
C      PARAMETER USED TO CALCULATE REFLECTION COEFFICIENT
S=DSQRT((DSQRT((RDIE-(1./2.)*(1.+DCOS(2.*GAMA1)))**2.+Y**2.)+(RDIE
-(1./2.)*(1.+DCOS(2.*GAMA1))))/2.)
C      FUNCTION OF DIELECTRIC CONSTANT AND FREQUENCY FOR COMPUTING REFLEC
C      TION COEFFICIENT
Q=Y/(2.*S)
C      PARAMETERS USED TO CALCULATE VERTICAL POLARIZATION REFLECTION COEF
C      FICIENT
```

CONT. ON PG 5

EARSD
PG 4 OF 11

FIGURE 25 CONTINUED

```
BV=(RDIE**2.+Y**2.)/(S**2.+Q**2.)
PV=(2.*(S*RDIE+Q*Y))/(S**2.+Q**2.)
```

```
C       VERTICAL POLARIZATION REFLECTION COEFFICIENT
```

```
RV=DSQRT((1.+(BV/2.)*(1.-DCOS(2.*GAMAL))-PV*DSIN(GAMAL))/(1.+(BV/2
.)*(1.-DCOS(2.*GAMAL))+PV*DSIN(GAMAL)))
```

```
C       PHASE ANGLE CHANGE FOR A VERTICAL POLARIZED WAVE
```

```
PHAV=DATAN((Y*DSIN(GAMAL)-Q)/(RDIE*DSIN(GAMAL)-S))-DATAN((Y*DSIN(G
AMAL)+Q)/(RDIE*DSIN(GAMAL)+S))+PI
```

```
C       PARAMETERS USED TO CALCULATE HORIZONTAL POLARIZATION REFLECTION CO
C       EFFICIENT
```

```
BH=1./(S**2.+Q**2.)
PH=(2.*S)/(S**2.+Q**2.)
```

```
C       HORIZONTAL REFLECTION COEFFICIENT
```

```
RH=DSQRT((1.+(BH/2.)*(1.-DCOS(2.*GAMAL))-PH*DSIN(GAMAL))/(1.+(BH/2
.)*(1.-DCOS(2.*GAMAL))+PH*DSIN(GAMAL)))
```

```
C       PHASE ANGLE CHANGE FOR A HORIZONTAL POLARIZED WAVE
```

```
PHAH=DATAN(-Q/(DSIN(GAMAL)-S))-DATAN(Q/(DSIN(GAMAL)+S))+PI
```

```
C       CIRCULAR REFLECTION COEFFICIENT
```

```
RC=DABS((RV+RH)/2.)
```

```
C       PHASE ANGLE CHANGE FOR A CIRCULAR POLARIZED WAVE
```

```
PHAC=(PHAV+PHAH)/2.
```

```
C       SCATTERING REFLECTION COEFFICIENT
```

```
SCAT=DSQRT(DEXP(-(((4.*PI)/WAVE)*H*DSIN(GAMAL))**2))
```

```
C       MULTIPATH FIELD STRENGTH (INDIRECT SIGNAL)
```

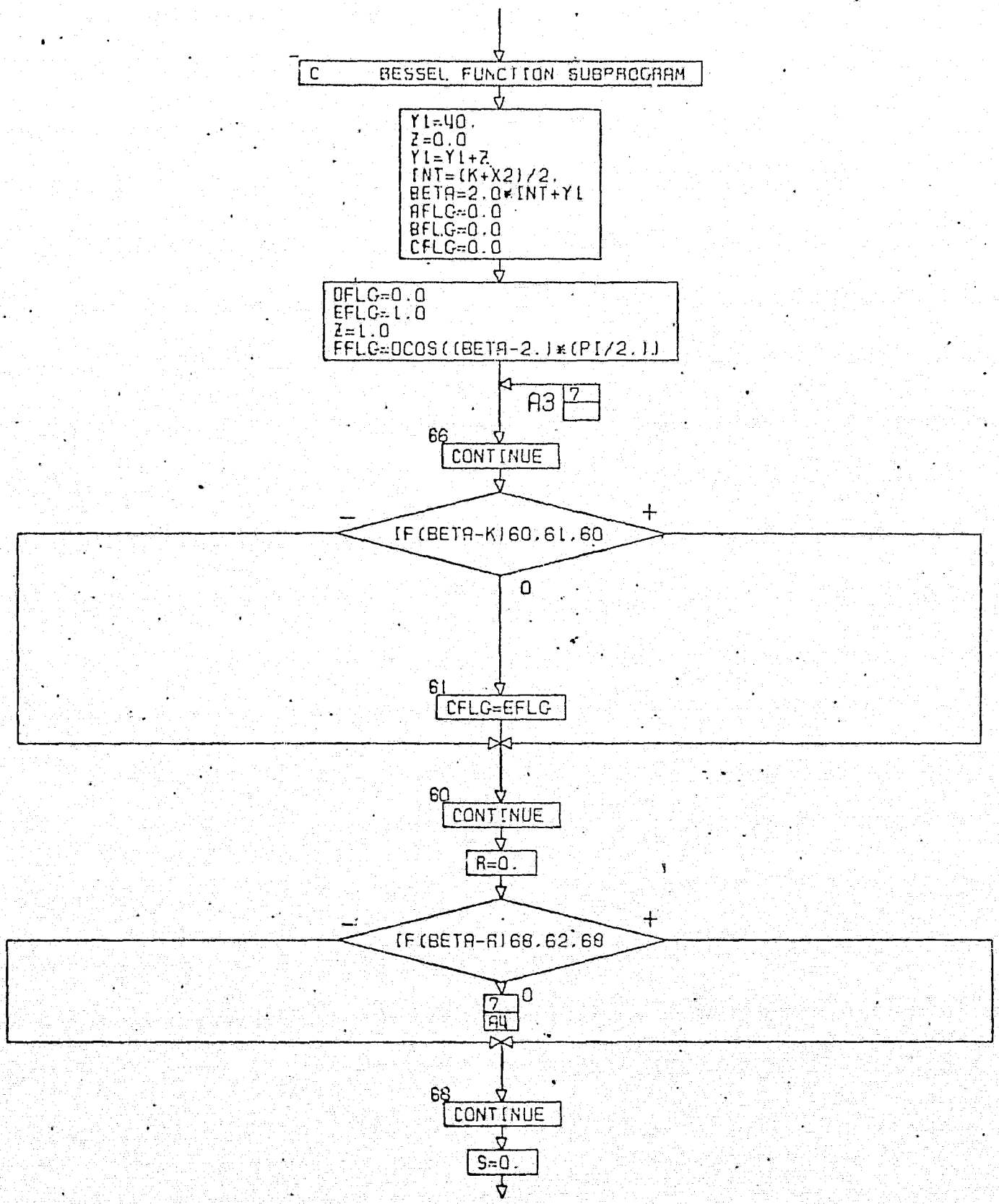
```
FIELD=((RANG/(RANG1+RANG2))*DIV*DABS(RC)*SCAT)**2.+2.*((RANG/(RANG
1+RANG2))*DIV*DABS(RC)*SCAT)*(DCOS((((2.*PI)/WAVE)*PRDIF)+PHAC))
```

