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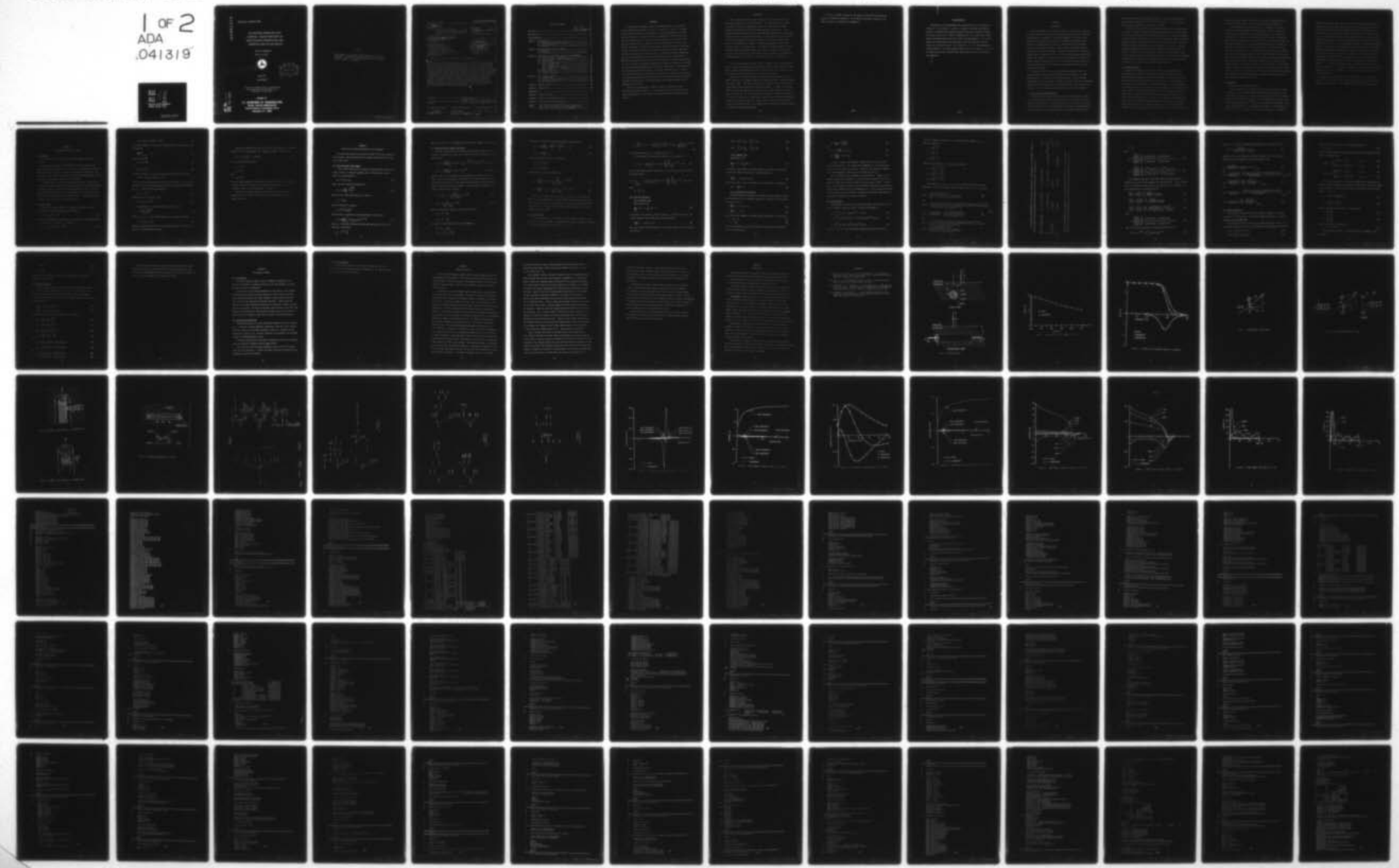

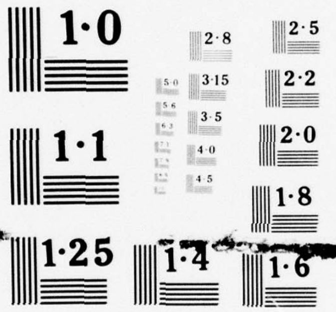

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FAA LIGHTNING PROTECTION STUDY: LIGHTNING - INDUCED TRANSIENTS ON BURIED SHIELDED TRANSMISSION LINES: NUMERICAL ANALYSIS AND RESULTS

John D. Nordgard
Chin-Lin Chen

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16. Abstract

This report is primarily concerned with the analysis of induced transient current and voltage pulses on buried shielded transmission lines, due to earth conduction effects of nearby lightning discharges. A numerical method is presented in this report to determine the amount of coupling between a lightning discharge to ground and an earth-return transmission line. The transmission line is assumed to be a long straight horizontal coaxial cable with an inner shield and an outer armor, terminated on both ends with typical communication equipment load impedances. The general case is considered here, in which the outermost conductor is not necessarily in perfect contact with the conducting earth but has a contact impedance with the earth, as in cables with an outer dielectric covering for corrosion or water protection. Indirect strikes to the cable via conductive coupling mechanisms through the earth are considered. Several average lightning channel conditions and several representative buried cable geometries are examined. The results are conveniently displayed via numerous graphs of the time histories and frequency spectra of the resulting transient current and voltage surges.

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Lightning, transmission lines, induced transients

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FOREWORD

The Post-Doctoral Program at Rome Air Development Center is pursued via Project 9567 under the direction of Dr. W. W. Everett, Jr. and Mr. J. Scherer. The Post-Doctoral Program is a cooperative venture between RADC and the participating universities: Syracuse University (Department of Electrical and Computer Engineering), the U. S. Air Force Academy (Department of Electrical Engineering), Purdue University (School of Electrical Engineering), University of Kentucky (Department of Electrical Engineering), Georgia Institute of Technology (School of Electrical Engineering), Clarkson College of Technology (Department of Electrical Engineering), State University of New York at Buffalo (Department of Electrical Engineering), Florida Technological University (Department of Electrical Engineering), Florida Institute of Technology (College of Engineering), Air Force Institute of Technology (Department of Electrical Engineering), and the University of Adelaide (Department of Electrical Engineering), in South Australia. The Post-Doctoral Program provides, via contract, the opportunity for faculty and visiting faculty at the participating universities to spend a year full time on exploratory development and operational problem-solving efforts with the post-doctorals splitting their time between RADC (or the ultimate customer) and the educational institutions.

This effort was conducted via RADC Job Order No. 9567 0006 for the Federal Aviation Administration. Mr. Fred Sakate was the FAA focal point and participated closely in the technical coordination meetings and cable testing sessions.

BIOGRAPHIES

John D. Nordgard is an Associate Professor in the School of Electrical Engineering, Georgia Institute of Technology. He received the B.E.E. (1966) from Georgia Institute of Technology and the M.S. (1967) and PH.D. (1969) degrees in Applied Physics from California Institute of Technology. He has worked as Electronic Engineer for the Charleston Naval Shipyard and as Associate Engineer for the Jet Propulsion Laboratory. He spent one year at the University of Oslo doing research on the polar ionosphere. He joined the Georgia Tech faculty in 1970 where he is engaged in teaching electromagnetic field theory and doing research in related areas. His research interest includes the areas of moving media, heterogeneous media, plasma physics, scattering, high field emission, illumination, and multiconductor transmission media. His memberships include Tau Beta Pi, Eta Kappa Nu, Phi Kappa Phi, Sigma Xi, IEEE, and IES.

Chin-Lin Chen was born in Honan, China, on March 27, 1937. He received the B.S.E.E. degree from National Taiwan University, Taipei, Taiwan, China, in 1958, the M.S. degree from North Dakota State University, Fargo, ND, in 1961, and the Ph.D. degree from Harvard University, Cambridge, MA, in 1965.

He served as a teaching assistant at North Dakota State University from 1959 to 1961 and as a research assistant and Teaching Fellow at Harvard University from 1962 to 1965. From 1965 to 1966, he was a Research Fellow in the Division of Engineering and Applied Physics, Harvard University. In 1966, he joined the School of Electrical Engineering, Purdue University, West Lafayette, IN, as an assistant professor. He is now an associate professor of Electrical Engineering. His research interests are in the areas of scattering and diffraction of electromagnetic waves, antenna radiation, surface acoustic wave devices, ultrasonics, transient protection devices, and the application of interactive computer graphics in electrical engineering education.

Dr. Chen is a member of Sigma Xi, Eta Kappa Nu, and IEEE and the American Society for Engineering Education. Since 1966, he has been a reviewer for the IEEE Transactions on Antennas and Propagations.

ACKNOWLEDGEMENT

The authors wish to acknowledge the contributions of Mr. Fred Sakate of the FAA, Dr. W. W. Everett, Jr. and Mr. J. Scherer of the RADC Post-Doctoral Program in formulating the program approach and for their guidance throughout the course of this study. They are indebted to Dr. B. J. Leon and Mr. Warren Peele of Purdue University for their support and encouragement. To all other members fo the Post-Doctoral Program team on the FAA Lightning Protection Study, and in particular to Mr. R. M. Cosel (F. I. T.), Mr. Keith Huddleston (Georgia Tech), Dr. R. Larson (Georgia Tech), and Dr. A. W. Revay, Jr. (F. I. T.), the authors would like to express their appreciation for their contributions and assistance.

CHAPTER 1

Introduction

The work described in this report is part of a larger study program to provide protection for communication electronics equipment against transient electromagnetic disturbances. Strong electromagnetic disturbances may be caused by nearby lightning activities or man-made electromagnetic pulses. Current and voltage pulses are induced in nearby cables running between buildings or equipment enclosures. These currents and voltages are then coupled into the terminal equipment. Excessive interference in conventional exposed metallic communication lines is indicated unless adequate protection measures are provided. This may require extra electromagnetic shielding of certain important communication lines and associated buildings housing sensitive equipment and/or the installation of protective devices on certain communication equipment.

The larger study, known as the FAA Lightning Protection Study, has been performed by the Post-Doctoral Program through several of its member universities for the Federal Aviation Administration. The institutions include the Air Force Institute of Technology, Florida Institute of Technology, Georgia Institute of Technology, and Purdue University. The individual participants in the FAA Lightning Protection Study are listed in Appendix C.

1.1 FAA Lightning Protection Study

The FAA Lightning Protection Study consists of three technical tasks: (1) the determination of the voltage and current levels likely to be conducted to FAA equipment; (2) the determination of the susceptibility levels of FAA equipment; and (3) the determination of lightning protective devices that are available to reduce the levels of (1) to those permitted by (2).

These three tasks have been performed in parallel with close interaction and are essentially completed.(1), (2), (3), (4) Appendix C lists the schools having primary responsibility for each of the tasks.

This report is the result of the work done under the first technical task. This study is primarily concerned with the numerical analysis of the resultant circuit disturbances caused by earth conduction effects of lightning discharges. A numerical model is presented in this study to determine the amount of coupling between a lightning discharge and an earth-return transmission line. Only the detailed numerical calculations are to be reported in this report since the theoretical foundation and analysis were presented in an earlier report.(4) Actually, this work can be considered as an extension of that earlier report since the earlier report only contained a description of the theory of lightning-induced transients; whereas, this present report contains the applications of that theory to a typical buried shielded transmission line.

1.2 Problem Statement

Numerous interference and protection problems are encountered in the development and operation of extensive communication and power systems. These problems are caused by the internal coupling of such systems with each other and by the external presence of the earth which, in some measure, is involved as a return conductor. The earth also serves as a return conductor for lightning currents, which often occasion disturbances in communication and power circuits. Lightning disturbances are largely atmospheric phenomena governed by the physical properties of the air. However, the behavior and effects of the lightning near the surface of the ground in communication and power systems are primarily earth conduction problems caused by the finite conductivity of the earth. Therefore, problems arise both in communication and power system circuits concerning the protection of transmission lines and associated equipment against interference and possible breakdown caused by excessive voltage or current surges induced by lightning discharges.

To deal adequately with such problems, it is necessary to consider solutions to the basic problem in which the earth, as well as conducting current paths, are involved in the lightning discharge. The analysis of such problems is inherently more complicated than the problem of completely metallic circuits embedded in an insulating medium, since the great extent of the earth necessitates the use of electromagnetic field theory, rather than conventional transmission line or circuit theory, in the solution of most aspects of the problem. It is, therefore, necessary to restrict the analysis to fairly simple fundamental cases, in which simplified models of the earth, cable, and lightning channel geometries are used, on account of the complexities that would otherwise arise. Therefore, ionization effects caused by high induced voltages or electrolytic actions are not considered. Also, the heterogeneous character of the earth as a conductor and an electrolyte are not considered. Furthermore, the extremely variable nature of the lightning currents and voltages are not considered; however, typically average values of the lightning channel parameters are used.

1.3 Overview

This report is organized as follows.

First, the geometry of the cable and the lightning channel are stated in Chapter 2. Then, the basic equations which govern the behavior of the electromagnetic disturbances caused by earth conduction effects of lightning discharges are summarized in Chapter 3. These equations were derived in the earlier theoretical analysis (4) and are to be studied and programmed in this present numerical analysis. These equations include: the fields due to an electric dipole in free space; the fields of a vertically or horizontally oriented dipole above a flat earth; the mutual coupling impedances between the dipole-like lightning channel and a buried wire; the equivalent distributed transmission line formulas of the coupling phenomena; the induced electric field intensity along the outer conductor of the cable for a lightning stroke to ground; the Green's Functions for a distributed voltage or current source; characteristic equation of the transmission line; the characteristic values of the transmission line, e.g., the propagation constant and associated propagation modes; the induced current and voltage surges on the outer armor of the cable; the voltage and current standing waves on the transmission line; the induced current and voltage surges on the center conductor of the coaxial cable; and the impedance transfer functions of an armored and shielded coaxial cable. The details of the above theoretical analysis were presented in the earlier report.(4) The numberical techniques used to compute the theoretical formulas given above are discussed in Chapter 4. A listing of the resulting computer code is given in Appendix A. A typical sample of the input data is given in Appendix B.

Finally, the output results are displayed in Chapter 5 via numerous graphs of the time histories and frequency spectra of the resulting transient current and voltage surges. Some intermediate results are also presented.

CHAPTER 2

Problem Geometry and Pulse Model

2.1 Geometry

The geometry of the cable and the lightning channel are shown in Figure 1.

The cable is buried at a uniform depth d below the surface of the earth. The cable is coaxial with an inner core, an intermediate shield and armor, and an outer sheath for corrosion and mechanical protection. The cable has a length ℓ and is terminated in typical load impedances $Z_\ell^\pm$ at each end, which are grounded to the armor and the shield.

A ground stroke of lightning carrying a total current I terminates at a distance y_s from the cable. The lightning channel is vertical and extends to a height h above the ground. The lightning channel carries a typical "double exponential" return stroke current pulse, with a rise time on the order of 1 μs and a decay time on the order of 50 μs. The peak current of a typical return stroke is on the order of 20 KA.

2.2 Pulse Model

The current pulses produced in a lightning stroke may be closely represented by a "double exponential" distribution

$$I(t) = I_0(e^{-\alpha t} - e^{-\beta t}) \tag{1}$$

The pulse rises rapdily to a peak value I_p at the time t_p and decays slowly to a value of cI_p at the time t_d, where $c < 1$,

$$I_p = I(t_p) = I_0(e^{-\alpha t_p} - e^{-\beta t_p}) \tag{2}$$

$$cI_p = I(t_d) = I_0(e^{-\alpha t_d} - e^{-\beta t_d}) \tag{3}$$

A relation between α, β, and t_p can be determined from the expression for the extremum

$$\left.\frac{dI(t)}{dt}\right|_{t=t_p} = 0, \tag{4}$$

which implies that

$$\alpha/\beta = e^{(\alpha-\beta)t_p} \tag{5}$$

or

$$\alpha e^{-\alpha t_p} = \beta e^{-\beta t_p} \tag{6}$$

A relation between α, β, t_p, and t_d may be obtained from (2) and (3),

$$(e^{-\alpha t_d} - e^{-\beta t_d}) = c(e^{-\alpha t_p} - e^{-\beta t_p}) \tag{7}$$

α and β may be solved numerically from (5) and (7) once c, t_p, and t_d are specified. A simple and accurate approximation may be made by noting that $t_d >> t_p$. Then (3) may be approximated by

$$cI_p \approx I_0\, e^{-\alpha t_d} \tag{8}$$

Combination of (2) and (3), yields

$$I_p = I_0(1 - \frac{\alpha}{\beta})\, e^{-\alpha t_p} \tag{9}$$

An expression for α may be obtained from (8) and (9),

$$\alpha = \frac{\ln c + \ln(1-\frac{\alpha}{\beta})}{t_p - t_d} \tag{10}$$

When $t_d >> t_p$, $\alpha << \beta$, the above equation may be further simplified,

$$\alpha = (\ln c)/(t_p - t_d) \tag{11}$$

Knowing α, a numerical value for β may be calculated from (6) using, for example, a Newton-Raphson technique.

Knowning the complete wave form $I(t)$ in the time-domain, the frequency spectrum $i(\omega)$ of the current in the frequency-domain is determined by

$$i(\omega) = I_0 \left(\frac{1}{\alpha - j\omega} - \frac{1}{\beta - j\omega} \right). \tag{12}$$

For a typical lightning stroke,

$t_r = 1.2\ \mu s$

$t_d = 50\ \mu s$

and

$I_0 = 20$ KA

Using the above parameters, the resulting wave for $I(t)$ in the time-domain is shown graphically in Figure 2; the resulting wave spectrum $i(\omega)$ in the frequency-domain is shown graphically in Figure 3.

The computer program superposes pulse trains of the above "double exponential" form to model the prestrikes, the return stroke, and any subsequent restrikes.

CHAPTER 3

Discussion of Theoretical Results to be Programmed

The theoretical results of the earlier report (4) are now summarized and discussed. Detailed description of symbols and definitions of terms can be found there.

3.1 Vertical Dipole (Free Space)

The current density $\underline{J}$ of a vertically polarized point dipole with a total current I a distance z_0 on the z axis in free space, as shown in Figure 4, is approximated by

$$\underline{J} = \hat{z}\ I d\ell\ \delta(z-z_0)\ . \tag{13}$$

Then, the resulting Hertz potential $\underline{\Pi}$ is

$$\underline{\Pi} = \hat{z}\ j\ \frac{I d\ell}{4\pi\omega\varepsilon_0}\ \frac{e^{-jk_0R}}{R} \tag{14}$$

where the free space wave number k_0 is given by

$$k_0 = \omega\sqrt{\mu_0\varepsilon_0}$$

and the distance R is given by

$$R = \sqrt{\rho^2 + (z-z_0)^2}\ .$$

Alternatively, by applying a cylindrical Hankel transformation,

$$\underline{\Pi} = \hat{z}\ j\frac{I d\ell}{4\pi\omega\varepsilon_0}\int_0^\infty d\tau\ \frac{\tau}{\xi_0}\ J_0(\tau\rho)e^{-\xi_0|z-z_0|} \tag{15}$$

where J_0 is the Bessel function of order zero and where the axial wave number ξ_0 is defined by

$$\xi_0 = \sqrt{\tau^2 - k_0^2}$$

Notice that there is no ϕ dependence due to the axial symmetry of the geometry.

3.2 Vertical Dipole (Above Flat Earth)

The Hertz potentials of a vertically polarized point dipole with a total current I a distance z_0 on the z axis above a flat earth, as shown in Figure 5, have the form

$$\underline{\Pi}_a = \hat{z}\, j \frac{I d\ell}{4\pi\omega\varepsilon_0}\int_0^\infty d\tau\; J_0(\tau\rho)\left(\frac{\tau}{\xi_a}\, e^{-\xi_a\left|z-z_0\right|} + r(\tau)e^{-\xi_a z}\right), \quad (z>0) \qquad (17)$$

$$\underline{\Pi}_e = \hat{z}\, j \frac{I d\ell}{4\pi\omega\varepsilon_0}\int_0^\infty d\tau\; J_0(\tau\rho)\; t(\tau)e^{+\xi_e z} \qquad (z<0) \qquad (18)$$

where $\underline{\Pi}_a$ and $\underline{\Pi}_e$ are, respectively, the potentials in the air and in the earth. Also, r is the reflection coefficient of the wave reflected from the air-earth interface and t is the transmission coefficient of the wave transmitted through the air-earth interface. From the boundary conditions on the fields at the air-earth interface,

$$r(\tau) = \frac{\tau}{\xi_a}\left(1 - 2\,\frac{k_a^2\xi_e}{k_e^2\xi_a + k_a^2\xi_e}\right) e^{-\xi_a z_0} \qquad (19)$$

$$t(\tau) = 2\tau\,\frac{k_a^2}{k_e^2\xi_a + k_a^2\xi_e}\; e^{-\xi_a z_0} \qquad (20)$$

where the axial wave numbers ξ_a and ξ_e are defined by

$$\xi_a = \sqrt{\tau^2 - k_a^2}$$

$$\xi_e = \sqrt{\tau^2 - k_e^2}$$

and where the wave numbers k_a and k_e are defined by

$$k_a = k_0 = \omega\sqrt{\mu_0\varepsilon_0}$$

$$k_e = \omega\sqrt{\mu_e\left(\varepsilon_e + j\,\frac{\sigma_e}{\omega}\right)}$$

Alternately, by applying a cylindrical Hankel transformation,

$$\underline{\Pi}_a = \hat{z}\, j \frac{I d\ell}{4\pi\omega\varepsilon_0}\left(\frac{e^{-jk_aR}}{R} + \frac{e^{-jk_aR'}}{R'} - \Lambda_a\right) \tag{21}$$

$$\underline{\Pi}_e = \hat{z}\, j \frac{I d\ell}{4\pi\omega\varepsilon_0}\, \Lambda_e \tag{22}$$

where the distances R and R' are defined by

$$R = \sqrt{\rho^2 + (z-z_0)^2}$$

$$R' = \sqrt{\rho^2 + (z+z_0)^2}$$

and the terms Λ_a and Λ_e are defined by

$$\Lambda_a = 2k_a^2 \int_0^\infty d\tau\, \tau\, J_0(\tau\rho)\, \frac{\dfrac{\xi_e}{\xi_a}}{k_e^2\xi_a + k_a^2\xi_e}\, e^{-\xi_a(z+z_0)} \tag{23}$$

$$\Lambda_e = 2k_a^2 \int_0^\infty d\tau\, \tau\, J_0(\tau\rho)\, \frac{1}{k_e^2\xi_a + k_a^2\xi_e}\, e^{+\xi_e z}\, e^{-\xi_a z_0} \tag{24}$$

The first two terms involving R and R' in (21) for $\underline{\Pi}_a$ represent the fields due to the dipole and its image through a perfectly conducting earth. The terms Λ_a and Λ_e in (21) and (22) for $\underline{\Pi}_a$ and $\underline{\Pi}_e$ are, respectively, the correction terms in the air and in the earth, which account for the finite conductivity of the earth.

3.3 Ground Stroke

The Hertz potential $\underline{\Pi}_s$ in the earth due to a vertical lightning stroke to ground with a total height h is determined by integrating the Hertz potential $\underline{\Pi}_e$ in the earth along the z axis from 0 to h, i.e.,

$$\underline{\Pi}_s = \int_0^h dz' \, \underline{\Pi}_e = \hat{z} \, j \frac{1}{4\pi\omega\varepsilon_0} \int_0^\infty dz' \int_0^\infty d\tau \; 2\tau \; J_0(\tau\rho) \frac{k_a^2}{k_e^2 \xi_a + k_a^2 \xi_e} e^{+\xi_e z - \xi_a z'} \tag{25}$$

In the above expression, it is assumed that h >> 1.