```
C       BESSEL FUNCTION ARGUMENT
```

```
X2=((PI*DIA)/WAVE)*DSIN(GAMAL-PT(L))
```

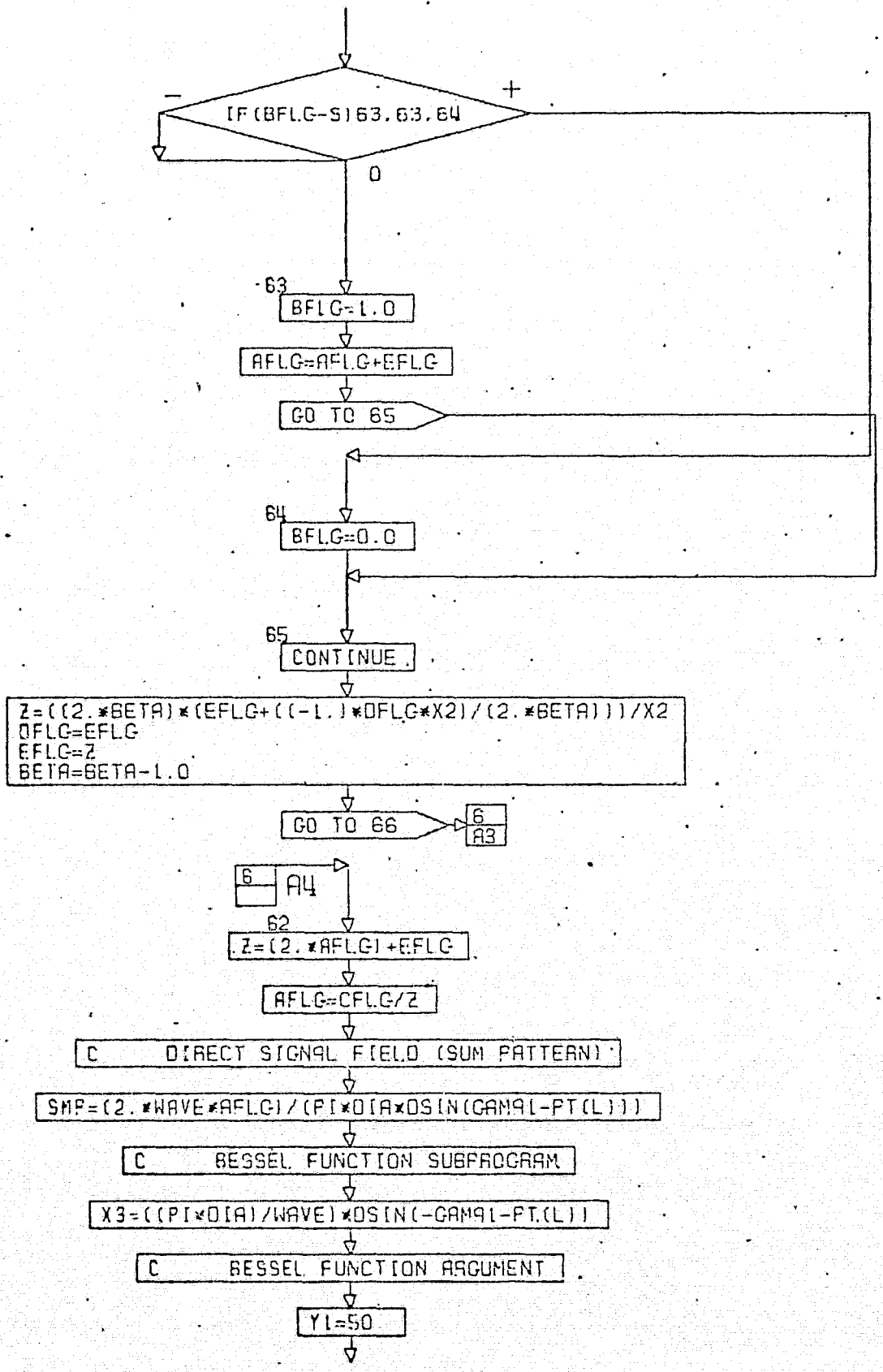
CONT. ON PG 6

FIGURE 25 CONTINUED



CONT. ON PG 7

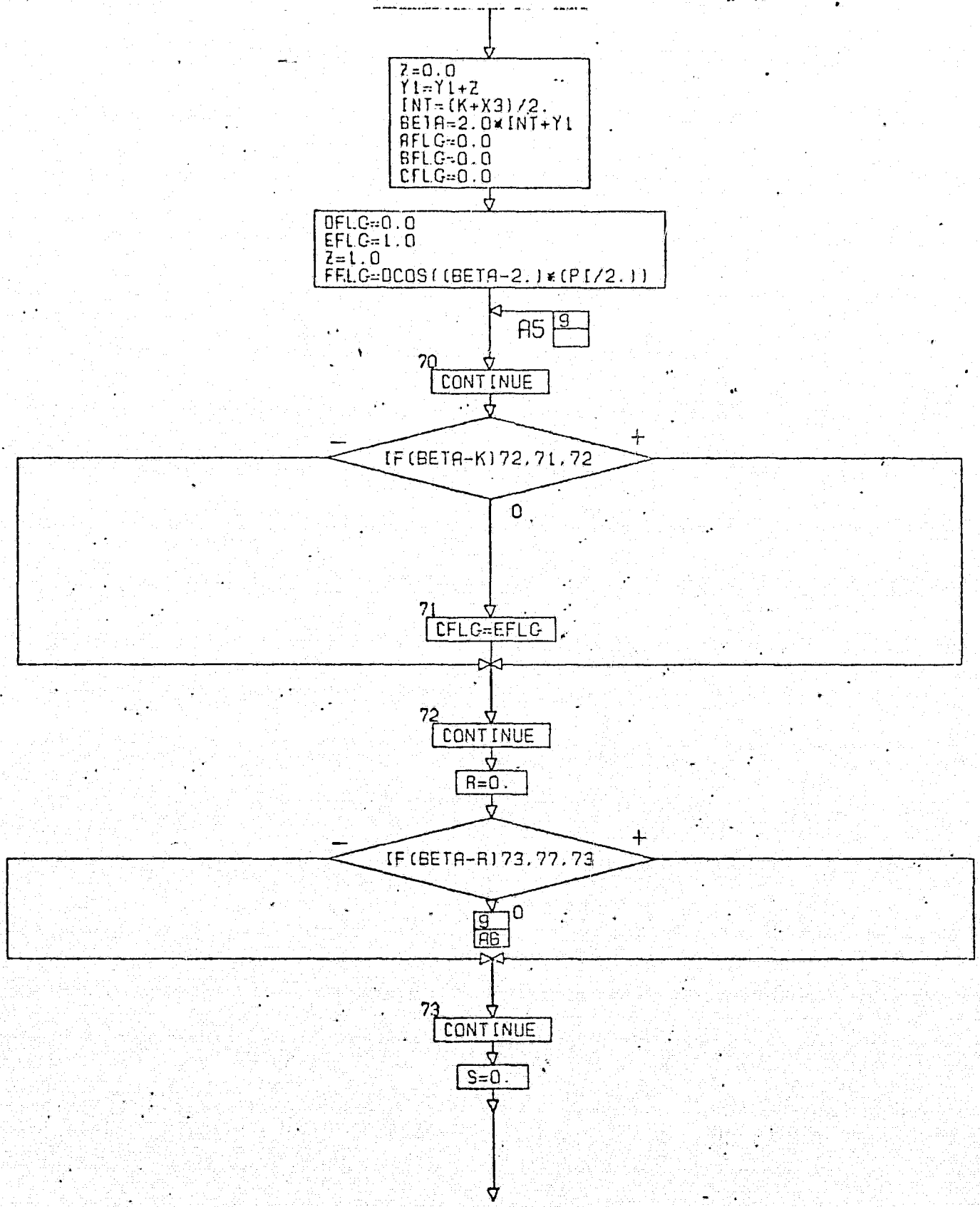
FIGURE 25 CONTINUED



CONT. ON PG 8.

EA9SD