The corresponding electrostatic potential ϕ_s in the earth is

$$\phi_s = \phi_e = - j \frac{1}{2\pi\omega\varepsilon_0} \int_0^\infty d\tau\tau \; J_0(\tau\rho) \frac{k_a^2 \frac{\xi_e}{\xi_a}}{k_e^2 \xi_a + k_a^2 \xi_e} e^{+\xi_e z} , \; (z<0) \tag{26}$$

and the corresponding field intensity E_s in the earth along the position of the buried cable is

$$E_s = E_e \Big|_{\substack{y=y_s \\ z=-d}} = -j \frac{1}{2\pi\omega\varepsilon_0} \frac{x}{R_s^3} \int_0^\infty d\tau\tau^2 \; J_1(\tau\rho) \frac{k_a^2 \frac{\xi_e}{\xi_a}}{k_e^2 \xi_a + k_a^2 \xi_e} e^{-\xi_e d} , \; (z<0) \tag{27}$$

where

$$R_s = \sqrt{x^2 + y_s^2}$$

3.4 Governing Equations

3.4.1 Faraday's Law

When Faraday's Law

$$\oint_{C_1} \underline{dl} \cdot \underline{E} = - j\omega \int_{S_1} \underline{dS} \cdot \underline{B} \tag{28}$$

is applied to the contour C_1 and the surface S_1, as shown in Figure 6, the rate of change of the voltage wave V along the cable is

$$\frac{dV(x)}{dx} = - j\omega\phi(x) - E(x) \tag{29}$$

where the voltage V and the potential ϕ, per unit length in the x-direction, are defined by

$$V(x) = -\int_{\infty}^{r_i} dr\, E_{re} - \int_{r_i}^{r_\omega} dr\, E_{ri} \tag{30}$$

$$\phi(x) = -\int_{\infty}^{r_i} dr\, B_{\theta e} - \int_{r_i}^{r_\omega} dr\, B_{\theta i} \tag{31}$$

3.4.2 Amperes' Law

When Amperes' Law

$$\oint_{C_2} \underline{dl} \cdot \underline{H} = j\omega \int_{S_2} \underline{dS} \cdot \underline{D} \tag{32}$$

is applied to the contour C_2 and the surface S_2, as shown in Figure 6b, the rate of change of the current I along the cable is

$$\frac{dI(x)}{dx} = -\, j\omega\tilde{\varepsilon}\, E(x) \quad (2\pi r_\omega) \tag{33}$$

where the current I, per unit length in the x direction, is defined by

$$I(x) = \oint \underline{dl} \cdot \underline{H} \tag{34}$$

3.4.3 Transmission Line Model

The above equations developed from Faraday's Law and Amperes' Law are put into the form of the standard Telegrapher's Equation on a distributed transmission line

$$\frac{dV(x)}{dx} = -\, Z\, I(x) + E_S \tag{35}$$

$$\frac{dI(x)}{dx} = -\, Y\, V(x) \tag{36}$$

where the series impedance Z and the parallel admittance Y are defined by

$$Z = Z_L + Z_S \tag{37}$$

$$Y = \frac{1}{Z_T} \tag{38}$$

The surface impedance Z_S and the longitudinal and transverse impedances Z_L and Z_T are defined by

$$Z_S = \frac{E(x)}{I(x)} = \frac{E'(x)+E_S}{I(x)} \tag{39}$$

and

$$Z_L = j\omega \frac{\phi(x)}{I(x)} = Z_{L1} + Z_{L2} \tag{40}$$

$$Z_T = \frac{V(x)}{\frac{dI(x)}{dx}} = Z_{T1} + Z_{T2} \tag{41}$$

In (39), E' denotes the secondary induced field due to the primary return stroke field E_s. The longitudinal impedance Z_L is later decomposed into the sum of two terms Z_{L1} and Z_{L2}. Similarly, the transverse impedance Z_T is later decomposed into the sum of two terms Z_{T1} and Z_{T2}.

Strictly speaking, the impedances are functions of x. However, only a moderate variation with respect to x over the major portions of the wire is expected, except near the points where the current varies rapidly. Furthermore, it can be shown that when the fields under consideration are travelling waves, these impedances are truly independent of x. Thus, a good approximation to the impedances can be obtained by considering the natural modes guided by the coaxial configuration, as shown in Figure 7.

3.5 Natural Modes

To determine the exact form of the natural modes, the potentials in the earth, insulator, and outer armor of the wire are expanded as

$$\underline{\Pi}_\omega = \int_{-\infty}^{+\infty} d\zeta \; F_\omega(\zeta) \; J_0(\xi_\omega r) e^{-j\zeta x}, \quad (r<r_\omega) \tag{42}$$

$$\underline{\Pi}_i = \int_{-\infty}^{+\infty} d\zeta \, [F'_i(\zeta) J_0(\xi_i r) + F''_i(\zeta) Y_0(\xi_i r)] e^{-j\zeta x}, \quad (r_\omega<r<r_i) \tag{43}$$

$$\underline{\Pi}_e = \int_{-\infty}^{+\infty} d\zeta \; F_e(\zeta) \; H_0^{(2)}(\xi_e r) e^{-j\zeta x}, \quad (r>r_i) \tag{44}$$

where F , F'_i, F''_i, F_e are the unknown expansion coefficients determined from the dispersion relationship. The transverse wave numbers ξ_ω, ξ_i, and ξ_e are defined by

$$\xi_\omega = \sqrt{k_\omega^2 - \zeta^2}$$

$$\xi_i = \sqrt{k_i^2 - \zeta^2}$$

$$\xi_e = \sqrt{k_e^2 - \zeta^2}$$

where the wave numbers k_ω, k_i, and k_e are defined by

$$k_\omega = \omega\sqrt{\mu\omega(\varepsilon_\omega + j\,\frac{\sigma_\omega}{\omega})}$$

$$k_i = \omega\sqrt{\mu_i(\varepsilon_i + j\,\frac{\sigma_i}{\omega})}$$

$$k_e = \omega\sqrt{\mu_e(\varepsilon_e + j\,\frac{\sigma_e}{\omega})}$$

The impedances Z_S, Z_{L1}, Z_{L2}, Z_{T1}, and Z_{T2} defined in (39)-(41) may be expressed in terms of the unknown expansion coefficients F_ω, F'_i, F''_i, and F_e:

$$Z_s(x) = \frac{\int F_\omega(\zeta)\xi_c^{\,2} J_0(\xi_c b)e^{-j\zeta x}d\zeta}{2\pi b(\sigma_c + j\omega\varepsilon_c)\int F_\omega(\zeta)\xi_c J_1(\xi_c b)e^{-j\zeta x}d\zeta} \tag{45}$$

and

$$Z_{L1}(x) = \frac{-j\omega\mu_1(\sigma_1+j\omega\varepsilon_1)\int\{F'_i(\zeta)[J_0(\xi_1 c)-J_0(\xi_1 b)]+F''_i(\zeta)[Y_0(\xi_1 c)-Y_0(\xi_1 c)]\}e^{-j\zeta x}d\zeta}{2\pi b(\sigma_c+j\omega\varepsilon_c)\int F_\omega(\zeta)\xi_c J_1(\xi_c b)e^{-j\zeta x}d\zeta} \tag{46}$$

$$Z_{L2}(x) = \frac{j\omega\mu_e(\sigma_e+j\omega\varepsilon_e)}{2\pi b(\sigma_c+j\omega\varepsilon_c)}\;\frac{\int F_e(\zeta)H_0^{(2)}(\xi_e c)e^{-j\zeta x}d\zeta}{\int F_\omega(\zeta)\xi_c J_1(\xi_c b)e^{-j\zeta x}d\zeta} \tag{47}$$

and

$$Z_{T1}(x) = \frac{-\int\{F'_i(\zeta)[J_0(\xi_1 c)-J_0(\xi_1 b)]+F''_i(\zeta)[Y_0(\xi_1 c)-Y_0(\xi_1 c)]\}\zeta e^{-j\zeta x}d\zeta}{2\pi b(\sigma_c+j\omega\varepsilon_c)\int\zeta\xi_c F_\omega(\zeta)J_1(\xi_c b)e^{-j\zeta x}d\zeta} \tag{48}$$

$$Z_{T2}(x) = \frac{\int\zeta F_e(\zeta)H_0^{(2)}(\xi_e c)e^{-j\zeta x}d\zeta}{2\pi b(\sigma_c+j\omega\varepsilon_c)\int\zeta\xi_c F_\omega(\zeta)J_1(\xi_c b)e^{-j\zeta x}d\zeta}$$

The dispersion relationship for the coaxial configuration, as determined from the boundary conditions on the fields at the wire-insulator interface and the insulator-earth interface, are

$$\begin{bmatrix} (\sigma_c + j\omega\varepsilon_c)\xi_c\ J_1(\xi_c b) & -(\sigma_i + j\omega\varepsilon_i)\xi_i\ J_1(\xi_i b) & -(\sigma_i + j\omega\varepsilon_i)\xi_i\ Y_i(\xi_i b) & 0 \\ 0 & (\sigma_i + j\omega\varepsilon_i)\xi_i\ J_1(\xi_i c) & (\sigma_i + j\omega\varepsilon_i)\xi_i\ Y_i(\xi_i c) & -(\sigma_e + j\omega\varepsilon_e)\xi_e\ H_1^{(2)}(\xi_e c) \\ \xi_c^2\ J_0(\xi_c b) & -\xi_i^2\ J_0(\xi_i b) & -\xi_i^2\ Y_0(\xi_i b) & 0 \\ 0 & \xi_i^2\ J_0(\xi_i c) & \xi_i^2\ Y_0(\xi_i c) & -\xi_e^2\ H_0^{(2)}(\xi_e c) \end{bmatrix} \begin{bmatrix} F_\omega \\ F_i' \\ F_i'' \\ F_e \end{bmatrix} = 0$$

which is a homogeneous matrix equation for the unknown expansion coefficients. For a non-trivial solution for the expansion coefficients, the determinant of the above matrix must be zero, i.e.

$$\Delta_1 = \Delta_2$$

where

$$\Delta_1 = \frac{\dfrac{\sigma_c+j\omega\varepsilon_c}{\sigma_1+j\omega\varepsilon_1}\,\dfrac{\xi_1}{\xi_c}\,J_1(\xi_c b)J_0(\xi_1 b) - J_0(\xi_c b)J_1(\xi_1 b)}{\dfrac{\sigma_c+j\omega\varepsilon_c}{\sigma_1+j\omega\varepsilon_1}\,\dfrac{\xi_1}{\xi_c}\,J_1(\xi_c b)Y_0(\xi_1 b) - J_0(\xi_c b)Y_1(\xi_1 b)} \tag{51}$$

$$\Delta_2 = \frac{\dfrac{\sigma_e+j\omega\varepsilon_e}{\sigma_i+j\omega\varepsilon_i}\,\dfrac{\xi_1}{\xi_e}\,H_1^{(2)}(\xi_e c)J_0(\xi_1 c) - H_0^{(2)}(\xi_e c)J_1(\xi_1 c)}{\dfrac{\sigma_e+j\omega\varepsilon_e}{\sigma_1+j\omega\varepsilon_1}\,\dfrac{\xi_1}{\xi_e}\,H_1^{(2)}(\xi_e c)Y_0(\xi_1 c) - H_0^{(2)}(\xi_e c)Y_1(\xi_1 c)} \tag{52}$$

The propagation constant ζ determined from the above expressions is denoted by ζ_0, which is the eigenvalue of the determinant. Also, the dependence of the expansion coefficients F_i', F_i'', and F_e on F_ω is attained, i.e. *the eigenfunctions of the determinant are*

$$\frac{F_i'(\zeta)}{F_\omega(\zeta)} = \frac{\sigma_c+j\omega\varepsilon_c}{\sigma_1+j\omega\varepsilon_1}\,\frac{\xi_c}{\xi_1}\,\frac{J_1(\xi_c b)}{J_1(\xi_1 b) - \Gamma Y_1(\xi_1 b)} \tag{53}$$

$$\frac{F_i''(\zeta)}{F_\omega(\zeta)} = \frac{-(\sigma_c+j\omega\varepsilon_c)}{\sigma_1+j\omega\varepsilon_1}\,\frac{\xi_c}{\xi_1}\,\frac{\Gamma J_1(\xi_c b)}{J_1(\xi_i b) - \Gamma Y_1(\xi_1 b)} \tag{54}$$

$$\frac{F_e(\zeta)}{F_\omega(\zeta)} = \frac{\sigma_c+j\omega\varepsilon_c}{\sigma_1+j\omega\varepsilon_1}\,\frac{\xi_1\xi_c}{\xi_e^{\,2}}\,\frac{J_1(\xi_c b)[J_0(\xi_1 c) - \Gamma Y_0(\xi_1 c)]}{H_0^{(2)}(\xi_e c)[J_1(\xi_1 b) - \Gamma Y_1(\xi_1 b)]} \tag{55}$$

where

$$\Gamma = \frac{\dfrac{\sigma_c+j\omega\varepsilon_c}{\sigma_1+j\omega\varepsilon_1}\,\dfrac{\xi_1}{\xi_c}\,J_1(\xi_c b)J_0(\xi_1 b) - J_0(\xi_c b)J_1(\xi_1 b)}{\dfrac{\sigma_c+j\omega\varepsilon_c}{\sigma_1+j\omega\varepsilon_1}\,\dfrac{\xi_i}{\xi_c}\,J_1(\xi_c b)Y_0(\xi_1 b) - J_0(\xi_c b)Y_1(\xi_1 b)} \tag{56}$$

When the current on the wire is a traveling wave of the form

$$I(x) = I_0\,e^{-j\zeta_0 x} = \int_{-\infty}^{+\alpha} d\zeta\, I_0\,\delta(\zeta-\zeta_0)\,e^{-j\zeta x} \tag{57}$$

where I_0 is a constant, the remaining eigenfunction F_ω is determined to be

$$F_\omega(\zeta) = \frac{I_0 \delta(\zeta-\zeta_0)}{\sqrt{2\pi}\, b(\sigma_c+j\omega\varepsilon_c)\ \xi_c\ J_1(\xi_c b)} \tag{58}$$

Therefore, due to the presence of the delta function in F_ω, the integrals in (45)-(49) for the impedances are easily evaluated to give

$$Z_s = \left.\frac{\xi_c\ J_0(\xi_c b)}{2\pi b(\sigma_c+j\omega\varepsilon_c)\ \ J_1(\xi_c b)}\right|_{\zeta=\zeta_0} \tag{59}$$

and

$$Z_{L1} = \frac{-j\omega\mu_1(\sigma_1+j\omega\varepsilon_1)}{2\pi b(\sigma_c+j\omega\varepsilon_c)} \left.\frac{F_i'(\zeta)[J_0(\xi_1 c)-J_0(\xi_1 b)] + F_i''(\zeta)[Y_0(\xi_1 c)-Y_0(\xi_1 b)]}{\xi_c F_\omega(\zeta) J_1(\xi_c b)}\right|_{\zeta=\zeta_0}, \tag{60}$$

$$Z_{L2} = \frac{j\omega\mu_e(\sigma_e+j\omega\varepsilon_e)}{2\pi b(\sigma_c+j\omega\varepsilon_c)} \frac{F_e(\zeta)}{F_\omega(\zeta)} \left.\frac{H_0^{(2)}(\xi_e c)}{\xi_c J_1(\xi_c b)}\right|_{\zeta=\zeta_0} \tag{61}$$

and

$$Z_{T1} = \frac{-1}{2\pi b(\sigma_c+j\omega\varepsilon_c)} \left.\frac{F_i'(\zeta)[J_0(\xi_1 c)-J_0(\xi_1 b)] + F_i''(\zeta)[Y_0(\xi_1 c)-Y_0(\xi_1 b)]}{\xi_c F_\omega(\zeta) J_1(\xi_c b)}\right|_{\zeta=\zeta_0}, \tag{62}$$

$$Z_{T2} = \frac{1}{2\pi b(\sigma_c+j\omega\varepsilon_c)} \frac{F_e(\zeta)}{F_\omega(\zeta)} \left.\frac{H_0^{(2)}(\xi_e c)}{\sigma_c J_1(\xi_c b)}\right|_{\zeta=\zeta_0} \tag{63}$$

3.6 Green's Functions

The voltage and current waves on the outermost conductor of a coaxial transmission line excited by a distributed voltage source due to a lightning discharge are now summarized.

The voltage $V(x)$ and the current $I(x)$ on the transmission line due to a distributed voltage source $\mathcal{V}(x')$ are determined by the superposition integrals

$$V(x) = \int_0^\ell dx' G_V(x;x')\mathcal{V}(x') \tag{64}$$

$$I(x) = \int_0^\ell dx' G_I(x;x')\mathcal{V}(x') \tag{65}$$

where $V(x')$ is the field due to the lightning stroke, i.e.

$$V(x') = E_S \tag{66}$$

and the voltage Green's function $G_V(x,x')$ and the current Green's function $G_I(x,x')$ are known to be

$$G_V(x,x') = \begin{cases} V^-(e^{+\gamma x} + \Gamma^- e^{-\gamma x}) & (x < x') \quad (67) \\ V^+(e^{-\gamma x} + \Gamma^+ e^{+\gamma x} e^{-2\gamma \ell}) & (x > x') \quad (68) \end{cases}$$

$$G_I(x,x') = \begin{cases} -\dfrac{V^-}{Z_c}(e^{+\gamma x} - \Gamma^- e^{-\gamma x}) & (x < x') \quad (69) \\ +\dfrac{V^+}{Z_c}(e^{-\gamma x} - \Gamma^+ e^{+\gamma x} e^{-2\gamma \ell}) & (x > x') \quad (70) \end{cases}$$

The unknown constants $V^{\pm}$, which are the magnitudes of the forward and backward traveling waves, are determined from the boundary conditions imposed by the continuity of the current wave and the discontinuity of the voltage wave at $x = x'$, i.e.

$$V^- = + \frac{e^{-\gamma x'} - \Gamma^+ e^{+\gamma x'} e^{-2\gamma \ell}}{\Delta} \tag{71}$$

$$V^+ = - \frac{e^{+\gamma x'} - \Gamma^- e^{-\gamma x'}}{\Delta} \tag{72}$$

where the reflection coefficients $\Gamma^{\pm}$ are defined by

$$\Gamma^- = \frac{Z^- - Z_c}{Z^- + Z_c} \tag{73}$$

$$\Gamma^+ = \frac{Z^+ - Z_c}{Z^+ + Z_c} \tag{74}$$

and the determinant Δ is defined by

$$\Delta = -2(1 - \Gamma^- \Gamma^+ e^{-2\gamma \ell}) \tag{75}$$

The propagation constant γ and the characteristic impedance Z_c are defined by

$$\gamma = \sqrt{YZ} \tag{76}$$

$$Z_c = \sqrt{\frac{Z}{Y}} \tag{77}$$

where the series impedance Z and the shunt admittance Y were defined earlier in (37) and (38).

3.7 Transfer Functions

Once the induced current and voltage surges on the outer conductor $(\rho = \rho_>)$ of a coaxial conductor are known due to a nearby lightning discharge, the induced current and voltage surges on the inner conductor $(\rho = \rho_<)$ are determined via the use of the impedance transfer functions for a coaxial cable, i.e.

$$E_x\Big|_{\rho=\rho_>} = Z_{ee} I_{ext} + Z_{ei} I_{int} \tag{78}$$

$$E_x\Big|_{\rho=\rho_<} = Z_{ie} I_{ext} + Z_{ii} I_{int} \tag{79}$$

where the internal and external impedances are defined by

$$Z_{ee} = \frac{k}{-j\omega\hat{\varepsilon}} \frac{1}{2\pi\rho_>} \frac{\Delta_{ee}}{\Delta} \tag{80}$$

$$Z_{ei} = \frac{1}{-j\pi\hat{\varepsilon}} \frac{1}{2\pi} \frac{1}{\rho_<\rho_>} \frac{1}{\Delta} \tag{81}$$

$$Z_{ie} = \frac{1}{-j\omega\varepsilon} \frac{1}{2\pi} \frac{1}{\rho_<\rho_>} \frac{1}{\Delta'} \tag{82}$$

$$Z_{ii} = \frac{k}{-j\omega\hat{\varepsilon}} \frac{1}{2\pi\rho_<} \frac{\Delta_{ii}}{\Delta'} \tag{83}$$

and

$$\Delta_{ee} = Y_1(k\rho_<)J_0(k\rho_<) + J_1(k\rho_<)Y_0(k\rho_>) \tag{84}$$

$$\Delta_{ii} = Y_1(k\rho_>)J_0(k\rho_>) + J_1(k\rho_>)Y_0(k\rho_<) \tag{85}$$

and

$$\Delta = J_1(k\rho_>)Y_1(k\rho_<) - J_1(k\rho_<)Y_1(k\rho_>) \tag{86}$$

$$\Delta' = J_1(k\rho_<)Y_1(k\rho_>) - J_1(k\rho_>)Y_1(k\rho_<) \tag{87}$$

Since the coaxial cable may be composed of several concentric shells rather than just one, as depicted above, the above formulas may be used recursively to obtain the current and voltages on the innermost cylinder due to the current and voltages on the outermost cylinder.

CHAPTER 4

The Computer Program

4.1 Introduction

The "LPS" Program has been written in FORTRAN IV language for the CDC Cyber 74 computer to produce solutions to the electromagnetic coupling problems which are outlined above.

Several factors were given consideration in the design of the program. Efficient coding was used to reduce computer run time as much as possible. Full single word accuracy and, where necessary, double precision accuracy was utilized in the calculation of special functions. Single precision accuracy on the Cyber maintains fifteen digits of accuracy. Maximum use was made of core storage. The sizes of the basic solution arrays (up to 100 x 100 complex) were determined so that secondary storage devices such as tapes or disk packs do not necessarily have to be utilized in running the program.

4.2 Glossary of the Routines

The program operates via a MAIN program and numerous auxiliary routines, e.g., a runstream, program sequences, subroutines, functions, and a library, which are listed in a flow chart contained in Figure 8. Standard I/O and mathematical routines, e.g., intrinsic functions, are assumed to be available through the FORTRAN operating system.

The MAIN program controls the overall runstream and sets up the parameter, type, and dimension statements and the common blocks.

The runstream calls the program sequences, which in turn call various subroutines and functions. A library of special functions and operations was developed to support the program.

4.3 The Input Routine

Subroutine PSIO reads the user's control information, prints out headings, and obtains information for all operations. The input cards and their formats are listed in Table 1.

CHAPTER 5

Numerical Results

Several average lightning channel conditions and representative buried cable geometries are examined. The results are conveniently displayed via numerous graphs of the time histories (time-domain results) and the frequency spectra (frequency-domain results) of the resulting transient voltage and current pulses.

In particular, a typical RG-58/U coaxial cable buried one meter below the ground in wet soil is considered. The cable is assumed to be shielded and armored and is coated with a protective layer of insulation. The radius of the wire is 0.813 mm, the inner and outer radii of the shields are, respectively, 2.953 mm and 3.953 mm, the inner and outer radii of the armor are, respectively, 4.953 mm and 5.953 mm, and the outer radius of the sheath is 6.953 mm. The relative permeabilities of all of the insulators and conductors are assumed to be unity; whereas, the relative permittivities of the stabilized polyethylene spacers are assumed to be 2.26. The absolute conductivities of the copper conductors are assumed to be 5.7×10^{7} mhos/m; the absolute conductivities of the stabilized polyethylene spacers are assumed to be 1.0×10^{-8} mhos/m. The earth is assumed to be wet with relative permeability 1.0, relative permittivity 5.0, and absolute conductivity 1.5×10^{-3} mhos/m. A "double exponential" lightning channel pulse is assumed, with typical rise-times and half-life decay times on the order of 1.2 μs and 50 μs, respectively. A peak current of 20 KA is also assumed. The lightning channel is considered to be vertical and, for comparison purposes, is assumed to terminate at d = 0 m, 10m, 50m, 100m, 200m, 500m, 1km, 2km, 5km, and 10km from the cable, at a point near the end of the cable. The cable is assumed to be 1 km in length.

Particular attention is paid to the magnitudes of the voltage and current waveforms at both ends of the line and at the middle of the line, i.e., at x = 0 m, 500 m, and 1 km.

As an example, Figures 9 through 16 contain plots of the computer output which resulted from the input data contained in Appendix B. In particular, Figure 9 shows the frequency-domain distribution of the external excitation, i.e., axial electric field on the outer conductor of the cable, as a function of position at various frequencies due to the lightning stroke directly over the load. Figure 10 shows the frequency-domain distribution of the induced current transient on the outer conductor of the cable as a function of position at various frequencies due to the distributed external excitation of the lightning stroke. Figure 11 shows the frequency spectrum of the transfer ratio for the current or voltage between the inner and outer conductors of the cable. Figure 12 shows the frequency-domain distribution of the internal excitation, i.e., the axial electric field on the inner conductor of the cable, as a function of position at various frequencies due to the imperfect shielding of the armor and the shield. Figures 13 and 14 show, respectively, the frequency spectra of the current and voltage pulses on the inner conductor of the cable; and, Figures 15 and 16 show, respectively, the time histories of the current and voltage pulses on the inner conductor of the cable.