PG 7 OF 11

FIGURE 25 CONTINUED



EARSO
PG 8 OF 11

FIGURE 25 CONTINUED

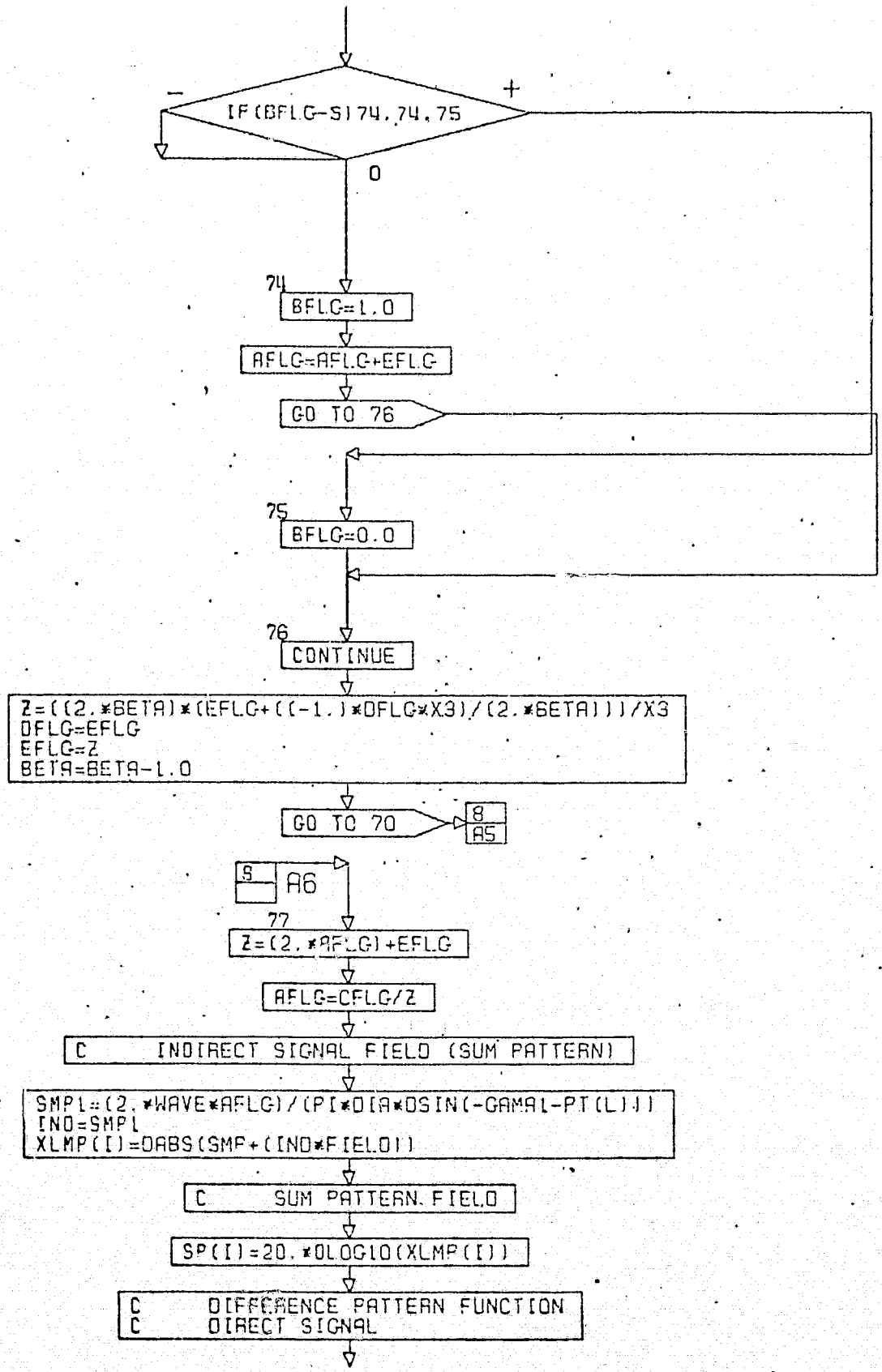


FIGURE 25 CONTINUED