Table 2 contains the values of the peak current and voltage and the rise times and the half-life decay times of the pulses on the inner conductor of the cable at the loads, and at the midpoint of the cable as a function of the distance of the lightning stroke from the cable with the other parameters of the model held constant. The lightning stroke cocurs near the end of the cable. The program is capable of varying all of the parameters in the model simultaneously; but, only this one case is studied here. This case is of interest and is treated in particular since it is very similar to the conditions which actually exist during a thunderstorm, i.e., the distance from the cable to the lightning stroke varies from stroke to stroke; whereas, the remaining parameters of the model are fixed at the initial time of installation of the system.

An examination of Table 2 reveals that the ability of the lightning stroke to induce current and voltage transients on the inner conductor of the cable at the load decreases slowly with increasing distance between the lightning stroke and the cable, as one would naturally expect. We also note that there is relatively little difference between the values corresponding to lightning strikes occuring near the ends and near the middle of the cable, which indicates that the coupling mechanism is relatively insensitive to axial displacements along the length of the cable.

The maximum current and voltage peaks observed on the inner conductor of the cable at the load are 652 V and 13.1 A, and these maxima both occur when the stroke is directly over the cable.

CHAPTER 6

Conclusions

This report presents the numerical results of a lightning protection study which was performed for the Federal Aviation Administration (FAA).

In particular, this study considers the lightning induced transients on a buried shielded and armored coaxial transmission line.

A lightning stroke to ground (not an intra or inter cloud stroke) near a buried coaxial cable can induce current and voltage surges on the inner core of the cable, even if the cable has an outer armor and an inner shield.

The external coupling mechanism, i.e., from the terminal ground point of the "vertical" lightning channel to the outer conductor of the cable, is either arcing, i.e., by dielectric breakdown through the earth to the cable jacket, for a "direct" strike, or conductive enerization of the cable jacket through the conductive earth, for an "indirect" strike. The internal coupling mechanism, i.e., from the outer jacket to the inner core of the cable, is conductive transfer through the various metal skins and dielectric spacers, i.e., skin effects, due to the finite conductivities of these materials.

In particular, these lightning induced surges tend to cause excessive voltages to appear at the ends of the wires; and, therefore, tend to cause excessive currents to flow into the terminating equipment loads. Obviously, then, circuit distrubances or failures are likely to occur unless adequate protective measures are provided.

Since there is a tendency to move from "high voltage" electron tubes or discrete transistor circuitry to "low voltage" solid state integrated electronics, the surge protection of carbon blocks, neon bulbs, etc., (devices which are presently in service) may no longer be adequate.

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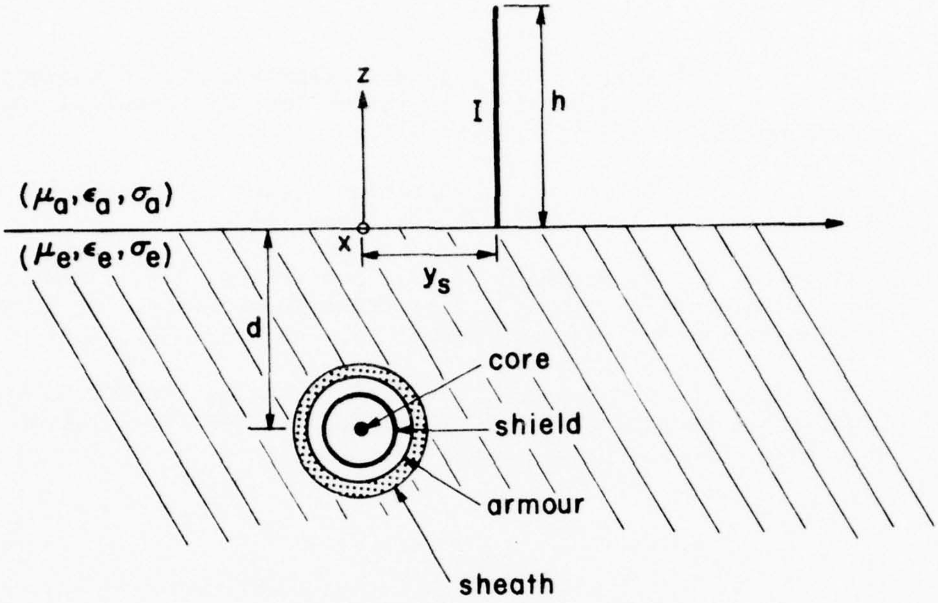
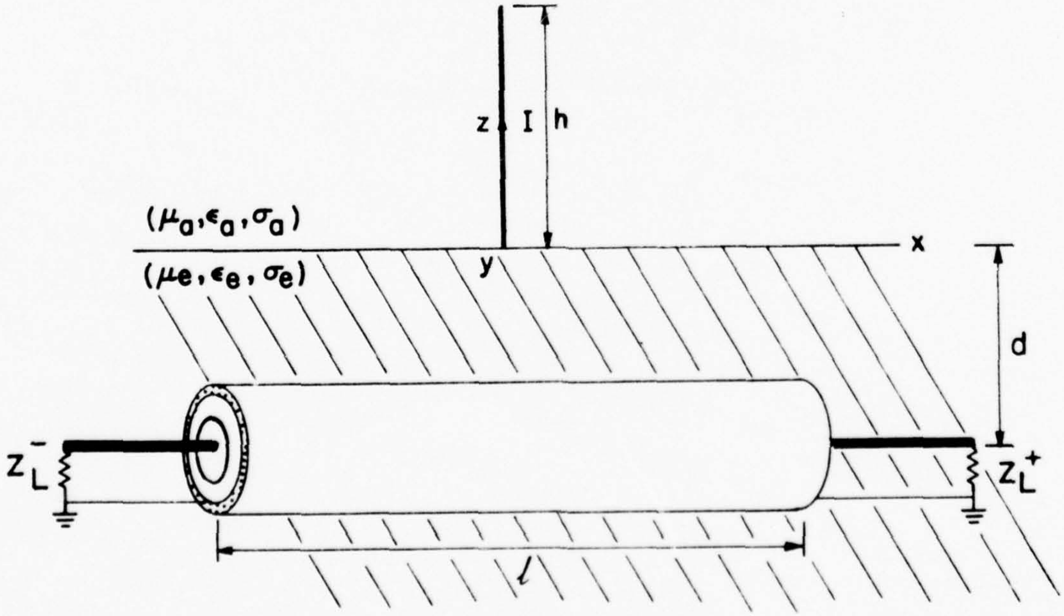
(2) Chen, C. L., "FAA Lightning Protection Study: Lightning Protection Devices," Report No. FAA-RD-74-104, April 1974.

(3) Huddleston, G. K., Nordgard, J. D., and Larson, R. W., "FAA Lightning Protection Study: Lightning Protection Requirements for AN/GRN-27(V) Instrument Landing System," Report No. FAA-RD-74-131, April 1974.

(4) Nordgard, J. D. and Chen, C. L., "FAA Lightning Protection Study: Lightning-induced Transients on Buried Shielded Transmission Lines," Report No. FAA-RD-75-108, June 1975.



(AXIAL VIEW)



(TRANSVERSE VIEW)

FIG. 1. PROBLEM GEOMETRY

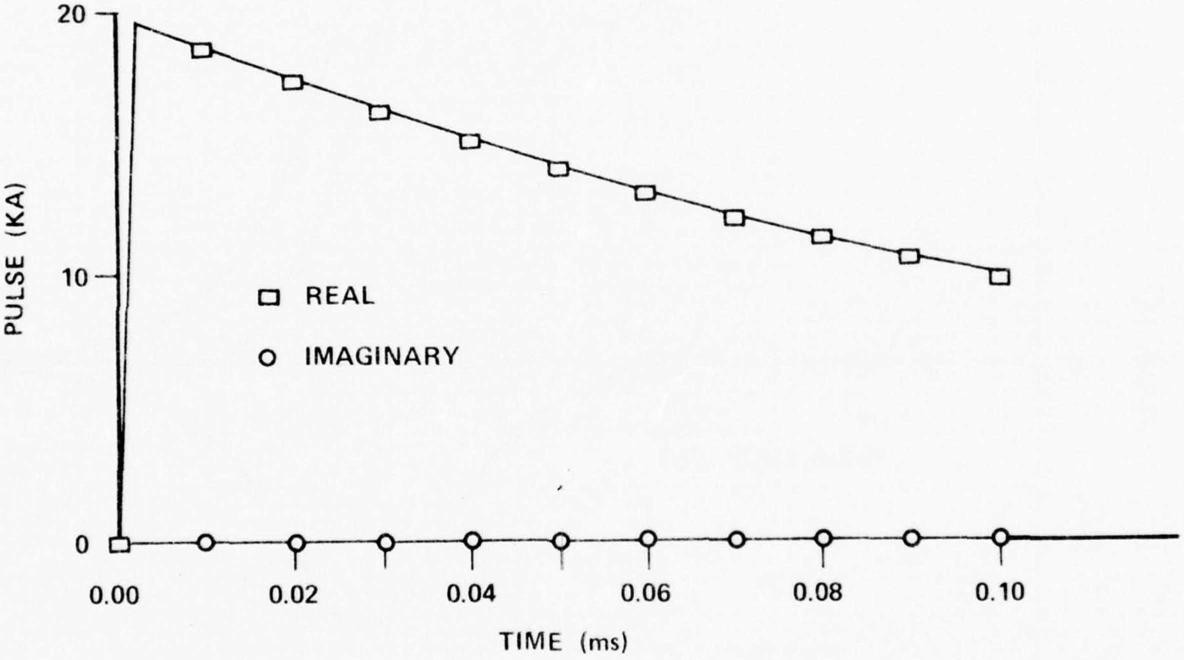


FIGURE 2. LIGHTNING PULSE (TIME DOMAIN) VS. TIME

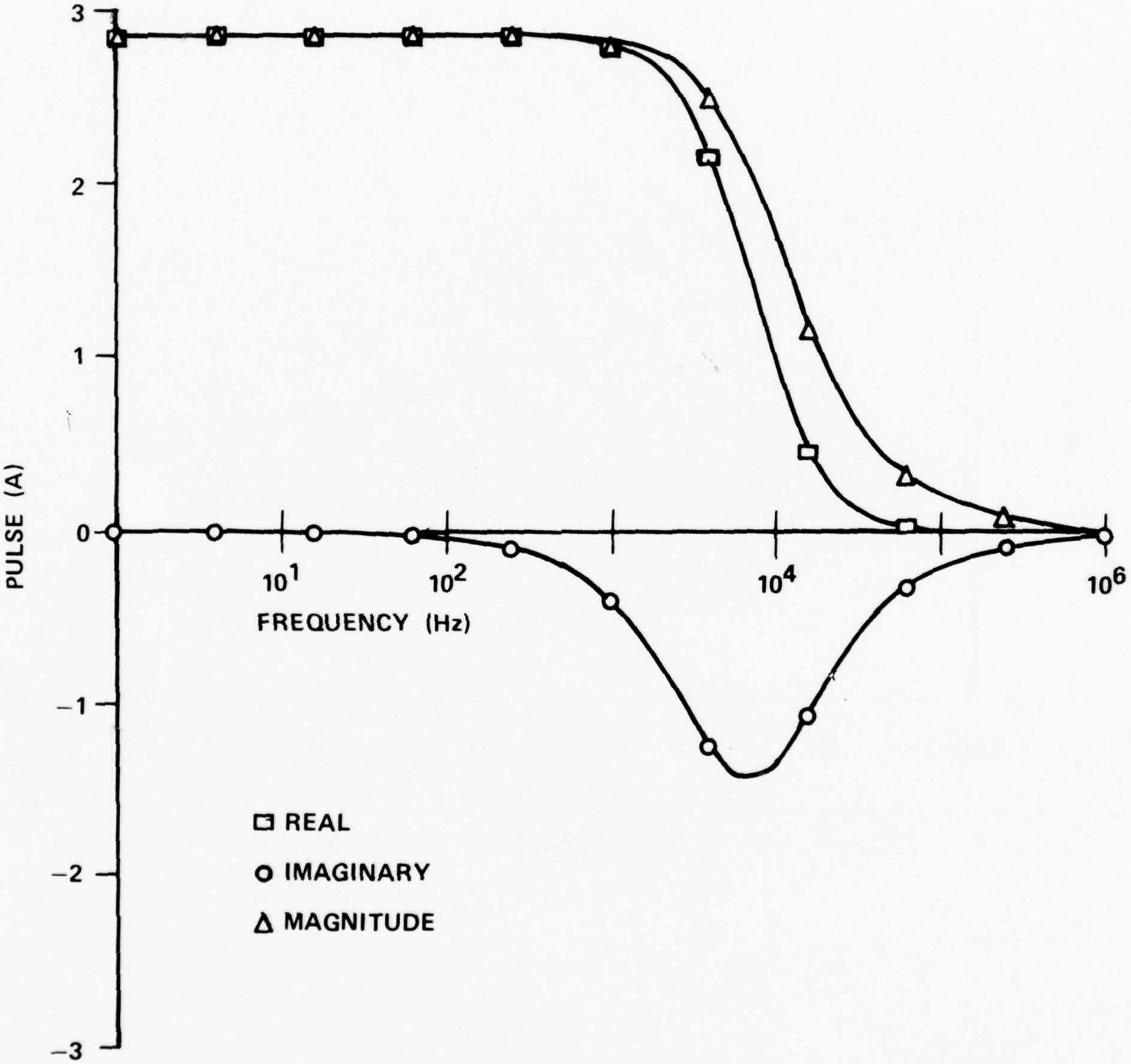


FIGURE 3. LIGHTNING PULSE (FREQUENCY DOMAIN) VS. FREQUENCY

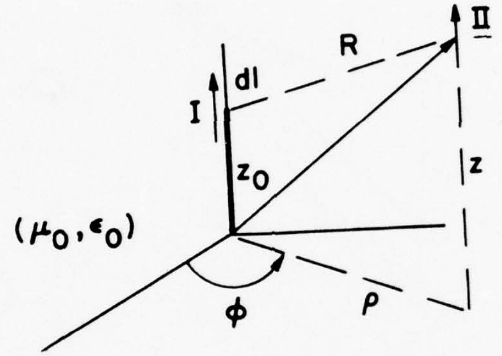


FIG. 4. A POINT DIPOLE IN FREE SPACE

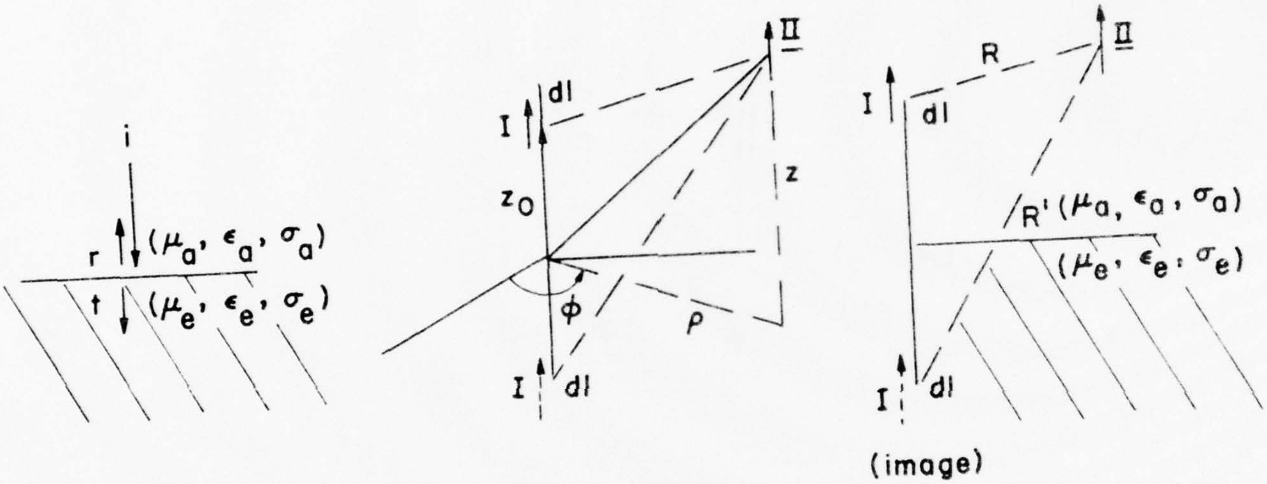


FIG. 5. A POINT DIPOLE ABOVE FLAT EARTH

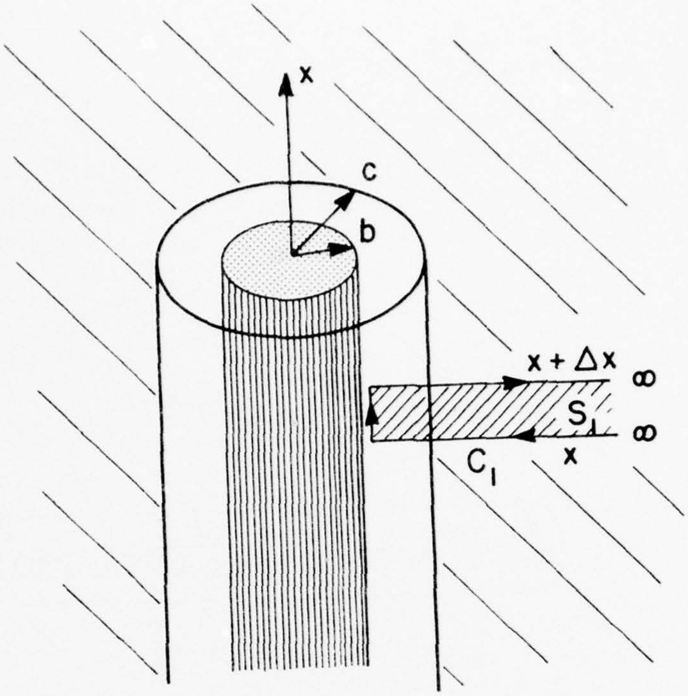


FIG. 6a. CONTOUR C_1 AND SURFACE S_1 IN FARADAY'S LAW

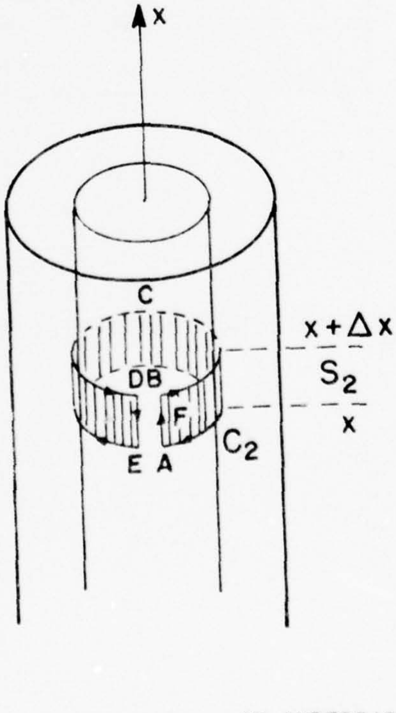


FIG. 6b. CONTOUR C_2 AND SURFACE S_2 IN AMPERE'S LAW

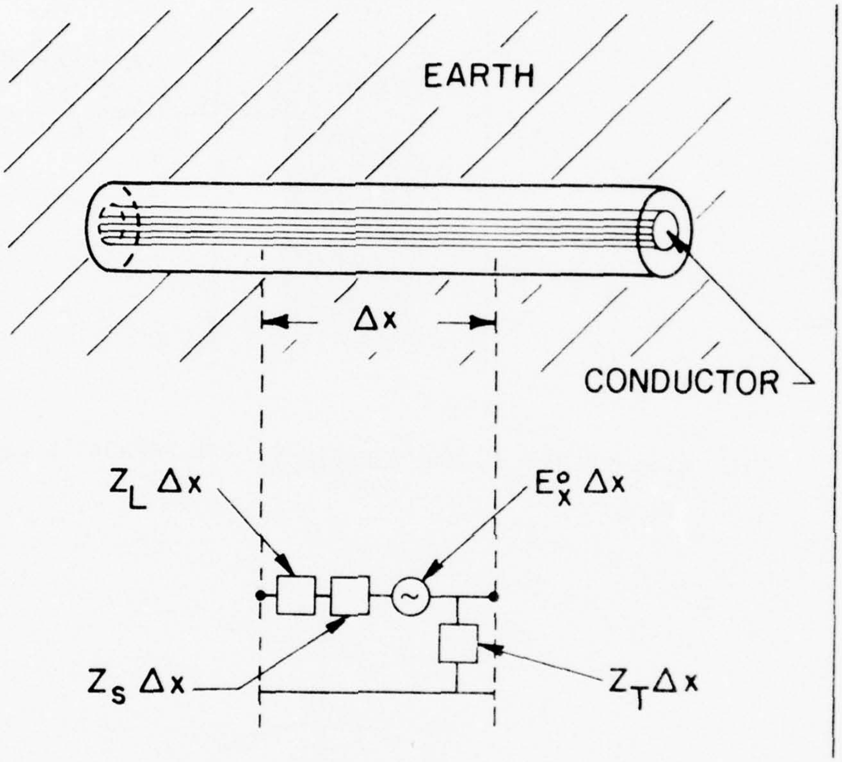
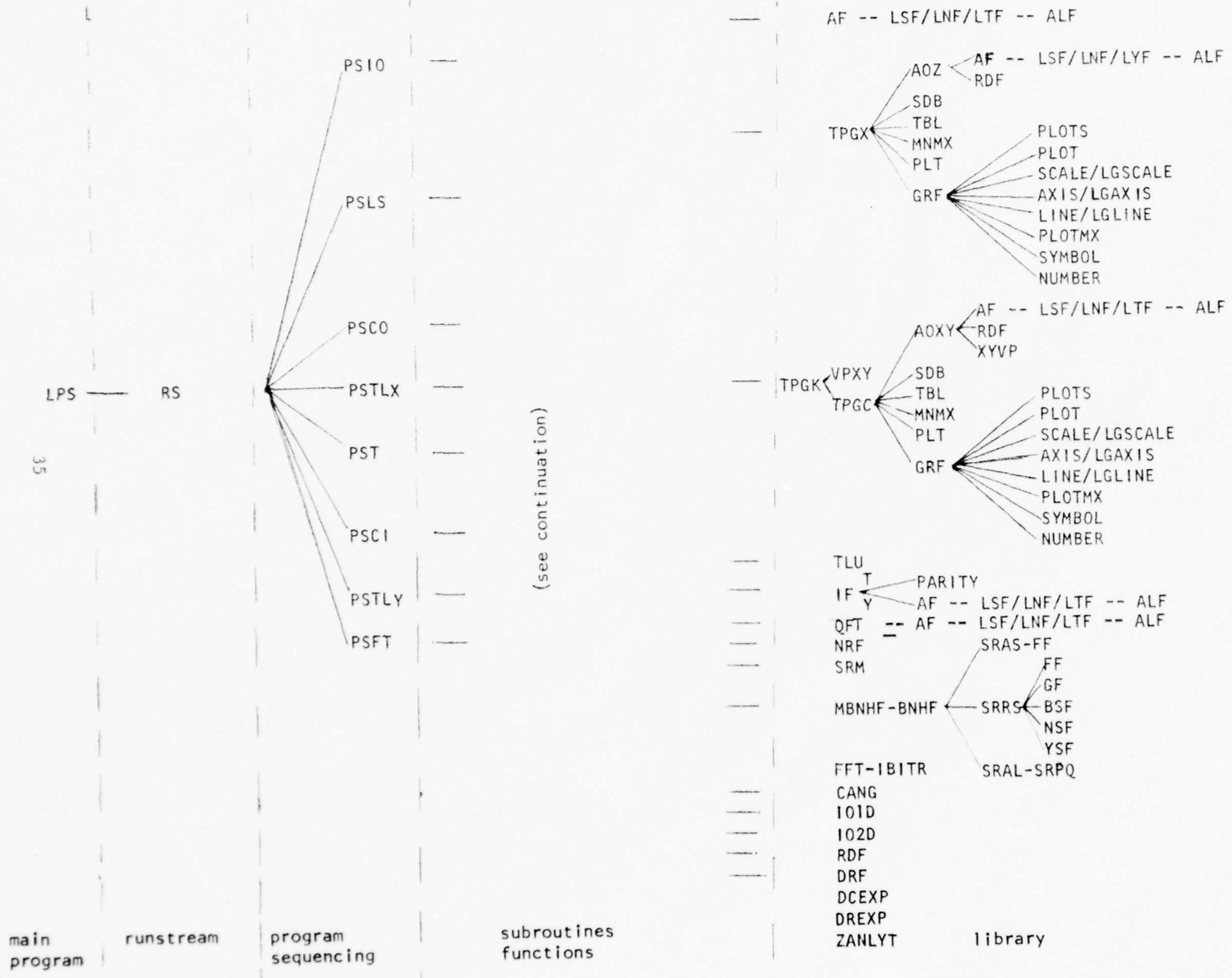


FIG. 7. DISTRIBUTED TRANSMISSION LINE MODEL

Figure 8
(flow chart)



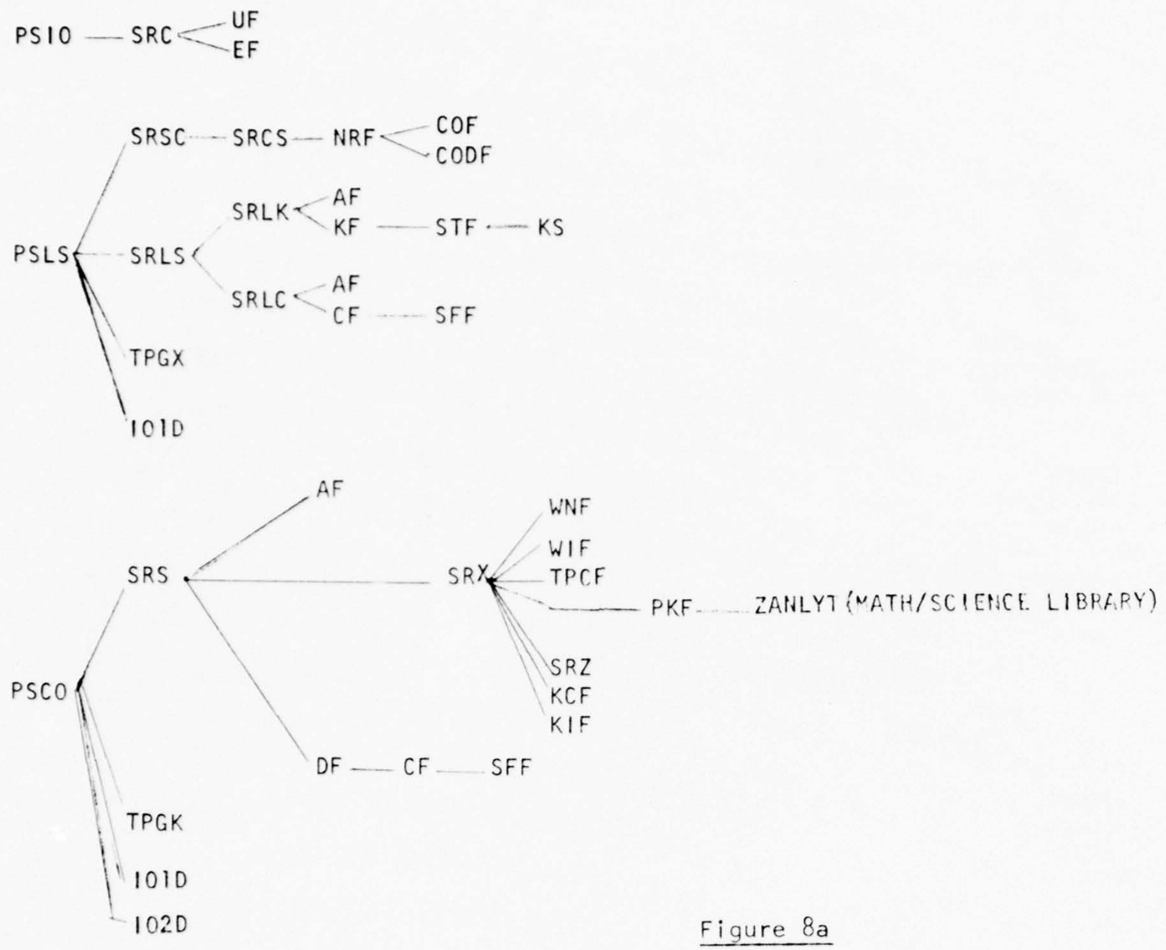


Figure 8a
(flow chart cont.)

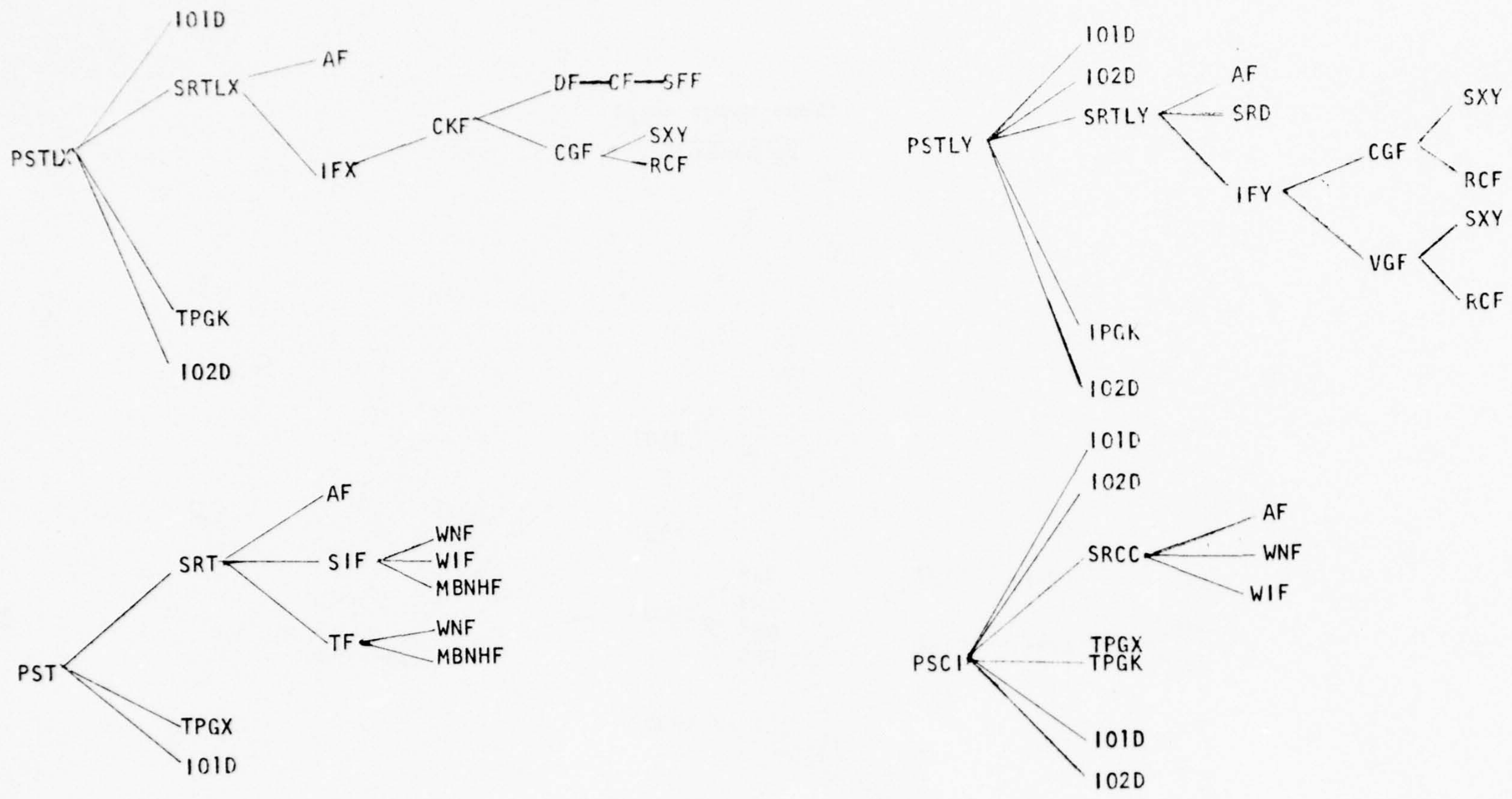


Figure 8b
(flow chart cont.)

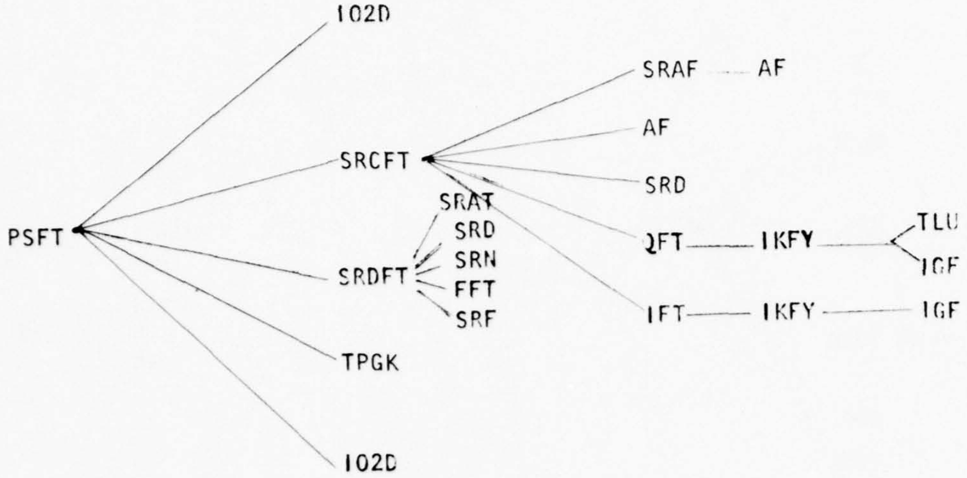


Figure 8c

(flow chart cont.)