```
DIFF=DSIN(PI*((GAMAL-PT(L))/HPBW)+PI)-DSIN(PI*((GAMAL-PT(L))/HPBW)
)
```

```
C.     INDIRECT SIGNAL
```

```
DIFFL=DSIN(PI*((-GAMAL-PT(L))/HPBW)+PI)-DSIN(PI*((-GAMAL-PT(L))/HP
BW))
```

```
YLMP(I)=DABS(DIFF+(DIFFL*FIELD))
```

```
C      DIFFERENCE PATTERN FIELD
```

```
DP(I)=20.*DLOG10(YLMP(I)).
LSP(I)=SP(I)
LDP(I)=DP(I)
MLSP(I)=SNGL(LSP(I))
NLDP(I)=SNGL(LDP(I))
```

```
4 - - - - > 40
CONTINUE
```

```
J=1
```

```
DO 51 I=1,M
```

```
QFREQ(I)=SNGL(FREQ(J))
WRITE(8)MLSP(I),QFREQ(I),NLDP(I)
J=J+1
```

```
51
CONTINUE
```

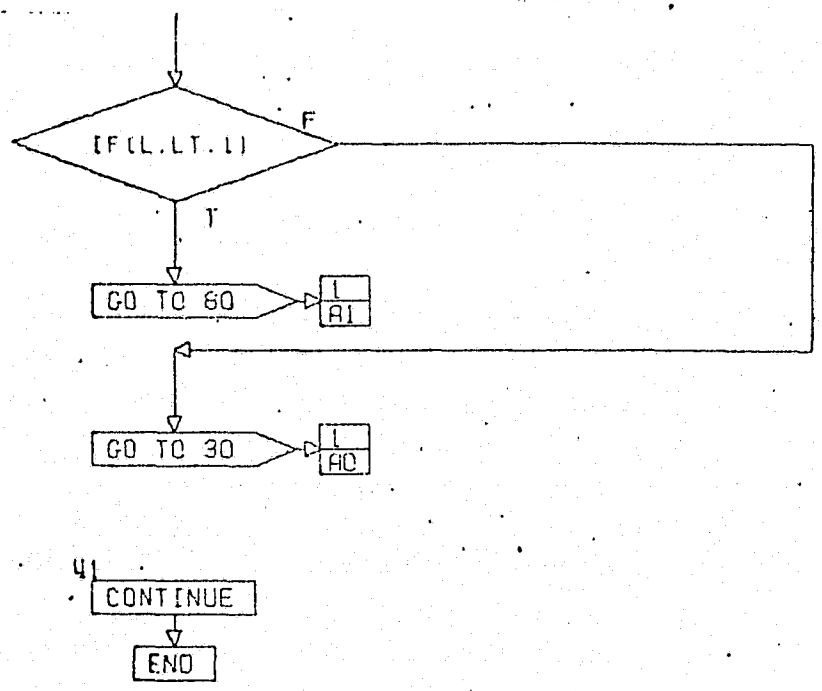
```
ENDFILE8
NAMELIST/DCEP/PT
WRITE(6,DCEP)
NAMELIST/PATH2/QFREQ
WRITE(6,PATH2)
NAMELIST/MULTI/LSP,LDP
WRITE(6,MULTI)
```

```
C      OFFSET INCREMENT
```

```
PT(L+1)=PT(L)+.87222222220-2
L=L+1
```

CONT. ON PG 11

FIGURE 25 CONTINUED



EA9SD
PG 11 FINAL

FIGURE 25 CONTINUED