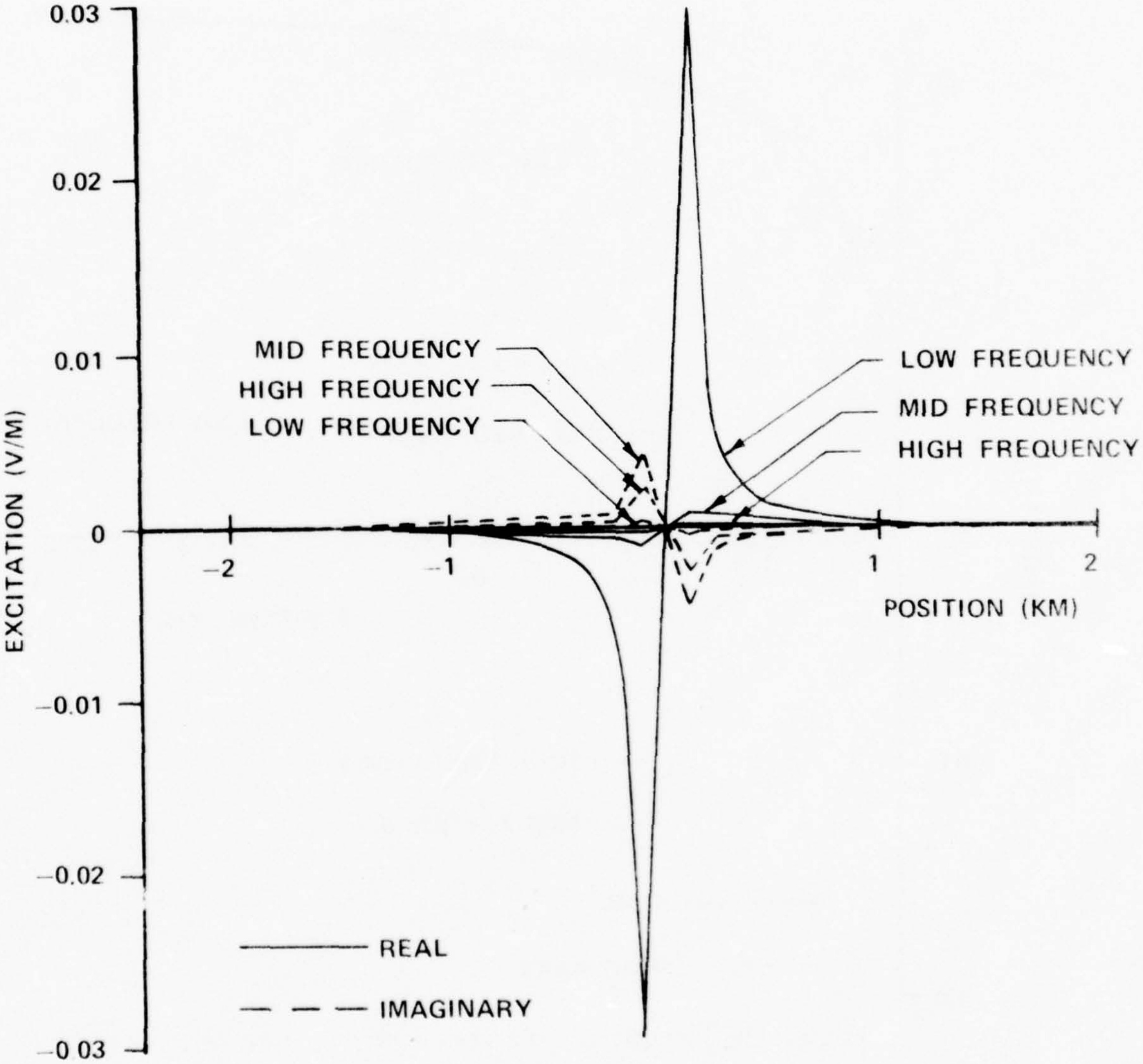


FIGURE 9. OUTER EXCITATION (FREQUENCY DOMAIN) VS. POSITION

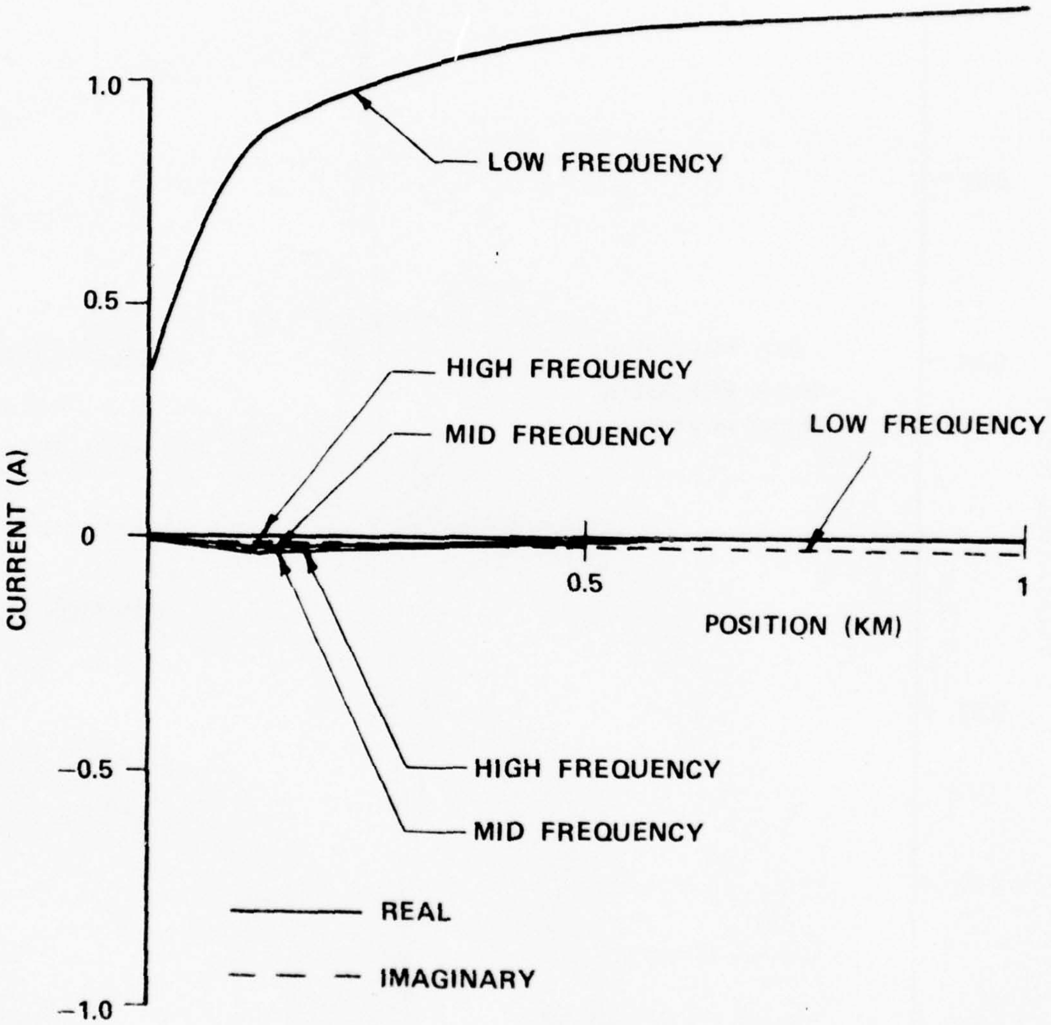


FIGURE 10. OUTER CURRENT (FREQUENCY DOMAIN) VS. POSITION

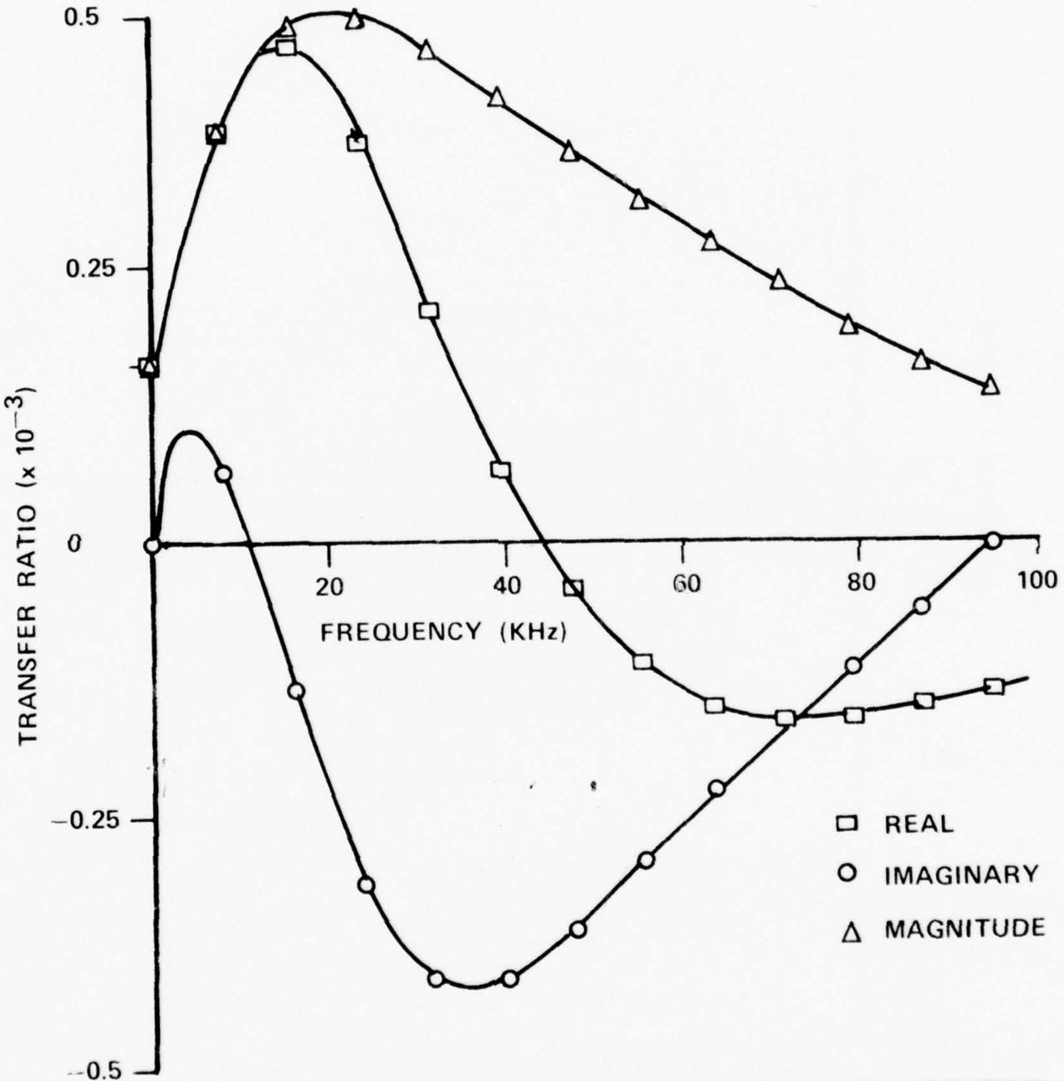


FIGURE 11. TRANSFER RATIO (FREQUENCY DOMAIN) VS. FREQUENCY

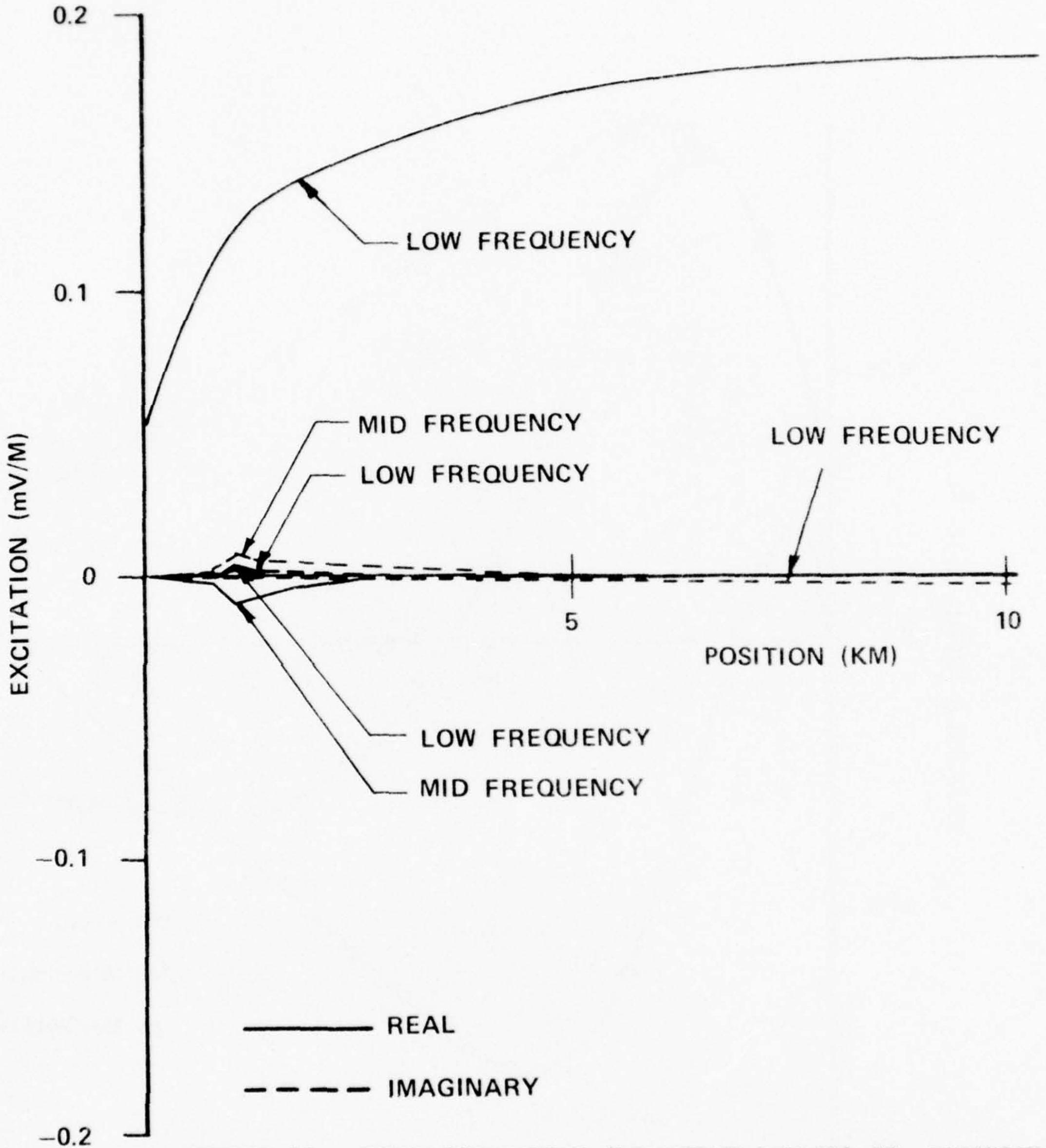


FIGURE 12. INNER EXCITATION (FREQUENCY DOMAIN) VS. POSITION

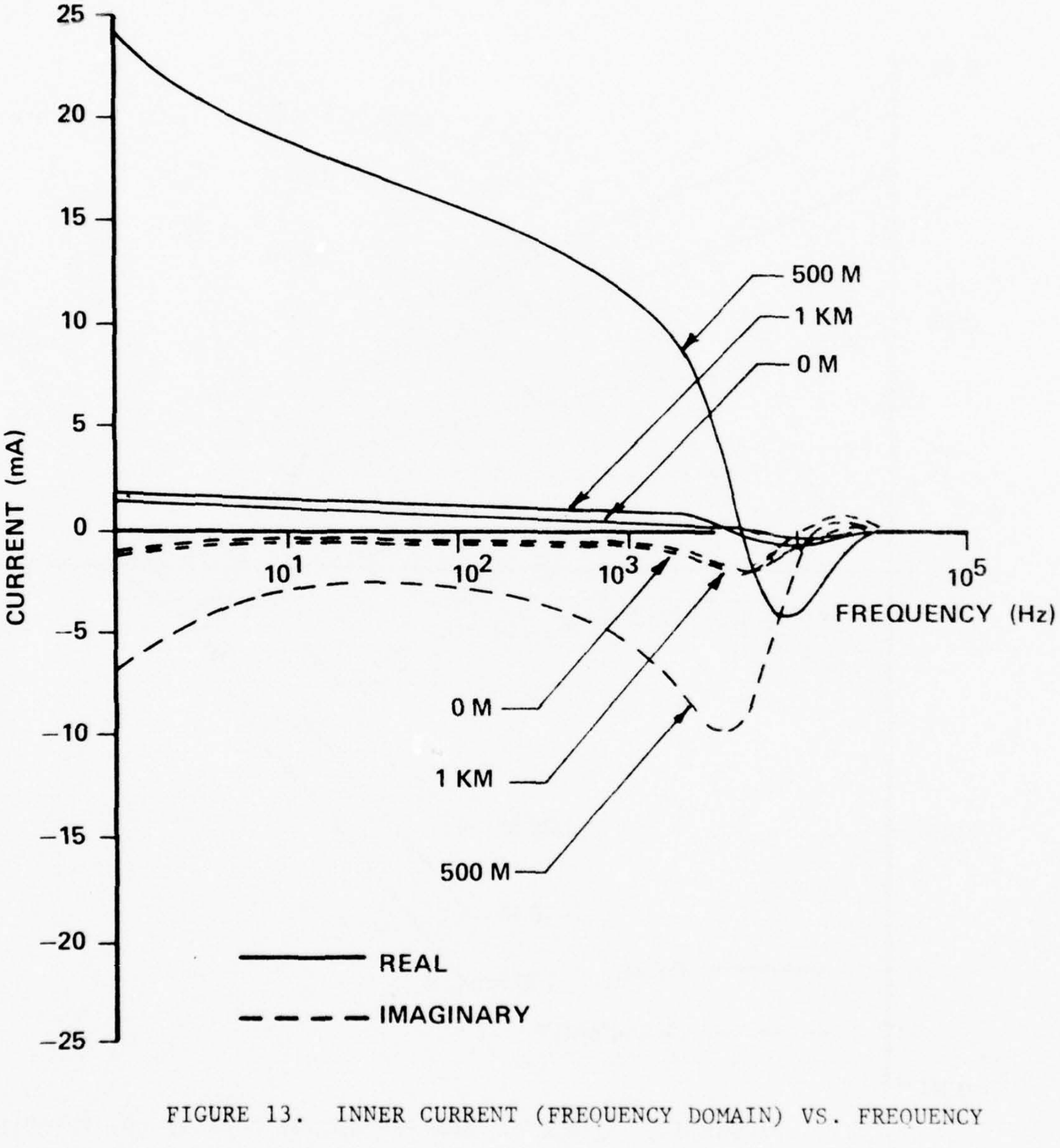


FIGURE 13. INNER CURRENT (FREQUENCY DOMAIN) VS. FREQUENCY

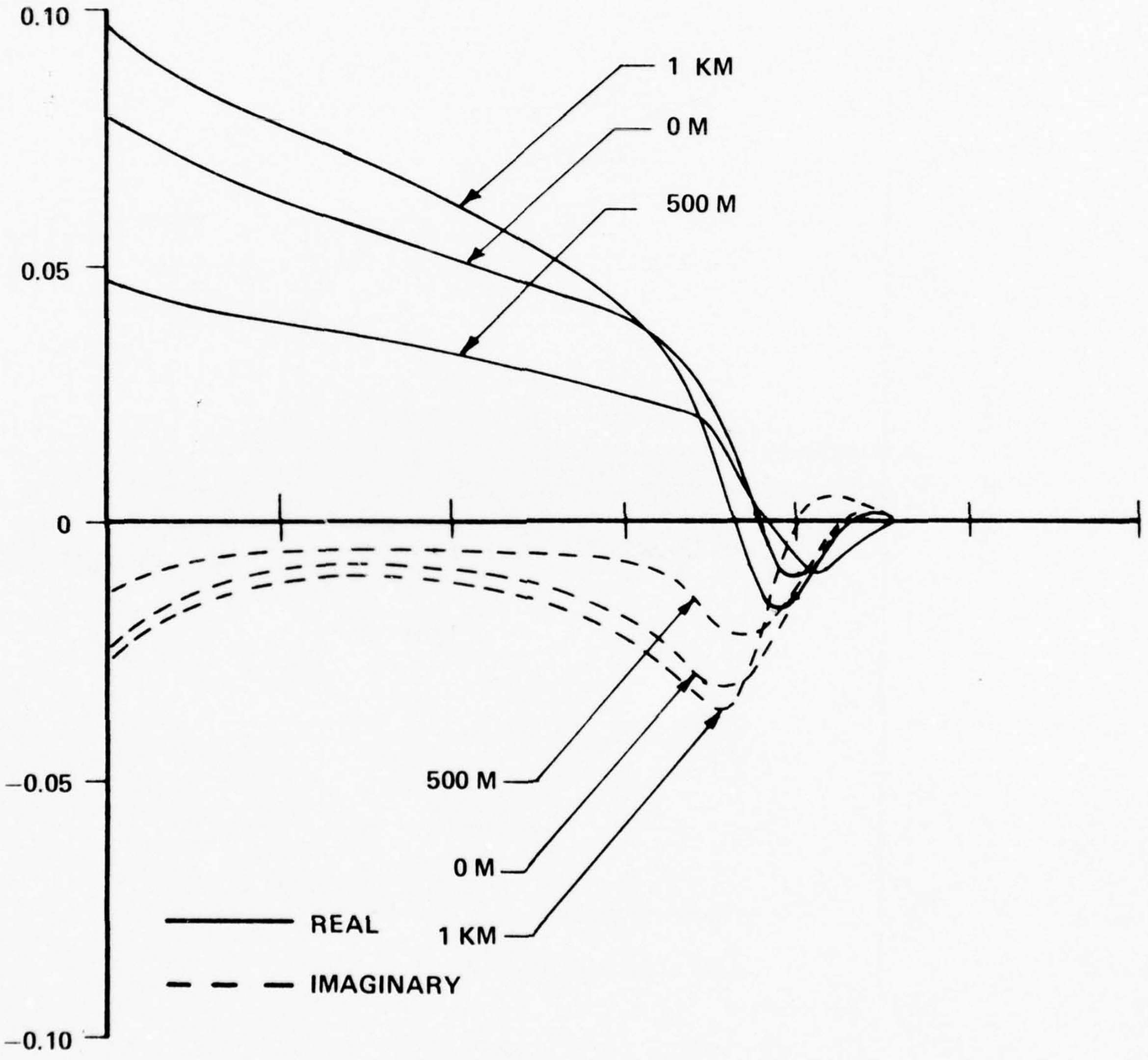


FIGURE 14. INNER VOLTAGE (FREQUENCY DOMAIN) VS. FREQUENCY

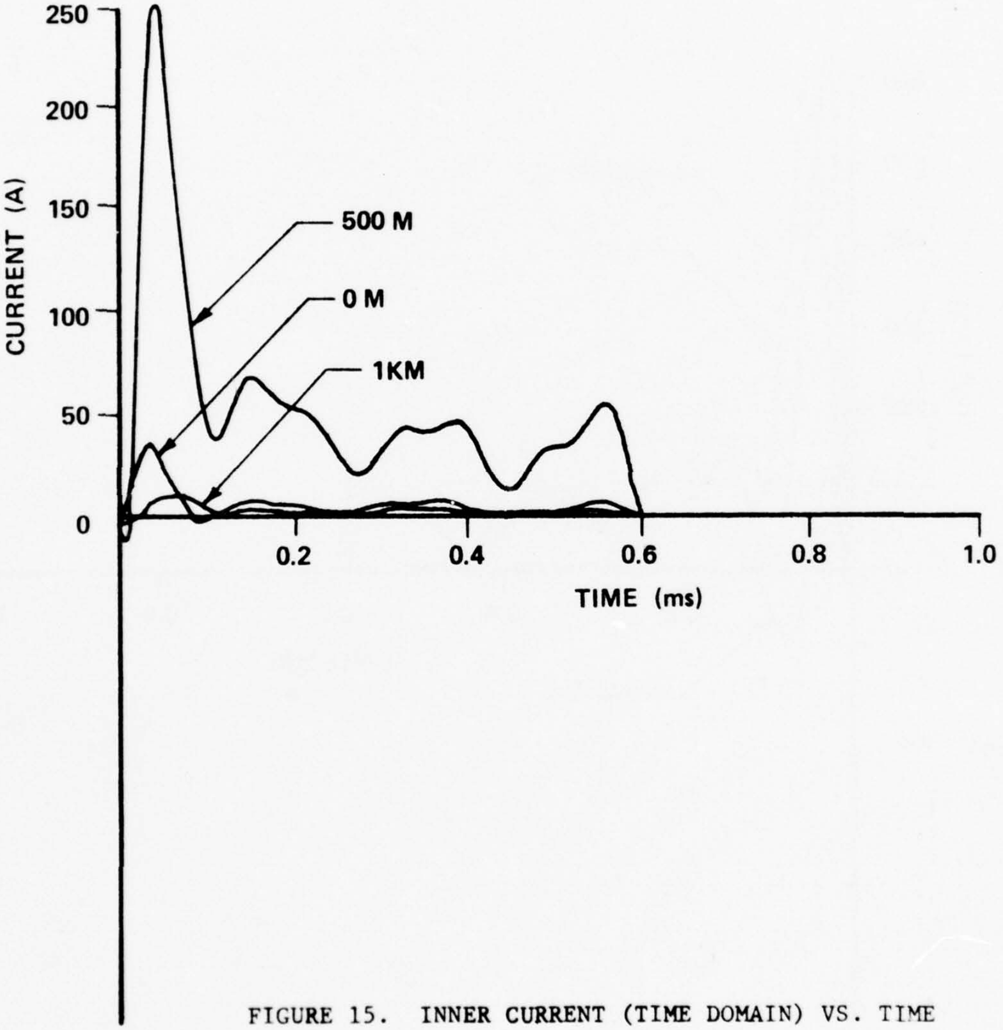


FIGURE 15. INNER CURRENT (TIME DOMAIN) VS. TIME

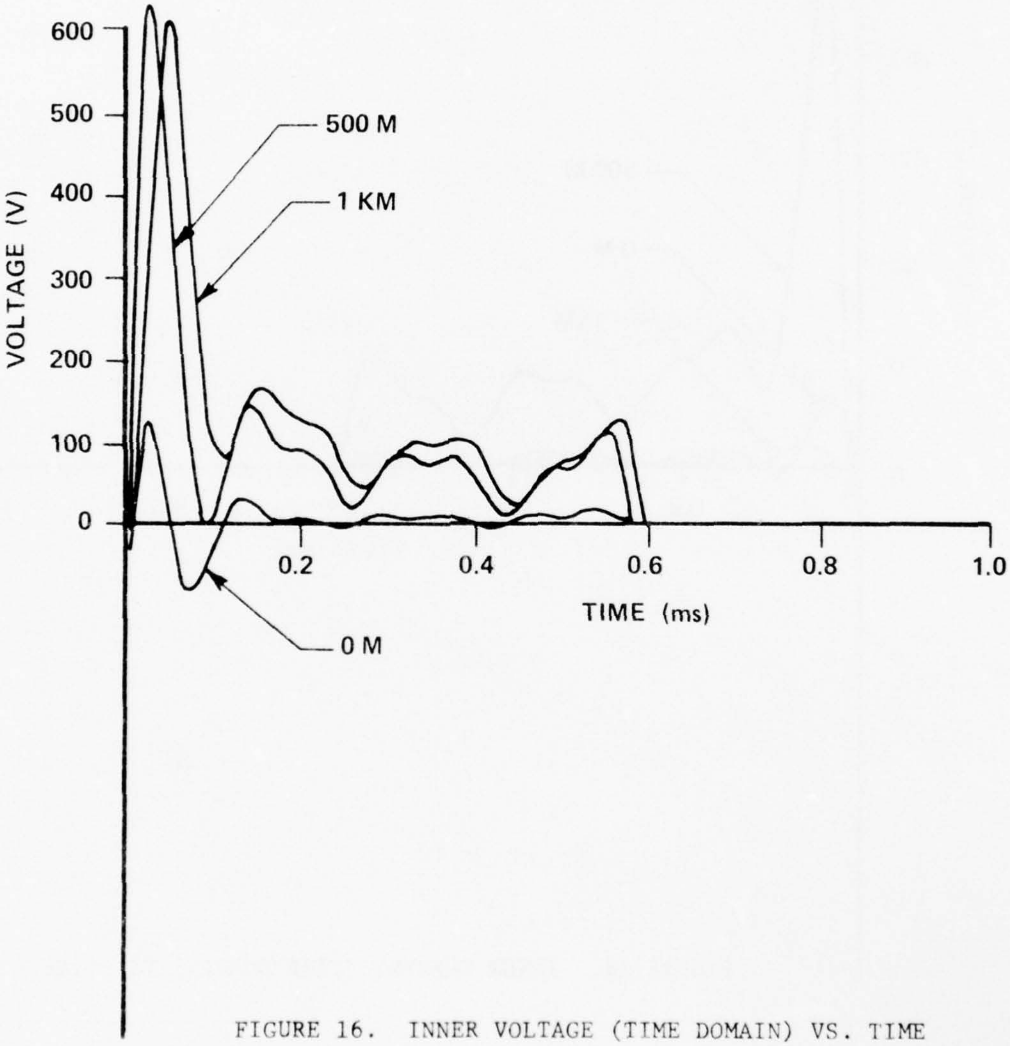


FIGURE 16. INNER VOLTAGE (TIME DOMAIN) VS. TIME

APPENDIX A

Program Listing

```
      PROGRAM LPS
     +(INPUT,OUTPUT,PLOTS,
     + DLSP,DLSQ,DCOE,DCIE,DCOC,DCOV,DCIC,DCIV,DFTK,DFTU,
     + TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PLOTS,
     + TAPE21=DLSP,TAPE22=DLSQ,
     + TAPE23=DCOE,TAPE24=DCIE,
     + TAPE25=DCOC,TAPE26=DCOV,
     + TAPE27=DCIC,TAPE28=DCIV,
     + TAPE29=DFTK,TAPE30=DFTU)
C#######################################################################
C      MAIN PROGRAM
C#######################################################################
C      FAA LIGHTNING PROTECTION STUDY
C      CDC CYBER 74 (FORTRAN 4)
C      GEORGIA TECH/SCHOOL OF EE/ATLANTA,GA 30332
C      NORDGARD / 12 MAY 76 (REVISED)
C
C      PARAMETER DP=100
C      PARAMETER DE=342,DX=32,DF=64,DT=128
C      PARAMETER DA=130,DO=5
C      PARAMETER DM=8
C      PARAMETER DW=64
C
       INTEGER DP
       INTEGER DE,DX,DF,DT
       INTEGER DA,DO
       INTEGER DM
       INTEGER DW
       INTEGER CP,LP,PQ
       INTEGER DLSP,DLSQ
       INTEGER DCOE,DCIE
       INTEGER DCOC,DCOV
       INTEGER DCIC,DCIV
       INTEGER DFTK,DFTU
       INTEGER RLS,RCO,RTT,RCI,RTL,RFT
       INTEGER WLS,WCO,WTT,WCI,WTL,WFT
       INTEGER TT,TX,TV,TH
       REAL     MIN,MAX
       COMPLEX P,Q
       COMPLEX K,C
       COMPLEX U,V
       COMPLEX E,IT
       COMPLEX PC,ZC
       COMPLEX MF
       COMPLEX PCX,ZCX
       COMPLEX YSX,ZSX
       COMPLEX WNX,WIX
       COMPLEX ZMX,ZPX
       COMPLEX ZLM,ZLP
       COMPLEX WJ,WH
       COMPLEX J0WW,J1WW
       COMPLEX J0IW,J1IW,Y0IW,Y1IW
       COMPLEX J0IS,J1IS,Y0IS,Y1IS
       COMPLEX H0ES,H1ES
       COMPLEX EMW,EMI,EME
       COMPLEX APCW,APCI,APCE
       COMPLEX Y
C
       DIMENSION P(51),Q(51)
       DIMENSION E(41,51),IT(41,61)
       DIMENSION K(3,61),C(3,61)
       DIMENSION U(3,61),V(3,61)
       DIMENSION PC(61),ZC(61)
       DIMENSION MF(61)
```

```
      DIMENSION A(63),O(63,5)
      DIMENSION TT(8),TX(8),TV(6),TH(8)
      DIMENSION X(61),Y(61)
C
      COMMON/A10/CR,LP,PQ
      COMMON/A11/DLSP,DLSQ
      COMMON/A12/DCOE,DCIE
      COMMON/A13/DCOC,DCOV
      COMMON/A14/DCIC,DCIV
      COMMON/A15/DFTK,DFTU
      COMMON/B11/IMX,EMX
      COMMON/B12/ML,RL,SL
      COMMON/B13/MIN,MAX,MD
      COMMON/B14/NDX,MDX,MYY
      COMMON/B15/NQ,NI
      COMMON/B20/MN,NM
      COMMON/B21/MLS,MCO,MTT,MCI,MTL,MFT
      COMMON/B22/RLS,RCO,RTT,RCI,RTL,RFT
      COMMON/B23/WLS,WCO,WTT,WCI,WTL,WFT
      COMMON/B27/MRC
      COMMON/B30/MQX
      COMMON/B31/MM
      COMMON/C11/TM,WM
      COMMON/C12/NK,NC
      COMMON/C13/TS,TR,TD,TP,TC
      COMMON/C14/AX,BX,CX
      COMMON/C15/APS,BPS,CPS
      COMMON/C16/ARX,BRX,CRX
      COMMON/C17/ARS,BRS,CRS
      COMMON/C20/PGPS,PGRX,PGRS
      COMMON/C21/PSPS,DCPS,DKPS,MPS,NPS
      COMMON/C22/PSRX,DCRX,DKRX,MRX,NRX
      COMMON/C23/PSRS,DCRS,DKRS,MRS,NRS
      COMMON/C24/TSPS,TRPS,TDPS,TPPS,TCPS
      COMMON/C25/TSRX,TRRX,TDRX,TPRX,TCRX
      COMMON/C26/TSRS,TRRS,TDRS,TPRS,TCRS
      COMMON/D10/SI,SF,NS
      COMMON/D11/XI,XF,NX
      COMMON/D12/YI,YF,NY
      COMMON/D13/WI,WF,NW
      COMMON/D14/TI,TF,NT
      COMMON/D15/MS,MX,MY,MW,MT
      COMMON/D16/IEI,IEF,NEI
      COMMON/D17/IXI,IXF,NXI
      COMMON/D18/IYI,IYF,NYI
      COMMON/D19/IWI,IWF,NWI
      COMMON/D20/ITI,ITF,NTI
      COMMON/D21/XX,XT
      COMMON/D22/XXI,XXF,NXX,MXX
      COMMON/D23/XYI,XYF,NYX,MYX
      COMMON/D24/XPI,XPY,NPX,MPX
      COMMON/E11/RW
      COMMON/E12/RSM,RSP
      COMMON/E13/RAM,RAP
      COMMON/E14/RC
      COMMON/E15/ZO,YO
      COMMON/F11/URE,ERE,UE,EE,OE
      COMMON/F12/URI,ERI,UI,EI,OI
      COMMON/F13/URA,ERA,UA,EA,OA
      COMMON/F14/UR2,ER2,U2,E2,O2
      COMMON/F15/URS,ERS,US,ES,OS
      COMMON/F16/UR1,ER1,U1,E1,O1
      COMMON/F17/URW,ERW,UW,EW,OW
      COMMON/G11/ZLM,ZLP
```

```
      COMMON/H11/PCX,ZCX
      COMMON/H12/YSX,ZSX
      COMMON/H13/WNX,WIX
      COMMON/H14/ZMX,ZPX
      COMMON/I10/WJ,WH
      COMMON/I11/J0WW,J1WW
      COMMON/I12/J0IW,J1IW,Y0IW,Y1IW
      COMMON/I13/J0IS,J1IS,Y0IS,Y1IS
      COMMON/I14/H0ES,H1ES
      COMMON/I15/EMW,EMI,EME
      COMMON/I16/APCW,APCI,APCE
C
C     EQUIVALENCE (K,C)
C     EQUIVALENCE (U,V)
C
      DATA CR.LP,PQ/5,6.7/
      DATA DLSP,DLSQ/21.22/
      DATA DCOE,DCIE/23.24/
      DATA DCOC.DCOV/25,26/
      DATA DCIC,DCIV/27,28/
      DATA DFTK,DFTU/29,30/
      DATA DP/51/
      DATA DE,DX,DF,DT/41,3.61,61/
      DATA DA,DO/63,5/
      DATA DM/6/
      DATA DW/61/
C
      CALL RS
     +(A,O,DA,DO,TT.TX,TV,TH,DM,X,Y.DW,
     + P,Q,DP,K.C,U,V,E.IT,PC,ZC,MF,DE,DX,DF,DT)
C
      STOP
      END
C######################################################################
C     RUNSTREAM
C######################################################################
      SUBROUTINE RS
     +(A,O,PA,PO,TT.TX,TV,TH,PM,X,Y,PW,
     + P,Q,PP,K.C,U,V,E,IT,PC,ZC,MF,PE,PX,PF,PT)
C
C     RUNSTREAM
C
      INTEGER PP
      INTEGER PE,PX,PF,PT
      INTEGER PA,PO
      INTEGER PM
      INTEGER PW
      INTEGER TT,TX,TV,TH
      COMPLEX P.Q
      COMPLEX K,C
      COMPLEX U,V
      COMPLEX E.IT
      COMPLEX PC,ZC
      COMPLEX MF
      COMPLEX Y
C
      DIMENSION P(PP),Q(PP)
      DIMENSION K(PX,PT).C(PX,PF)
      DIMENSION U(PX,PT),V(PX,PF)
      DIMENSION E(PE,PF),IT(PE,PF)
      DIMENSION PC(PF),ZC(PF)
      DIMENSION MR(PF)
      DIMENSION A(PA),O(PA.PO)
      DIMENSION TT(PM).TX(PM),TV(PM).TH(PM)
```

```
      DIMENSION X(PW),Y(PW)
C
      COMMON/B21/MLS,MCO,MTT,MCI,MTL,MFT
C
      CALL PSIO
C
      IF(MLS.NE.0) CALL PSLS
     +(A,O,PA,PO,TT,TX,TV,TH,PM,P,Q,PP)
      IF(MCO.NE.0) CALL PSCO
     +(A,O,PA,PO,TT,TX,TV,TH,PM,E,PC,ZC,PE,PF)
      IF(MTL.NE.0) CALL PSTL
     +(A,O,PA,PO,TT,TX,TV,TH,PM,X,Y,PW,IT.IT,E,PC,ZC,PE,PE,PF)
      IF(MTT.NE.0) CALL PST
     +(A,O,PA,PO,TT,TX,TV,TH,PM,MR,PF)
      IF(MCI.NE.0) CALL PSCI
     +(A,O,PA,PO,TT,TX,TV,TH,PM,E,PC,ZC,IT,MR,PE,PF)
      IF(MTL.NE.0) CALL PSTL
     +(A,O,PA,PO,TT,TX,TV,TH,PM,X,Y,PW,C,V,E,PC,ZC,PE,PX,PF)
      IF(MFT.NE.0) CALL PSFT
     +(A,O,PA,PO,TT,TX,TV,TH,PM,X,Y,PW,K,C,U,V,PX,PF,PT)
C
      RETURN
      END
C#######################################################################
C     PROGRAM SEQUENCES
C#######################################################################
      SUBROUTINE PSIO
C
C     INPUT/OUTPUT
C
      INTEGER CR,LP,PQ
      INTEGER RLS,RCO,RTT,RCI,RTL,RFT
      INTEGER WLS,WCO,WTT,WCI,WTL,WFT
      REAL    MIN,MAX
      COMPLEX ZLM,ZLP
C
      COMMON/A10/CR,LP,PQ
      COMMON/B11/IMX,EMX
      COMMON/B12/ML,RL,SL
      COMMON/B13/MIN,MAX,MP
      COMMON/B14/NDX,MDX,MXX
      COMMON/B15/NQ,NI
      COMMON/B20/MN,NM
      COMMON/B21/MLS,MCO,MTT,MCI,MTL,MFT
      COMMON/B22/RLS,RCO,RTT,RCI,RTL,RFT
      COMMON/B23/WLS,WCO,WTT,WCI,WTL,WFT
      COMMON/B27/MR
      COMMON/B30/MPX
      COMMON/C11/TM,WM
      COMMON/C12/NK,NC
      COMMON/C20/PGPS,PGRX,PGRS
      COMMON/C21/PSPS,DCPS,DKPS,MPS,NPS
      COMMON/C22/PSRX,DCRX,DKRX,MRX,NRX
      COMMON/C23/PSRS,DCRS,DKRS,MRS,NRS
      COMMON/C24/TSPS,TRPS,TDPS,TPPS,TCPS
      COMMON/C25/TSRX,TRRX,TDRX,TPRX,TCRX
      COMMON/C26/TSRS,TRRS,TDRS,TPRS,TCRS
      COMMON/D10/SI,SF,NS
      COMMON/D11/XI,XF,NX
      COMMON/D12/YI,YF,NY
      COMMON/D13/WI,WF,NW
      COMMON/D14/TI,TF,NT
      COMMON/D15/MS,MX,MY,MW,MT
      COMMON/D16/IEI,IEF,NEI
```

```
      COMMON/D17/IXI,IXF,NXI
      COMMON/D18/IYI,IYF,NYI
      COMMON/D19/IWI,IWF,NWI
      COMMON/D20/ITI,ITF,NTI
      COMMON/E11/RW
      COMMON/E12/RSM,RSP
      COMMON/E13/RAM,RAP
      COMMON/E14/RS
      COMMON/E15/DO,SO
      COMMON/F11/URE,ERE,UE,EE,OE
      COMMON/F12/URI,ERI,UI.EI.OI
      COMMON/F13/URA,ERA,UA.EA,OA
      COMMON/F14/UR2,ER2,U2.E2,O2
      COMMON/F15/URS,ERS,US.ES,OS
      COMMON/F16/UR1,ER1,U1.E1,O1
      COMMON/F17/URW.ERW,UW.EW,OW
      COMMON/G11/ZLM.ZLP
C
    1 FORMAT(10I10)
    2 FORMAT(10G10.0)
    3 FORMAT(I10,10G10.0)
    4 FORMAT(2G10.0,10I10)
    5 FORMAT(3G10.0,10I10)
   10 FORMAT("1","INPUT/OUTPUT")
   11 FORMAT("0","MAXIMUM ITERATION    ",  I20    /
     +         " ","MAXIMUM ERROR        ",1PG20.10)
   12 FORMAT("0","LOG MODE             ",  I20    /
     +         " ","LOG RATIO            ".1PG20.10/
     +         " ","LOG SCALE            ".1PG20.10)
   13 FORMAT("0","PLOT MINIMUM         ",1PG20.10/
     +         " ","PLOT MAXIMUM         ".1PG20.10/
     +         " ","PLOT MODE            ",  I20    )
   14 FORMAT("0","POLYNOMIAL DEGREE    ",  I20    /
     +         " ","CALCULATE DERIVATIVE",  I20    /
     +         " ","TABLE  ORDER         ",  I20    )
   15 FORMAT("0","QUADRATURE  GRID     ",  I20    /
     +         " ","INTEGRATION GRID     ",  I20    )
   16 FORMAT(" ","TITLE NUMBER         ",  I20    )
   21 FORMAT("0","MODE  STROKE         ",  I20    /
     +         " ","MODE  COUPLE (OUTER)",  I20    /
     +         " ","MODE  TRANSFER       ",  I20    /
     +         " ","MODE  COUPLE (INNER)",  I20    /
     +         " ","MODE  TRANSMISSION  ",  I20    /
     +         " ","MODE  INVERSE        ",  I20    )
   22 FORMAT("0","READ  STROKE         ",  I20    /
     +         " ","READ  COUPLE (OUTER)",  I20    /
     +         " ","READ  TRANSFER       ",  I20    /
     +         " ","READ  COUPLE (INNER)",  I20    /
     +         " ","READ  TRANSMISSION  ",  I20    /
     +         " ","READ  INVERSE        ",  I20    )
   23 FORMAT("0","WRITE STROKE         ",  I20    /
     +         " ","WRITE COUPLE (OUTER)",  I20    /
     +         " ","WRITE TRANSFER       ",  I20    /
     +         " ","WRITE COUPLE (INNER)",  I20    /
     +         " ","WRITE TRANSMISSION  ",  I20    /
     +         " ","WRITE INVERSE        ",  I20    )
   27 FORMAT("0","MODE ROOT            ",  I20    )
   30 FORMAT(" ","MODE PLOT            ",  I20    )
   31 FORMAT("0","MULTIPLIER           ",1PG20.10,1X,"TIME      DOMAIN"/
     +         " ","MULTIPLIER           ",1PG20.10,1X,"FREQUENCY DOMAIN")
   32 FORMAT("0","NUMBER OF PULSES     ",  I20    ,1X,"TIME      DOMAIN"/
     +         " ","NUMBER OF PULSES     ",  I20    ,1X,"FREQUENCY DOMAIN")
   40 FORMAT("0","PULSE GUESS    PRESTRIKE        ",1PG20.10/
     +         " ","PULSE GUESS    RETURN           ",1PG20.10/
```

```
 +         " ","PULSE GUESS     RESTRIKE        ",1PG20.10)
41 FORMAT("0","PULSE PEAK      PRESTRIKE       ",1PG20.10/
 +         " ","DECAY CONSTANT PRESTRIKE       ",1PG20.10/
 +         " ","DECAY CONSTANT PRESTRIKE       ",1PG20.10/
 +         " ","MODE DECAY     PRESTRIKE       ",   I20    /
 +         " ","MODE NUMBER    PRESTRIKE       ",   I20    )
42 FORMAT("0","PULSE PEAK      RETURN          ",1PG20.10/
 +         " ","DECAY CONSTANT RETURN          ",1PG20.10/
 +         " ","DECAY CONSTANT RETURN          ",1PG20.10/
 +         " ","MODE DECAY     RETURN          ",   I20    /
 +         " ","MODE NUMBER    RETURN          ",   I20    )
43 FORMAT("0","PULSE PEAK      RESTRIKE        ",1PG20.10/
 +         " ","DECAY CONSTANT RESTRIKE        ",1PG20.10/
 +         " ","DECAY CONSTANT RESTRIKE        ",1PG20.10/
 +         " ","MODE DECAY     RESTRIKE        ",   I20    /
 +         " ","MODE NUMBER    RESTRIKE        ",   I20    )
44 FORMAT("0","TIME START      PRESTRIKE       ",1PG20.10/
 +         " ","TIME RISE      PRESTRIKE       ",1PG20.10/
 +         " ","TIME DECAY     PRESTRIKE       ",1PG20.10/
 +         " ","TIME PULSE     PRESTRIKE       ",1PG20.10/
 +         " ","TIME CONSTANT  PRESTRIKE       ",1PG20.10)
45 FORMAT("0","TIME START      RETURN          ",1PG20.10/
 +         " ","TIME RISE      RETURN          ",1PG20.10/
 +         " ","TIME DECAY     RETURN          ",1PG20.10/
 +         " ","TIME PULSE     RETURN          ",1PG20.10/
 +         " ","TIME CONSTANT  RETURN          ",1PG20.10)
46 FORMAT("0","TIME START      RESTRIKE        ",1PG20.10/
 +         " ","TIME RISE      RESTRIKE        ",1PG20.10/
 +         " ","TIME DECAY     RESTRIKE        ",1PG20.10/
 +         " ","TIME PULSE     RESTRIKE        ",1PG20.10/
 +         " ","TIME CONSTANT  RESTRIKE        ",1PG20.10)
50 FORMAT("0","INITIAL EXCITATION  ",1PG20.10/
 +         " ","FINAL   EXCITATION  ",1PG20.10/
 +         " ","NUMBER OF BANDS     ",   I20    )
51 FORMAT("0","INITIAL POSITION    ",1PG20.10/
 +         " ","FINAL   POSITION    ",1PG20.10/
 +         " ","NUMBER OF BANDS     ",   I20    )
52 FORMAT("0","INITIAL FREQUENCY   ",1PG20.10/
 +         " ","FINAL   FREQUENCY   ",1PG20.10/
 +         " ","NUMBER OF BANDS     ",   I20    )
53 FORMAT("0","INITIAL TIME        ",1PG20.10/
 +         " ","FINAL   TIME        ",1PG20.10/
 +         " ","NUMBER OF BANDS     ",   I20    )
54 FORMAT("0","MODE EXCITATION     ",   I20    /
 +         " ","MODE POSITION       ",   I20    /
 +         " ","MODE POSITION       ",   I20    /
 +         " ","MODE FREQUENCY      ",   I20    /
 +         " ","MODE TIME           ",   I20    )
55 FORMAT("0","INITIAL EXCITATION  ",   I20    /
 +         " ","FINAL   EXCITATION  ",   I20    /
 +         " ","NUMBER OF SAMPLES   ",   I20    )
56 FORMAT("0","INITIAL POSITION    ",   I20    /
 +         " ","FINAL   POSITION    ",   I20    /
 +         " ","NUMBER OF SAMPLES   ",   I20    )
57 FORMAT("0","INITIAL FREQUENCY   ",   I20    /
 +         " ","FINAL   FREQUENCY   ",   I20    /
 +         " ","NUMBER OF SAMPLES   ",   I20    )
58 FORMAT("0","INITIAL TIME        ",   I20    /
 +         " ","FINAL   TIME        ",   I20    /
 +         " ","NUMBER OF SAMPLES   ",   I20    )
61 FORMAT("0","RADIUS WIRE         ",1PG20.10)
62 FORMAT(" ","RADIUS SHIELD MINUS ",1PG20.10/
 +         " ","RADIUS SHIELD PLUS  ",1PG20.10)
63 FORMAT(" ","RADIUS ARMOR  MINUS ",1PG20.10/
```

```
     +        " ","RADIUS ARMOR  PLUS    ",1PG20.10)
   64 FORMAT(" ","RADIUS SHEATH          ",1PG20.10)
   65 FORMAT("0","DEPTH                  ",1PG20.10/
     +        " ","SEPARATION             ",1PG20.10)
   71 FORMAT("0","RELATIVE PERMEABILITY EARTH    ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY EARTH    ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY EARTH    ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY EARTH    ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY EARTH    ",1PG20.10)
   72 FORMAT("0","RELATIVE PERMEABILITY SHEATH   ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY SHEATH   ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY SHEATH   ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY SHEATH   ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY SHEATH   ",1PG20.10)
   73 FORMAT("0","RELATIVE PERMEABILITY ARMOR    ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY ARMOR    ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY ARMOR    ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY ARMOR    ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY ARMOR    ",1PG20.10)
   74 FORMAT("0","RELATIVE PERMEABILITY 2        ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY 2        ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY 2        ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY 2        ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY 2        ",1PG20.10)
   75 FORMAT("0","RELATIVE PERMEABILITY SHIELD   ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY SHIELD   ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY SHIELD   ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY SHIELD   ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY SHIELD   ",1PG20.10)
   76 FORMAT("0","RELATIVE PERMEABILITY 1        ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY 1        ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY 1        ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY 1        ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY 1        ",1PG20.10)
   77 FORMAT("0","RELATIVE PERMEABILITY WIRE     ",1PG20.10/
     +        " ","RELATIVE PERMITTIVITY WIRE     ",1PG20.10/
     +        " ","ABSOLUTE PERMEABILITY WIRE     ",1PG20.10/
     +        " ","ABSOLUTE PERMITTIVITY WIRE     ",1PG20.10/
     +        " ","ABSOLUTE CONDUCTIVITY WIRE     ",1PG20.10)
   81 FORMAT("0","LOAD IMPEDANCE MINUS",2(1PG20.10)/
     +        " ","LOAD IMPEDANCE PLUS ",2(1PG20.10))
C
      READ(CR, 3) IMX,EMX
      READ(CR, 3) ML,RL,SL
      READ(CR, 4) MIN,MAX,MP
      READ(CR, 1) NDX,MCX,MXX
      READ(CR, 1) NO,NI
      READ(CR, 1) MN,NM
      READ(CR, 1) MLS,MCO,MTT,MCI,MTL,MFT
      READ(CR, 1) RLS,RCO,RTT,RCI,RTL,RFT
      READ(CR, 1) WLS,WCO,WTT,WCI,WTL,WFT
      READ(CR, 1) MR
      READ(CR, 1) MFX
      READ(CR, 2) TM,WM
      READ(CR, 1) NK,NC
      READ(CR, 2) PGPS,PGRX,PGRS
      READ(CR, 5) PSPS,DCPS,DKPS,MPS,NPS
      READ(CR, 5) PSRX,DCRX,DKRX,MRX,NRX
      READ(CR, 5) PSRS,DCRS,DKRS,MRS,NRS
      READ(CR, 2) TSPS,TRPS,TDPS,TPPS,TCPS
      READ(CR, 2) TSRX,TRRX,TDRX,TPRX,TCRX
      READ(CR, 2) TSRS,TRRS,TDRS,TPRS,TCRS
      READ(CR, 4) SI,SF,NS
      READ(CR, 4) XI,XF,NX
```

```
      READ(CR, 4) YI,YF,NY
      READ(CR, 4) WI,WF,NW
      READ(CR, 4) TI,TF,NT
      READ(CR, 1) MS,MX,MY,MW,MT
      READ(CR, 1) IEI,IEF,NEI
      READ(CR, 1) IXI,IXF,NXI
      READ(CR, 1) IYI,IYF,NYI
      READ(CR, 1) IWI,IWF,NWI
      READ(CR, 1) ITI,ITF,NTI
      READ(CR, 2) RW
      READ(CR, 2) RSM,RSP
      READ(CR, 2) RAM,RAP
      READ(CR, 2) RS
      READ(CR, 2) DO
      READ(CR, 2) SO
      READ(CR, 2) URE,ERE.OE
      READ(CR, 2) URI,ERI.OI
      READ(CR, 2) UPA,ERA.OA
      READ(CR, 2) UR2,ER2,O2
      READ(CR, 2) URS.ERS.OS
      READ(CR, 2) UR1,ER1,O1
      READ(CR, 2) UPW,ERW.OW
      READ(CR, 2) ZLM
      READ(CR, 2) ZLP
C
      CALL SRC
C
      READ(CR, 1) MIO $IF(MIO.EQ.0) RETURN
C
      WRITE(LP,10)
      WRITE(LP,11) IMX,EMX
      WRITE(LP,12) ML,RL,SL
      WRITE(LP,13) MIN,MAX,MP
      WRITE(LP,14) NDX,MDX,MXX
      WRITE(LP,15) NQ,NI
      WRITE(LP,16) MN
      WRITE(LP,16) NM
      WRITE(LP,21) MLS,MCO,MTT,MCI.MTL.MFT
      WRITE(LP,22) RLS,RCO,RTT,RCI,RTL,RFT
      WRITE(LP,23) WLS,WCO,WTT,WCI,WTL,WFT
      WRITE(LP,27) MR
      WRITE(LP,30) MPX
      WRITE(LP,31) TM,WM
      WRITE(LP,32) NK,NC
      WRITE(LP,40) PGPS,PGRX.PGRS
      WRITE(LP,41) PSPS,DCPS,DKPS,MPS.NPS
      WRITE(LP,42) PSRX.DCRX,DKRX,MRX.NPX
      WRITE(LP,43) PSRS.DCRS.DKRS,MRS,NRS
      WRITE(LP,44) TSPS,TRPS,TDPS.TPPS,TCPS
      WRITE(LP,45) TSRX,TRRX,TDRX.TPRX,TCRX
      WRITE(LP,46) TSRS,TRRS,TDRS.TPRS,TCRS
      WRITE(LP,50) SI,SF,NS
      WRITE(LP,51) XI,XF,NX
      WRITE(LP,51) YI,YF,NY
      WRITE(LP,52) WI,WF,NW
      WRITE(LP,53) TI,TF,NT
      WRITE(LP,54) MS,MX,MY,MW,MT
      WRITE(LP,55) IEI,IEF,NEI
      WRITE(LP,56) IXI.IXF,NXI
      WRITE(LP,56) IYI,IYF,NYI
      WRITE(LP,57) IWI,IWF,NWI
      WRITE(LP,58) ITI,ITF,NTI
      WRITE(LP,61) RW
      WRITE(LP,62) RSM,RSP
```

```
      WRITE(LP,63) RAM,RAP
      WRITE(LP,64) RS
      WRITE(LP,65) DO,SO
      WRITE(LP,71) URE,ERE,UE,EE,OE
      WRITE(LP,72) URI,ERI,UI,EI,OI
      WRITE(LP,73) URA,ERA,UA,EA,OA
      WRITE(LP,74) UR2,ER2,U2,E2,O2
      WRITE(LP,75) URS,ERS,US,ES,OS
      WRITE(LP,76) UR1,ER1,U1,E1,O1
      WRITE(LP,77) URW,ERW,UW,EW,OW
      WRITE(LP,81) ZLM,ZLP
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE PSLS(A,O,PA,PO,TT,TX,TV,TH,PM,P,Q,PS)
C
C     LIGHTNING STROKE
C
      INTEGER PS
      INTEGER PA,PO
      INTEGER PM
      INTEGER CR,LP,PQ
      INTEGER TT,TX,TV,TH
      COMPLEX P,Q
C
      DIMENSION P(PS),Q(PS)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
C
      COMMON/A10/CR,LP,PQ
      COMMON/C11/TM,WM
      COMMON/C12/NK,NC
      COMMON/D15/ME,MX,MY,MW,MT
C
   10 FORMAT("1","LIGHTNING STOKE")
C
      DATA N1/1/
      DATA TO,WO/0.0,1.0/
C
      WRITE(LP,10) $CALL SRSC $CALL SRLS(P,Q,PS)
C
      CALL TPGX(A,O,PA,PO,TT,TX,TV,TH,PM,P,PS,TO,TM,NK,MT,N1,NK,N1)
      CALL TPGX(A,O,PA,PO,TT,TX,TV,TH,PM,Q,PS,WO,WM,NC,MW,N1,NC,N1)
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE PSCO(A,O,PA,PO,TT,TX,TV,TH,PM,E,PC,ZC,PE,PF)
C
C     COUPLING
C
      INTEGER PE,PF
      INTEGER PA,PO
      INTEGER PM
      INTEGER CR,LP,PQ
      INTEGER DCOE,DCIE
      INTEGER RLS,RCO,RTT,RCI,RTL,RFT
      INTEGER WLS,WCO,WTT,WCI,WTL,WFT
      INTEGER TT,TX,TV,TH
      COMPLEX E
      COMPLEX PC,ZC
C
      DIMENSION E(PE,PF)
```

```
      DIMENSION PC(PF),ZC(PF)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
C
      COMMON/A10/CR,LP,PQ
      COMMON/A12/DCOE,DCIE
      COMMON/B22/RLS,RCO,RTT,RCI,RTL,RFT
      COMMON/B23/WLS,WCO,WTT,WCI,WTL,WFT
      COMMON/B31/MM
      COMMON/D10/EI,EF,NE
      COMMON/D13/WI,WF,NW
      COMMON/D15/ME,MX,MY,MW,MT
      COMMON/D16/IEI,IEF,NEI
      COMMON/D19/IWI,IWF,NWI
C
   11 FORMAT("1","PROPAGATION PARAMETERS")
   12 FORMAT("1","COUPLING (OUTER)")
C
      MM=1
C
      WRITE(LP,11) $CALL SRS(E,PC,ZC,PE,PF)
      WRITE(LP,12)
      CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,E,PE,PF,
     + EI,EF,NE,ME,IEI,IEF,NEI,WI,WF,NW,MW,IWI,IWF,NWI)
C
      IF(WCO.NE.0) CALL FTCW(DCOE,E,PE,PF)
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE PST(A,O,PA,PO,TT,TX,TV,TH,PM,MR,PF)
C
C     TRANSFER (OUTER/INNER)
C
      INTEGER PF
      INTEGER PA,PO
      INTEGER PM
      INTEGER CR,LP,PQ
      INTEGER TT,TX,TV,TH
      COMPLEX MR
C
      DIMENSION MR(PF)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
C
      COMMON/A10/CR,LP,PQ
      COMMON/D13/WI,WF,NW
      COMMON/D15/ME,MX,MY,MW,MT
C
   10 FORMAT("1","TRANSFER (OUTER/INNER)")
C
      DATA N1/1/
C
      WRITE(LP,10) $CALL SRT(MR,PF)
C
      CALL TPGX(A,O,PA,PO,TT,TX,TV,TH,PM,MR,PF,WI,WF,NW,MW,N1,NW,N1)
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE PSCI(A,O,PA,PO,TT,TX,TV,TH,PM,E,PC,ZC,IT,MR,PE,PF)
C
C     COUPLING
```

```
C
      INTEGER PE,PF
      INTEGER PA,PO
      INTEGER PM
      INTEGER CR,LP,PQ
      INTEGER DCOE,DCIE
      INTEGER RLS,RCO,RTT,RCI,RTL,RFT
      INTEGER WLS,WCO,WTT,WCI,WTL,WFT
      INTEGER TT,TX,TV,TH
      COMPLEX E,IT
      COMPLEX PC,ZC
      COMPLEX MR
C
      DIMENSION E(PE,PF),IT(PE,PF)
      DIMENSION PC(PF),ZC(PF)
      DIMENSION MR(PF)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
C
      COMMON/A10/CR,LP,PQ
      COMMON/A12/DCOE,DCIE
      COMMON/B22/RLS,RCO,RTT,RCI,RTL,RFT
      COMMON/B23/WLS,WCO,WTT,WCI,WTL,WFT
      COMMON/B31/MM
      COMMON/D11/XI,XF,NX
      COMMON/D13/WI,WF.NW
      COMMON/D15/ME,MX,MY,MW,MT
      COMMON/D17/IXI,IXF,NXI
      COMMON/D19/IWI,IWF,NWI
C
   11 FORMAT("1","PROPAGATION PARAMETERS")
   12 FORMAT("1","COUPLING (INNER)")
C
      MM=0
C
      WRITE(LP,11) $CALL SRCC(E,PC,ZC,IT,MR,PE,PX,PF)
      WRITE(LP,12)
      CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,E,PE,PF,
     + XI,XF,NX,MX,IXI,IXF,NXI,WI,WF,NW,MW,IWI,IWF,NWI)
C
      IF(WCI.NE.0) CALL FTDW(DCIE,E,PE,PF)
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE PSTL
     +(A,O,PA,PO,TT,TX,TV,TH,PM,X,Y,PW,C.V,E,PC,ZC,PE,PX,PF)
C
C     TRANSMISSION LINE
C
      INTEGER PE,PX,PF
      INTEGER PA,PO
      INTEGER PM
      INTEGER PW
      INTEGER CR,LP,PQ
      INTEGER DCOE,DCIE
      INTEGER DCOC,DCOV
      INTEGER DCIC,DCIV
      INTEGER RLS,RCO,RTT,RCI,RTL,RFT
      INTEGER WLS,WCO,WTT,WCI,WTL,WFT
      INTEGER TT,TX,TV,TH
      COMPLEX C.V
      COMPLEX E
```

```
      COMPLEX PC,ZC
      COMPLEX Y
C
      DIMENSION C(PX,PF),V(PX,PF)
      DIMENSION E(PE,PF)
      DIMENSION PC(PF),ZC(PF)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
      DIMENSION X(PW),Y(PW)
C
      COMMON/A10/CR,LP,PQ
      COMMON/A12/DCOE,DCIE
      COMMON/A13/DCOC,DCOV
      COMMON/A14/DCIC,DCIV
      COMMON/B22/RLS,RCO,RTT,RCI,RTL,RFT
      COMMON/B23/WLS,WCO,WTT,WCI,WTL,WFT
      COMMON/B31/MM
      COMMON/D11/XI,XF,NX
      COMMON/D12/YI,YF,NY
      COMMON/D13/WI,WF,NW
      COMMON/D15/ME,MX,MY,MW,MT
      COMMON/D17/IXI,IXF,NXI
      COMMON/D18/IYI,IYF,NYI
      COMMON/D19/IWI,IWF,NWI
C
   10 FORMAT("1","TRANSMISSION LINE")
C
      IF((RTL.NE.0).AND.(MM.EQ.1)) CALL FTDR(DCOE,E,PE,PF)
      IF((RTL.NE.0).AND.(MM.EQ.0)) CALL FTDR(DCIE,E,PE,PF)
C
      WRITE(LP,10) $CALL SRTL(X,Y,PW,C,V,E,PC,ZC,PE,PX,PF)
C
      IF(MM.EQ.1) CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,C,PX,PF,
     + XI,XF,NX,MX,IXI,IXF,NXI,WI,WF,NW,MW,IWI,IWF,NWI)
      IF(MM.EQ.0) CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,C,PX,PF,
     + YI,YF,NY,MY,IYI,IYF,NYI,WI,WF,NW,MW,IWI,IWF,NWI)
      IF(MM.EQ.0) CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,V,PX,PF,
     + YI,YF,NY,MY,IYI,IYF,NYI,WI,WF,NW,MW,IWI,IWF,NWI)
C
      IF((WTL.NE.0).AND.(MM.EQ.1)) CALL FTDW(DCOC,C,PX,PF)
      IF((WTL.NE.0).AND.(MM.EQ.0)) CALL FTDW(DCIC,C,PX,PF)
      IF((WTL.NE.0).AND.(MM.EQ.0)) CALL FTDW(DCIV,V,PX,PF)
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE PSFT
     +(A,O,PA,PO,TT,TX,TV,TH,PM,X,Y,PW,K,C,U,V,PX,PF,PT)
C
C     FOURIER TRANSFORM
C
      INTEGER PX,PF,PT
      INTEGER PA,PO
      INTEGER PM
      INTEGER PW
      INTEGER CR,LP,PQ
      INTEGER DCIC,DCIV
      INTEGER DFTK,DFTU
      INTEGER RLS,RCO,RTT,RCI,RTL,RFT
      INTEGER WLS,WCO,WTT,WCI,WTL,WFT
      INTEGER TT,TX,TV,TH
```

```
      COMPLEX K,C
      COMPLEX U,V
      COMPLEX Y
C
      DIMENSION K(PX,PT),C(PX,PF)
      DIMENSION U(PX,PT),V(PX,PF)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
      DIMENSION X(PW),Y(PW)
C
      COMMON/A10/CR,LP,PQ
      COMMON/A14/DCIC,DCIV
      COMMON/A15/DFTK,DFTU
      COMMON/B22/RLS,RCO,RTT,RCI,RTL,RFT
      COMMON/B23/WLS,WCO,WTT,WCI,WTL,WFT
      COMMON/D12/YI,YF,NY
      COMMON/D14/TI,TF,NT
      COMMON/D15/ME,MX,MY,MW,MT
      COMMON/D18/IYI,IYF,NYI
      COMMON/D20/ITI,ITF,NTI
C
   10 FORMAT("1","IFT")
C
      IF(RFT.NE.0) CALL FTOR(DCIC,C,PX,PF)
      IF(RFT.NE.0) CALL FTOR(DCIV,V,PX,PF)
C
      WRITE(LP,10)
      CALL SRCFT(X,Y,PW,K,C,U,V,PX,PF,PT)
C
      CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,K,PX,PT,
     + YI,YF,NY,MY,IYI,IYF,NYI,TI,TF,NT,MT,ITI,ITF,NTI)
      CALL TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,U,PX,PT,
     + YI,YF,NY,MY,IYI,IYF,NYI,TI,TF,NT,MT,ITI,ITF,NTI)
C
      IF(WFT.NE.0) CALL FTOW(DFTK,K,PX,PT)
      IF(WFT.NE.0) CALL FTOW(DFTU,U,PX,PT)
C
      RETURN
      END
C#####################################################################
C     SUBROUTINES
C#####################################################################
      SUBROUTINE SRC
C
C     CONSTANTS
C
      COMMON/F11/URE,ERE,UE,EE,OE
      COMMON/F12/URI,ERI,UI,EI,OI
      COMMON/F13/URA,ERA,UA,EA,OA
      COMMON/F14/UR2,ER2,U2,E2,O2
      COMMON/F15/URS,ERS,US,ES,OS
      COMMON/F16/UR1,ER1,U1,E1,O1
      COMMON/F17/URW,ERW,UW,EW,OW
C
      UE=UF(URE) $EE=EF(ERE)
      UI=UF(URI) $EI=EF(ERI)
      UA=UF(URA) $EA=EF(ERA)
      U2=UF(UR2) $E2=EF(ER2)
      US=UF(URS) $ES=EF(ERS)
      U1=UF(UR1) $E1=EF(ER1)
      UW=UF(URW) $EW=EF(ERW)
C
```

```
      RETURN
      END
C*********************************************************************
      SUBROUTINE SRSC
C
C     CONSTANTS
C
      INTEGER CR,LP,PQ
C
      COMMON/A10/CR,LP,PQ
      COMMON/C15/APS,BPS,CPS
      COMMON/C16/ARX,BRX,CRX
      COMMON/C17/ARS,BRS,CRS
      COMMON/C20/PGPS,PGRX.PGRS
      COMMON/C21/PSPS,DCPS,DKPS,MPS,NPS
      COMMON/C22/PSRX,DCRX,DKRX,MRX.NRX
      COMMON/C23/PSRS,DCRS.DKRS,MRS,NRS
      COMMON/C24/TSPS,TRPS,TDPS,TPPS,TCPS
      COMMON/C25/TSRX,TRRX,TDRX,TPRX,TCRX
      COMMON/C26/TSRS,TRRS.TDRS,TPRS.TCRS
C
    1 FORMAT(10I10)
   11 FORMAT("0","ALPHA              PRESTRIKE          ",1PG20.10/
     +       " ","BETA               PRESTRIKE          ",1PG20.10/
     +       " ","GAMMA              PRESTRIKE          ",1PG20.10/
     +       "0","PULSE PEAK         PRESTRIKE          ",1PG20.10/
     +       " ","PULSE MAXIMUM      PRESTRIKE          ",1PG20.10/
     +       "0","PULSE GUESS        PRESTRIKE          ",1PG20.10)
   12 FORMAT("0","ALPHA              RETURN             ",1PG20.10/
     +       " ","BETA               RETURN             ",1PG20.10/
     +       " ","GAMMA              RETURN             ",1PG20.10/
     +       "0","PULSE PEAK         RETURN             ",1PG20.10/
     +       " ","PULSE MAXIMUM      RETURN             ",1PG20.10/
     +       "0","PULSE GUESS        RETURN             ",1PG20.10)
   13 FORMAT("0","ALPHA              RESTRIKE           ",1PG20.10/
     +       " ","BETA               RESTRIKE           ",1PG20.10/
     +       " ","GAMMA              RESTRIKE           ",1PG20.10/
     +       "0","PULSE PEAK         RESTRIKE           ",1PG20.10/
     +       " ","PULSE MAXIMUM      RESTRIKE           ",1PG20.10/
     +       "0","PULSE GUESS        RESTRIKE           ",1PG20.10)
C
      IF(NPS.NE.0) CALL SRCS
     +(TRPS,TDPS,TPPS,TCPS,DCPS,DKPS,MPS,PSPS,PMPS,PGPS,APS,BPS,CPS)
      IF(NRX.NE.0) CALL SRCS
     +(TRRX,TDRX,TPRX,TCRX.DCRX,DKRX,MRX,PSRX,PMRX,PGRX,ARX,BRX,CRX)
      IF(NRS.NE.0) CALL SRCS
     +(TRRS,TDRS,TPRS,TCRS,DCRS,DKRS,MRS,PSRS,PMRS,PGRS,ARS,BRS,CRS)
C
      READ(CR, 1) MLC $IF(MLC.EQ.0) RETURN
C
      IF(NPS.NE.0) WRITE(LP,11) APS,BPS,CPS,PSPS,PMPS,PGPS
      IF(NRX.NE.0) WRITE(LP,12) ARX,BRX,CRX,PSRX,PMRX,PGRX
      IF(NRS.NE.0) WRITE(LP,13) ARS,BRS.CRS,PSRS,PMRS,PGRS
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE SRCS(TR,TD,TP,TC,DC,DK,ME,CO,CC,CG,A,B,C)
C
C     CONSTANTS
C
      DOUBLE PRECISION AT,EMAT
      DOUBLE PRECISION BT,EMBT
C
```

```
      REAL     NRF
C
      COMMON/C13/TSX,TRX,TDX,TPX,TCX
      COMMON/C14/A0,B0,X0
C
      EXTERNAL COF
      EXTERNAL CODF
C
      TRX=TR $TDX=TD $T=TD-TR
C
      A0=-ALOG(DC)/T  $A=A0
      B0=A0*CG        $B=NRF(B0,COF,CODF)
      C=0 $IF(ME.NE.0) C=-ALOG(DK)/TC
C
      AT=A*TR $EMAT=DEXP(-AT)
      BT=B*TR $EMBT=DEXP(-BT)
C
      CC=C0*(EMAT-EMBT)
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRLS(P,Q,PS)
C
C     PULSE
C
      INTEGER PS
      COMPLEX P,Q
C
      DIMENSION P(PS),Q(PS)
C
      CALL SRLK(P,PS)
      CALL SRLC(Q,PS)
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRLK(K,PS)
C
C     PULSE
C
      INTEGER PS
      REAL     KF
      COMPLEX K
C
      DIMENSION K(PS)
C
      COMMON/C11/TM,WM
      COMMON/C12/NK,NC
      COMMON/C15/ME,MX,MY,MW,MS
C
      TI=0 $TF=TM $NT=NK $MT=MS
C
      DO 100 IT=1,NT,1
      T=AF(TI,TF,NT,IT,MT) $K(IT)=KF(T)
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRLC(C,PS)
C
C     PULSE
C
```

```
      INTEGER PS
      COMPLEX C,CF
C
      DIMENSION C(PS)
C
      COMMON/C11/TM,WM
      COMMON/C12/NK,NC
      COMMON/D15/MS,MX,MY,MF,MT
C
      WI=0 $WF=WM $NW=NC $MW=MF
C
      DO 100 IW=1,NW,1
      W=AF(WI,WF,NW,IW,MW) $C(IW)=CF(W)
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRS(E,PC,ZC,PE,PF)
C
C     STROKE
C
      INTEGER PE,PF
      COMPLEX E
      COMPLEX PC,ZC
      COMPLEX DF
C
      DIMENSION E(PE,PF)
      DIMENSION PC(PF),ZC(PF)
C
      COMMON/D10/SI,SF,NS
      COMMON/D11/XI,XF,NX
      COMMON/D13/WI,WF,NW
      COMMON/D15/MS,MX,MY,MW,MT
      COMMON/D22/UI,UF,NU,MU
      COMMON/D23/VI,VF,NV,MV
      COMMON/D24/ZI,ZF,NZ,MZ
C
      UI=XI $VI=SI $ZI=WI
      UF=XF $VF=SF $ZF=WF
      NU=NX $NV=NS $NZ=NW
      MU=MX $MV=MS $MZ=MW
C
      DO 100 IW=1,NW,1
      W=AF(WI,WF,NW,IW,MW)
      CALL SRY(W,PC(IW),ZC(IW))
      DO 100 IS=1,NS,1
      S=AF(SI,SF,NS,IS,MS)
      E(IS,IW)=DF(S,W)
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRY(W,PC,ZC)
C
C     PROPAGATION CONSTANT/CHARACTERISTIC IMPEDANCE
C
C     PARAMETER PR=10
C
      INTEGER PR
      INTEGER CR,LP,PO
      COMPLEX WN,WNF
      COMPLEX WI,WIF
```

```
      COMPLEX PKG,ZKG
      COMPLEX RTS
      COMPLEX TPC
      COMPLEX ZX,ZL,ZT
      COMPLEX YS,ZS
      COMPLEX KI,KIF
      COMPLEX KC,KCF
      COMPLEX PC,ZC
      COMPLEX DR
      LOGICAL TEST
C
      DIMENSION RTS(10)
C
      COMMON/A10/CR,LP,PQ
      COMMON/B11/IMX,EMX
      COMMON/B27/MR
      COMMON/B30/MX
      COMMON/D21/XX,WX
      COMMON/E13/RAM,RAP
      COMMON/E14/RS
      COMMON/F11/URE,ERE,UE,EE,OE
      COMMON/H11/KC,KI
C
      EXTERNAL PKF
C
      DATA PR/10/
      DATA R2/1.41421356/
      DATA NPR/0/
      DATA NR /1/
      DATA TEST/.FALSE./
      DATA ES/1.0/
C
   10 FORMAT("0","FREQUENCY                   ",  1PG20.10 )
   11 FORMAT("0","FREQUENCY                   ",  1PG20.10 /
     +        " ","WAVE NUMBER                 ",2(1PG20.10)/
     +        " ","WAVE IMPEDANCE              ",2(1PG20.10)/
     +        " ","PROPAGATION CONSTANT        ",2(1PG20.10)/
     +        " ","PROPAGATION IMPEDANCE       ",2(1PG20.10)/
     +        " ","PROPAGATION CONSTANT        ",2(1PG20.10)/
     +        " ","ADMITTIVITY                 ",2(1PG20.10)/
     +        " ","IMPEDIVITY                  ",2(1PG20.10)/
     +        " ","CHARACTERISTIC CONSTANT     ",2(1PG20.10)/
     +        " ","CHARACTERISTIC IMPEDANCE    ",2(1PG20.10))
   12 FORMAT(" ","PROPAGATION   CONSTANT       ",2(1PG20.10))
   13 FORMAT(" ","CHARACTERISTC IMPEDANCE      ",2(1PG20.10))
C
      UC=UE $EC=EE $OC=OE
C
      WN=WNF(W,UC,EC,OC) $PKG=WN/R2
      WI=WIF(W,UC,EC,OC) $ZKG=WI
C
      IF(MR.EQ.0) GO TO 100 $IF(W.EQ.0) GO TO 100
C
      WX=W
      RTS(1)=0
      CALL SRM(NPR,NR,RTS,IMX,EMX,EMX,PKF,TEST)
      TPC=RTS(1)
      CALL SRZ(W,TPC,ZX,ZL,ZT)
      YS=1/ZT
      ZS=ZX+ZL
      KC=KCF(YS,ZS)
      KI=KIF(YS,ZS)
C
      IF(MX.NE.0) WRITE(LP,11) W,WN,WI,PKG,ZKG,TPC,YS,ZS,KC,KI
```

```
C
      PC=KC
      ZC=KI
C
      DR=PC-PKG
      ER=CABS(DR) $IF(CABS(PKG).NE.0) ER=CABS(DR/PKG)
      IF(ER.LT.ES) RETURN
C
 100  CONTINUE
C
                WRITE(LP,10) W
      PC=PKG $WRITE(LP,12) PC
      ZC=ZKG $WRITE(LP,13) ZC
C
      RETURN
      END
C**********************************************************************
      SUBROUTINE PKF(TPC,DET)
C
C     PROPAGATION CONSTANT
C
      INTEGER ORD
      COMPLEX CI
      COMPLEX EMW,EMI,EME
      COMPLEX WNW,WNI,WNE
      COMPLEX APCW,APCI,APCE
      COMPLEX WNF,APCF
      COMPLEX RIW,RIE
      COMPLEX TPC
      COMPLEX ARG
      COMPLEX BF,NF,HFM,HFP
      COMPLEX J0WW,J1WW
      COMPLEX J0IW,J1IW,Y0IW,Y1IW
      COMPLEX J0IS,J1IS,Y0IS,Y1IS
      COMPLEX H0ES,H1ES
      COMPLEX NJ,DJ,WJ
      COMPLEX NH,DH,WH
      COMPLEX DET
C
      COMMON/D21/X,W
      COMMON/E13/RX,RW
      COMMON/E14/RS
      COMMON/F11/URE,ERE,UE,EE,OE
      COMMON/F12/URI,ERI,UI,EI,OI
      COMMON/F13/URW,ERW,UW,EW,OW
      COMMON/I10/WJ,WH
      COMMON/I11/J0WW,J1WW
      COMMON/I12/J0IW,J1IW,Y0IW,Y1IW
      COMMON/I13/J0IS,J1IS,Y0IS,Y1IS
      COMMON/I14/H0ES,H1ES
      COMMON/I15/EMW,EMI,EME
      COMMON/I16/APCW,APCI,APCE
C
      CI=CMPLX(0.0,1.0)
C
      EMW=OW+CI*W*EW
      EMI=OI+CI*W*EI
      EME=OE+CI*W*EE
C
      WNW=WNF(W,UW,EW,OW) $APCW=APCF(TPC,WNW)
      WNI=WNF(W,UI,EI,OI) $APCI=APCF(TPC,WNI)
      WNE=WNF(W,UE,EE,OE) $APCE=APCF(TPC,WNE)
C
      RIW=(EMW/EMI)*(APCI/APCW)
```

```
      RIE=(EME/EMI)*(APCI/APCE)
C
      ORD=0 $ARG=APCI*RW
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      J0IW=BF $Y0IW=NF
C
      ORD=1 $ARG=APCI*RW
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      J1IW=BF $Y1IW=NF
C
      ORD=0 $ARG=APCW*RW
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      J0WW=BF
C
      ORD=1 $ARG=APCW*RW
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      J1WW=BF
C
      ORD=0 $ARG=APCI*RS
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      J0IS=BF $Y0IS=NF
C
      ORD=1 $ARG=APCI*RS
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      J1IS=BF $Y1IS=NF
C
      ORD=0 $ARG=APCE*RS
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      H0ES=HFP
C
      ORD=1 $ARG=APCE*RS
      CALL BNHF(ORD,ARG,BF,NF,HFM,HFP)
      H1ES=HFP
C
      NJ=RIW*J1WW*J0IW-J0WW*J1IW $NH=RIE*H1ES*J0IS-H0ES*J1IS
      DJ=RIW*J1WW*Y0IW-J0WW*Y1IW $DH=RIE*H1ES*Y0IS-H0ES*Y1IS
      WJ=NJ/DJ                   $WH=NH/DH
C
      DET=WJ-WH
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRZ(W,TPC,ZS,ZL,ZT)
C
C     IMPEDANCES
C
      COMPLEX CI
      COMPLEX TPC
      COMPLEX EMW,EMI,EME
      COMPLEX APCW,APCI,APCE
      COMPLEX J0WW,J1WW
      COMPLEX J0IW,J1IW,Y0IW,Y1IW
      COMPLEX J0IS,J1IS,Y0IS,Y1IS
      COMPLEX H0ES,H1ES
      COMPLEX WJ,WH
      COMPLEX PC
      COMPLEX DJ,DY,DH
      COMPLEX DP,DS,DW
      COMPLEX RP,RQ,RE
      COMPLEX CC
      COMPLEX CS,CLP,CLQ,CT
      COMPLEX CJY,CH
      COMPLEX ZS
```

```
      COMPLEX ZLP,ZLQ,ZL
      COMPLEX ZTP,ZTQ,ZT
C
      COMMON/E13/RX,RW
      COMMON/F11/URE,ERE,UE,EE,OE
      COMMON/F12/URI,ERI,UI,EI,OI
      COMMON/I10/WJ,WH
      COMMON/I11/J0WW,J1WW
      COMMON/I12/J0IW,J1IW,Y0IW,Y1IW
      COMMON/I13/J0IS,J1IS,Y0IS,Y1IS
      COMMON/I14/H0ES,H1ES
      COMMON/I15/EMW,EMI,EME
      COMMON/I16/APCW,APCI,APCE
C
      DATA PI/3.14159265/
C
      CI=CMPLX(0.0,1.0)
C
      PC=WJ
C
      DJ=(J0IS-J0IW)/J1WW
      DY=(Y0IS-Y0IW)/J1WW
      DH=H0ES/J1WW
C
      DR=J0WW/J1WW
      DS=J0IS-PC*Y0IS
      DW=J1IW-PC*Y1IW
C
      RP=+(EMW/EMI)*(APCW/APCI)*(J1WW/DW)
      RQ=-(EMW/EMI)*(APCW/APCI)*(J1WW/DW)*PC
      RE=+(EMW/EMI)*(APCI/APCE)*(APCW/APCE)*(J1WW/H0ES)*(DS/DW)
C
      CC=2*PI*RW*EMW*APCW
C
      CS=(APCW*APCW)/CC
      CLP=(CI*W*UI*EMI)/CC
      CLQ=(CI*W*UE*EME)/CC
      CT=1/CC
C
      CJY=RP*DJ+RQ*DY
      CH =RE*DH
C
      ZLP=-CLP*CJY  $ZTP=-CT*CJY  $ZS=CS*DR
      ZLQ=+CLQ*CH   $ZTQ=+CT*CH
      ZL=ZLP+ZLQ    $ZT=ZTP+ZTQ
C
      RETURN
      END
C**********************************************************************
      SUBROUTINE SRCC(E,PC,ZC,IT,MR,PE,PF)
C
C     COAXIAL CABLE
C
      INTEGER PE,PF
      INTEGER CR,LP,PQ
      COMPLEX WNX,WNF
      COMPLEX WIX,WIF
      COMPLEX E,IT
      COMPLEX PC,ZC
      COMPLEX MR
C
      DIMENSION E(PE,PF),IT(PE,PF)
      DIMENSION PC(PF),ZC(PF)
      DIMENSION MR(PF)
```

```
C
      COMMON/A10/CR,LP,PQ
      COMMON/B30/MC
      COMMON/D11/XI,XF,NX
      COMMON/D12/YI,YF,NY
      COMMON/D13/WI,WF,NW
      COMMON/D15/MS,MX,MY,MW,MT
      COMMON/D22/UI,UF,NU,MU
      COMMON/D23/VI,VF,NV,MV
      COMMON/D24/ZI,ZF,NZ,MZ
      COMMON/F16/UR1,ER1,U1,E1,01
C
   10 FORMAT("0","FREQUENCY                     ",  1PG20.10 )
   12 FORMAT(" ","PROPAGATION   CONSTANT    ",2(1PG20.10))
   13 FORMAT(" ","CHARACTERISTC IMPEDANCE   ",2(1PG20.10))
C
      UC=U1 $EC=E1 $OC=01
C
      UI=YI $VI=XI $ZI=WI
      UF=YF $VF=XF $ZF=WF
      NU=NY $NV=NX $NZ=NW
      MU=MY $MV=MX $MZ=MW
C
      DO 101 IW=1,NW,1
      W=AF(WI,WF,NW,IW,MW)               $IF(MC.NE.0) WRITE(LP,10) W
      WNX=WNF(W,UC,EC,OC) $PC(IW)=WNX $IF(MC.NE.0) WRITE(LP,12) WNX
      WIX=WIF(W,UC,EC,OC) $ZC(IW)=WIX $IF(MC.NE.0) WRITE(LP,13) WIX
      DO 102 IX=1,NX,1
      E(IX,IW)=IT(IX,IW)*MR(IW)
  102 CONTINUE
  101 CONTINUE
C
      RETURN
      END
C**********************************************************************
      SUBROUTINE SRTL(X,Y,PW,C,V,E,PC,ZC,PE,PX,PF)
C
C     TRANSMISSION LINE
C
      INTEGER PE,PX,PF
      INTEGER PW
      COMPLEX C,V
      COMPLEX E
      COMPLEX PC,ZC
      COMPLEX WNX,WIX
      COMPLEX ZMX,ZPX
      COMPLEX ZLM,ZLP
      COMPLEX CKF,VKF
      COMPLEX Y
      COMPLEX QF
      LOGICAL TEST
C
      DIMENSION C(PX,PF),V(PX,PF)
      DIMENSION E(PE,PF)
      DIMENSION PC(PF),ZC(PF)
      DIMENSION X(PW),Y(PW)
C
      COMMON/B15/NQ,NI
      COMMON/B31/MM
      COMMON/D21/XX,ZX
      COMMON/D22/XI,XF,NX,MX
      COMMON/D23/YI,YF,NY,MY
      COMMON/D24/ZI,ZF,NZ,MZ
      COMMON/G11/ZLM,ZLP
```

```
      COMMON/H13/WNX,WIX
      COMMON/H14/ZMX,ZPX
C
      EXTERNAL CKF,VKF
C
      DATA IM/0/
C
      CALL SRAF(X,PW,YI,YF,NY,MY)
C
      DO 100 IP=1,NZ,1
      ZX=AF(ZI,ZF,NZ,IP,MZ)
      WNX=PC(IP)
      WIX=ZC(IP)
      ZMX=ZLM $IF(MM.NE.0) ZMX=WIX
      ZPX=ZLP $IF(MM.NE.0) ZPX=WIX
      CALL SRD(IM,IP,E,PE,PF,Y,PW)
      DO 100 IX=1,NX,1
      XX=AF(XI,XF,NX,IX,MX)
      TEST=(MM.EQ.0).OR.(MM.EQ.1)
      IF(TEST) C(IX,IP)=QF(YI,YF,NY,MY,NQ,CKF,X,Y,PW)
      TEST=(MM.EQ.0).OR.(MM.EQ.2)
      IF(TEST) V(IX,IP)=QF(YI,YF,NY,MY,NQ,VKF,X,Y,PW)
 100  CONTINUE
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE SRT(MR,PF)
C
C     TRANSFER
C
      INTEGER PF
      INTEGER CR,LP,PQ
      REAL    MSI,MTA,MTD,MTS,MTT
      COMPLEX SI,SIF
      COMPLEX TA,TD,TS,TF
      COMPLEX TT
      COMPLEX MR
C
      DIMENSION MR(PF)
C
      COMMON/A10/CR,LP,PQ
      COMMON/D13/WI,WF,NW
      COMMON/D15/MS,MX,MY,MW,MT
      COMMON/E12/RSM,RSP
      COMMON/E13/RAM,RAP
      COMMON/F13/URA,ERA,UA,EA,OA
      COMMON/F14/UR2,ER2,U2,E2,O2
      COMMON/F15/URS,ERS,US,ES,OS
C
   10 FORMAT("0","    INDEX",1X," FREQUENCY",1X,"  SURFACE",1X,
     +          "    ARMOR",1X,"   SPACER",1X,"   SHIELD",1X,
     +          "    TOTAL"                                   //)
   11 FORMAT(" ",I10,1X,6(1PG10.3,1X))
C
      WRITE(LP,10)
      DO 100 IW=1,NW,1
      W=AF(WI,WF,NW,IW,MW) $IF(W.EQ.0) GO TO 100
      SI=SIF(RAP,W,UA,EA,OA)      $MSI=CABS(SI)
      TA=TF(RAM,RAP,W,UA,EA,OA) $MTA=CABS(TA)
      TD=TF(RSP,RAM,W,U2,E2,O2) $MTD=CABS(TD)
      TS=TF(RSM,RSP,W,US,ES,OS) $MTS=CABS(TS)
      TT=SI*TA*TD*TS $MR(IW)=TT $MTT=CABS(TT)
      WRITE(LP,11) IW,W,MSI,MTA,MTD,MTS,MTT
```

```
 100   CONTINUE
C
       RETURN
       END
C**********************************************************************
       SUBROUTINE SRD(IX,IY,W,PX,PY,Z,PZ)
C
C      DATA
C
       INTEGER PX,PY
       INTEGER PZ
       COMPLEX W,Z
C
       DIMENSION W(PX,PY)
       DIMENSION Z(PZ)
C
       IF(IX.EQ.0) GO TO 101
       IF(IY.EQ.0) GO TO 102
C
 101   CONTINUE
       DO 110 IS=1,PX,1
       Z(IS)=W(IS,IY)
 110   CONTINUE
       RETURN
C
 102   CONTINUE
       DO 120 IS=1,PY,1
       Z(IS)=W(IX,IS)
 120   CONTINUE
       RETURN
C
       END
C**********************************************************************
       SUBROUTINE SRCFT(X,Y,PW,K,C,U,V,PX,PF,PT)
C
C      FOURIER TRANSFORM (CONTINUOUS)
C
       INTEGER PX,PF,PT
       INTEGER PW
       COMPLEX K,C
       COMPLEX U,V
       COMPLEX IKF
       COMPLEX Y
       COMPLEX IF
C
       DIMENSION K(PX,PT),C(PX,PF)
       DIMENSION U(PX,PT),V(PX,PF)
       DIMENSION X(PW),Y(PW)
C
       COMMON/B15/NQ,NI
       COMMON/D12/YI,YF,NY
       COMMON/D13/WI,WF,NW
       COMMON/D14/TI,TF,NT
       COMMON/D15/MS,MX,MY,MW,MT
       COMMON/C21/TX,XX
C
       EXTERNAL IKF
C
       DATA IM/0/
C
       CALL SRAF(X,PW,WI,WF,NW,MW)
C
       DO 100 IY=1,NY,1
       XX=AF(YI,YF,NY,IY,MY)
```

```
      CALL SRD(IY,IM,C,FX,PF,Y,FW)
      DO 101 IT=1,NT,1
      TX=AF(TI,TF,NT,IT,MT)
      K(IY,IT)=IF(WI,WF,NW,MW,NI,IKF,X,Y,PW)
 101  CONTINUE
      CALL SRD(IY,IM,V,FX,PF,Y,PW)
      DO 102 IT=1,NT,1
      TX=AF(TI,TF,NT,IT,MT)
      U(IY,IT)=IF(WI,WF,NW,MW,NI,IKF,X,Y,PW)
 102  CONTINUE
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE GRAF(A,PF,XI,XF,NX,MX)
C
C     ARRAY
C
      INTEGER PF
C
      DIMENSION A(PF)
C
      DO 100 IX=1,NX,1
      XO=AF(XI,XF,NX,IX,MX) $A(IX)=XO
 100  CONTINUE
C
      RETURN
      END
C#######################################################################
C     FUNCTIONS
C#######################################################################
      REAL FUNCTION UF(UR)
C
C     PERMEABILITY
C
      DATA U0/12.5664E-07/
C
      U=U0*UR $UF=U
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION EF(ER)
C
C     PERMITTIVITY
C
      DATA E0/8.8542E-12/
C
      E=E0*ER $EF=E
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION KF(T)
C
C     CURRENT
C
      INTEGER PS
C
      COMMON/C15/APS,BPS,CPS
      COMMON/C16/ARX,BRX,CRX
      COMMON/C17/ARS,BRS,CRS
      COMMON/C21/PSPS,DCPS,DKPS,MPS,NPS
```

```
      COMMON/C22/PSRX,DCRX,DKFX,MRX,NRX
      COMMON/C23/PSRS,DCRS,DKFS,MRS,NRS
      COMMON/C24/TSPS,TRPS,TDPS,TPPS,TCPS
      COMMON/C25/TSRX,TRRX,TDRX,TPRX,TCRX
      COMMON/C26/TSRS,TRRS,TDRS,TPRS,TCRS
C
      DATA MS/-1/
      DATA NS/ 0/
      DATA PS/+1/
C
      PPS=STF(PSPS,TSPS,TPPS,T,APS,BPS,CPS,PS,NPS)
      PRX=STF(PSRX,TSRX,TPRX,T,ARX,BRX,CRX,NS,NRX)
      PRS=STF(PSRS,TSRS,TPRS,T,ARS,BRS,CRS,MS,NRS)
C
      PT=PPS+PRX+PRS $KF=PT
C
      RETURN
      END
C************************************************************************
      COMPLEX FUNCTION CF(W)
C
C     CURRENT
C
      INTEGER PS
      COMPLEX PPS,PRX,PRS
      COMPLEX SFF
      COMPLEX PT
C
      COMMON/C15/APS,BPS,CPS
      COMMON/C16/ARX,BRX,CRX
      COMMON/C17/ARS,BRS,CRS
      COMMON/C21/PSPS,DCPS,DKPS,MPS,NPS
      COMMON/C22/PSRX,DCRX,DKFX,MRX,NRX
      COMMON/C23/PSRS,DCRS,DKFS,MRS,NRS
      COMMON/C24/TSPS,TRPS,TDPS,TPPS,TCPS
      COMMON/C25/TSRX,TRRX,TDRX,TPRX,TCRX
      COMMON/C26/TSRS,TRRS,TDRS,TPRS,TCRS
C
      DATA MS/-1/
      DATA NS/ 0/
      DATA PS/+1/
C
      PPS=SFF(PSPS,TSPS,TPPS,W,APS,BPS,CPS,PS,NPS)
      PRX=SFF(PSRX,TSRX,TPRX,W,ARX,BRX,CRX,NS,NRX)
      PRS=SFF(PSRS,TSRS,TPPS,W,ARS,BRS,CRS,MS,NRS)
C
      PT=PPS+PRX+PRS $CF=PT
C
      RETURN
      END
C************************************************************************
      REAL FUNCTION STF(PS,TS,TP,T,A,B,C,SGN,NR)
C
C     STOKE (DOUBLE EXPONENTIAL)
C
      DOUBLE PRECISION AX
C
      INTEGER SGN
      REAL     K,KS
C
      STF=0 $IF(NR.EQ.0) RETURN
C
      SUM=0
      DO 100 IR=1,NR,1 $IS=IR-1
```

```
      TR=TS+IS*TP $K=KS(PS,TR,T,A,B)
      TT=TR-TS $AX=SGN*C*TT $TERM=K*DEXP(AX)
      SUM=SUM+TERM
 100  CONTINUE
      STF=SUM
C
      RETURN
      END
C*****************************************************************
      COMPLEX FUNCTION SFF(PS,TS,TP,W,A,B,C,SGN,NR)
C
C     STROKE (DOUBLE EXPONENTIAL)
C
      INTEGER SGN
      COMPLEX CI
      COMPLEX CA,CB,CC
      COMPLEX AS,AT
      COMPLEX CS,CT
      COMPLEX TERM,SUM
C
      CI=CMPLX(0.0,1.0)
C
      SFF=0 $IF(NR.EQ.0) RETURN
C
      CA=A+CI*W
      CB=B+CI*W
      CC=-SGN*C+CI*W
C
      CS=PS*(1/CA-1/CB)
      AS=-CI*W*TS $CT=CEXP(AS)
C
      SUM=0
      DO 100 IR=1,NR,1 $IS=IR-1
      AT=-IS*CC*TP $TERM=CEXP(AT)
      SUM=SUM+TERM
 100  CONTINUE
      SFF=CS*CT*SUM
C
      RETURN
      END
C*****************************************************************
      REAL FUNCTION KS(PS,TS,T,A,B)
C
C     CURRENT
C
      DOUBLE PRECISION AT,EMAT
      DOUBLE PRECISION BT,EMBT
C
      REAL     K
C
      KS=0 $IF(T.LT.TS) RETURN
C
      TT=T-TS
      AT=A*TT $EMAT=DEXP(-AT)
      BT=B*TT $EMBT=DEXP(-BT)
      K=PS*(EMAT-EMBT) $KS=K
C
      RETURN
      END
C*****************************************************************
      REAL FUNCTION COF(X)
C
C     CURRENT
C
```

```
      DOUBLE PRECISION AT,EMAT
      DOUBLE PRECISION BT,EMBT
C
      COMMON/C13/TS,TR,TD,TP,TC
      COMMON/C14/A,B,C
C
      AT=A*TR $EMAT=DEXP(-AT)
      BT=X*TR $EMBT=DEXP(-BT)
C
      F=BT*EMBT-AT*EMAT $COF=F
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION CODF(X)
C
C     CURRENT DERIVATIVE
C
      DOUBLE PRECISION AT,EMAT
      DOUBLE PRECISION BT,EMBT
C
      COMMON/C13/TS,TR,TD,TP,TC
      COMMON/C14/A,B,C
C
      AT=A*TR $EMAT=DEXP(-AT)
      BT=X*TR $EMBT=DEXP(-BT)
C
      FD=TR*(1-BT)*EMBT $CODF=FD
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION WNF(W,U,E,O)
C
C     WAVE NUMBER
C
      COMPLEX CI
      COMPLEX UC,EC
      COMPLEX WN2,WN
C
      CI=CMPLX(0.0,1.0)
C
      UC=U
      EC=E $IF(W.NE.0) EC=E-CI*(O/W)
C
      WN2=-W*W*UC*EC $WN=CSQRT(WN2) $WNF=WN
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION WIF(W,U,E,O)
C
C     WAVE IMPEDANCE
C
      COMPLEX CI
      COMPLEX UC,EC
      COMPLEX WI2,WI
C
      CI=CMPLX(0.0,1.0)
C
      UC=U
      EC=E $IF(W.NE.0) EC=E-CI*(O/W)
C
      WI2=+UC/EC $WI=CSQRT(WI2) $WIF=WI
```

```
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION KIF(Y,Z)
C
C     CHARACTERISTIC IMPEDANCE
C
      COMPLEX Y,Z
      COMPLEX KI2,KI
C
      KI2=Z/Y $KI=CSQRT(KI2) $KIF=KI
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION KCF(Y,Z)
C
C     PROPAGATION CONSTANT
C
      COMPLEX Y,Z
      COMPLEX KC2,KC
C
      KC2=Y*Z $KC=CSQRT(KC2) $KCF=KC
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION APCF(TPC,WN)
C
C     AXIAL PROPAGATION CONSTANT
C
      COMPLEX TPC,WN
      COMPLEX APC
C
      APC=CSQRT(TPC*TPC-WN*WN) $APCF=APC
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION DF(X,W)
C
C     DIPOLE
C
      REAL    KO
      COMPLEX CO,CF
      COMPLEX EO
      COMPLEX E
C
      COMMON/E15/ZD,YT
      COMMON/F11/URE,ERE,UE,EE,OE
C
      DATA PI/3.14159265/
C
      UC=UE $EC=EE $OC=OE
C
      KO=1/(2*PI*UC) $CO=CF(W) $EO=KO*CO
      R2=X*X+YT*YT+ZD*ZD $R=SQRT(R2)
      E=EO*(X/(R**3)) $DF=E
C
      RETURN
      END
C***************************************       ************************
      COMPLEX FUNCTION SIF(R,W,U,E,O)
```

```
C
C     SURFACE IMPEDANCE
C
      INTEGER ORD
      COMPLEX WN,WNF
      COMPLEX WI,WIF
      COMPLEX ARG
      COMPLEX MBF,MNF,MHFM,MHFP
      COMPLEX I0,I1
      COMPLEX DR
      COMPLEX SI
C
      DATA PI/3.14159265/
C
      WN=WNF(W,U,E,O)
      WI=WIF(W,U,E,O)
C
      ORD=0 $ARG=WN*R
      CALL MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
      I0=MBF
C
      ORD=1 $ARG=WN*R
      CALL MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
      I1=MBF
C
      DR=I0/I1 $SI=(WI/(2*PI*R))*DR $SIF=SI
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION TF(RI,RO,W,U,E,O)
C
C     TRANSFER RATIOS
C
      INTEGER ORD
      COMPLEX WN,WNF
      COMPLEX ARG
      COMPLEX MBF,MNF,MHFM,MHFP
      COMPLEX I00,K00
      COMPLEX I01,K01
      COMPLEX I10,K10
      COMPLEX I11,K11
      COMPLEX DET,WIR,WJR
      COMPLEX IR,JR
C
      DATA PI/3.14159265/
C
      WN=WNF(W,U,E,O)
C
      I00=0 $K00=0
      I01=0 $K01=0
      I10=0 $K10=0
      I11=0 $K11=0
C
      ORD=0 $ARG=WN*RO
      CALL MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
      I00=MBF $K00=MHFM
C
      ORD=1 $ARG=WN*RO
      CALL MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
      I10=MBF $K10=MHFM
C
      ORD=0 $ARG=WN*RI
      CALL MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
```

```
      I0I=MBF $K0I=MHFM
C
      ORD=1 $ARG=WN*RI
      CALL MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
      I1I=MBF $K1I=MHFM
C
      DET=I00 $IF(RI.NE.0) DET=I00*K1I+I1I*K00
      WIR=I10 $IF(RI.NE.0) WIR=I10*K1I-I11*K10
      WJR=1   $IF(RI.NE.0) WJR=I0I*K1I+I1I*K0I
C
      IR=((2*PI*RO)/WN)*(WIR/DET)
      JR=                WJR/DET $TF=JR
C
      RETURN
      END
C**********************************************************************
      COMPLEX FUNCTION CKF(XS,XP,X,Y,PW)
C
C     KERNAL (CURRENT)
C
      INTEGER PW
      COMPLEX Y
      COMPLEX EX,EDX
      COMPLEX GF,CGF
      COMPLEX KF
C
      DIMENSION X(PW),Y(PW)
C
      COMMON/B14/ND,MD,MC
      COMMON/D23/XI,XF,NX,MX
C
      CALL TLU(X,Y,PW,NX,ND,XP,EX,EDX,MD,MC)
      GF=CGF(XS,XP) $KF=EX*GF $CKF=KF
C
      RETURN
      END
C**********************************************************************
      COMPLEX FUNCTION VKF(XS,XP,X,Y,PW)
C
C     KERNAL (VOLTAGE)
C
      INTEGER PW
      COMPLEX Y
      COMPLEX EX,EDX
      COMPLEX GF,VGF
      COMPLEX KF
C
      DIMENSION X(PW),Y(PW)
C
      COMMON/B14/ND,MD,MC
      COMMON/D23/XI,XF,NX,MX
C
      CALL TLU(X,Y,PW,NX,ND,XP,EX,EDX,MD,MC)
      GF=VGF(XS,XP) $KF=EX*GF $VKF=KF
C
      RETURN
      END
C**********************************************************************
      COMPLEX FUNCTION CGF(X,XP)
C
C     GREENS FUNCTION (CURRENT)
C
      INTEGER CF,LP,PQ
      REAL    L
```

```
      COMPLEX AML,AYM,AYP,AZM,AZP
      COMPLEX EML,EYM,EYP,EZM,EZP
      COMPLEX DC,DET
      COMPLEX PC,ZC
      COMPLEX ZLM,ZLP
      COMPLEX RCM,RCP,RCF
      COMPLEX DCEXP
      COMPLEX GF
      LOGICAL LGT,LLT,LTT
C
      COMMON/A10/CR,LP,PQ
      COMMON/D22/XI,XF,NX,MX
      COMMON/D23/YI,YF,NY,MY
      COMMON/H13/PC,ZC
      COMMON/H14/ZLM,ZLP
C
   10 FORMAT("0","ERROR (CGF) : PARAMETER LIMITS NOT SATISFIED",
     +           " ",10(1PG20.10)//)
C
      LGT=(X.GT.XF).OR.(XP.GT.YF)
      LLT=(X.LT.XI).OR.(XP.LT.YI)
      LTT=LGT.OR.LLT
      IF(LTT) WRITE(LP,10) XI,X,XF,YI,XP,YF $IF(LTT) STOP
C
      L=YF-YI $SI=0 $SF=L
C
      Y =SXY(YI,YF,SI,SF,X )
      YP=SXY(YI,YF,SI,SF,XP)
C
      AD=Y-YP $YD=ABS(AD) $ZD=2*L-YD
      AS=Y+YP $YS=ABS(AS) $ZS=2*L-YS
C
      AML=-2*PC*L $EML=DCEXP(AML)
C
      AYM=-PC*YD $EYM=DCEXP(AYM)
      AYP=-PC*YS $EYP=DCEXP(AYP)
      AZM=-PC*ZD $EZM=DCEXP(AZM)
      AZP=-PC*ZS $EZP=DCEXP(AZP)
C
      RCM=RCF(ZLM,ZC)
      RCP=RCF(ZLP,ZC)
C
      IF(X.LT.XP) DC=EYM+RCM*RCP*EZM-RCM*EYP-RCP*EZP
      IF(X.GT.XP) DC=EYM+RCM*RCP*EZM-RCM*EYP-RCP*EZP
C
      DET=2*(1-RCM*RCP*EML)
C
      GF=(DC/DET)/ZC $CGF=GF
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION VGF(X,XP)
C
C     GREENS FUNCTION (VOLTAGE)
C
      INTEGER CR,LP,PQ
      REAL    L
      COMPLEX AML,AYM,AYP,AZM,AZP
      COMPLEX EML,EYM,EYP,EZM,EZP
      COMPLEX DV,DET
      COMPLEX PC,ZC
      COMPLEX ZLM,ZLP
      COMPLEX RCM,RCP,RCF
```

```
      COMPLEX DCEXP
      COMPLEX GF
      LOGICAL LGT,LLT,LTT
C
      COMMON/A10/CR,LP,PQ
      COMMON/D22/XI,XF,NX,MX
      COMMON/D23/YI,YF,NY,MY
      COMMON/H13/PC,ZC
      COMMON/H14/ZLM,ZLP
C
   10 FORMAT("0","ERROR (VGF) : PARAMETER LIMITS NOT SATISFIED",
     +         " ",10(1PG20.10)//)
C
      LGT=(X.GT.XF).OR.(XP.GT.YF)
      LLT=(X.LT.XI).OR.(XP.LT.YI)
      LTT=LGT.OR.LLT
      IF(LTT) WRITE(LP,10) XI,X,XF,YI,XP,YF $IF(LTT) STOP
C
      L=YF-YI $SI=0 $SF=L
C
      Y =SXY(YI,YF,SI,SF,X )
      YP=SXY(YI,YF,SI,SF,XP)
C
      AD=Y-YP $YD=ABS(AD) $ZD=2*L-YD
      AS=Y+YP $YS=ABS(AS) $ZS=2*L-YS
C
      AML=-2*PC*L $EML=DCEXP(AML)
C
      AYM=-PC*YD $EYM=DCEXP(AYM)
      AYP=-PC*YS $EYP=DCEXP(AYP)
      AZM=-PC*ZD $EZM=DCEXP(AZM)
      AZP=-PC*ZS $EZP=DCEXP(AZP)
C
      RCM=RCF(ZLM,ZC)
      RCP=RCF(ZLP,ZC)
C
      IF(X.LT.XP) DV=EYM-RCM*RCP*EZM+RCM*EYP-RCP*EZP
      IF(X.GT.XP) DV=EYM-RCM*RCP*EZM-RCM*EYP+RCP*EZP
C
      DET=2*(1-RCM*RCP*EML)
C
      GF=DV/DET $VGF=GF
C
      RETURN
      END
C*************************************************************************
      REAL FUNCTION SXY(XI,XF,YI,YF,X)
C
C     SCALING
C
      S=(YF-YI)/(XF-XI) $Y=S*(X-XI)+YI $SXY=Y
C
      RETURN
      END
C*************************************************************************
      COMPLEX FUNCTION RCF(ZL,ZC)
C
C     REFLECTION COEFFICIENT
C
      COMPLEX ZL,ZC
      COMPLEX RC
C
      RC=(ZL-ZC)/(ZL+ZC) $RCF=RC
C
```

```
      RETURN
      END
C*********************************************************************
      COMPLEX FUNCTION IKF(XD,XI,X,Y,PW)
C
C     INVERSE KERNAL FUNCTION
C
      INTEGER PW
      REAL    KR,KI
      COMPLEX Y
      COMPLEX KX,KDX
      COMPLEX GF,IGF
      COMPLEX KF
C
      DIMENSION X(PW),Y(PW)
C
      COMMON/B14/ND,MD,MX
      COMMON/D13/WI,WF,NW
C
      DATA PI/3.14159265/
C
      CALL TLU(X,Y,PW,NW,ND,XI,KX,KDX,MD,MX) $KR=REAL(KX) $KI=AIMAG(KX)
      GF=IGF(XD,XI)                          $GR=REAL(GF) $GI=AIMAG(GF)
C
      KF=2*(KR*GR-KI*GI)/(2*PI) $IKF=KF
C
      RETURN
      END
C*********************************************************************
      COMPLEX FUNCTION IGF(X,XT)
C
C     INVERSE GREENS FUNCTION
C
      INTEGER SGN
      COMPLEX CI
      COMPLEX CA
      COMPLEX DCEXP
      COMPLEX GF
C
      DATA SGN/+1/
C
      CI=CMPLX(0.0,1.0)
C
      CA=SGN*CI*X*XT $GF=DCEXP(CA) $IGF=GF
C
      RETURN
      END
C#####################################################################
C     LIBRARY
C#####################################################################
      REAL FUNCTION AF(XI,XF,NX,IX,MX)
C
C     ARGUMENTS
C
      INTEGER CR,LP,PQ
      REAL    LSF,LNF,LTF
C
      COMMON/A10/CR,LP,PQ
C
   10 FORMAT("0","ERROR (AF) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF(IX.LT.1 ) WRITE(LP,10)
      IF(IX.GT.NX) WRITE(LP,10)
C
```

```
      AF=XI $IF(NX.EQ.1) RETURN
C
      IF(MX.LT.0) X=LSF(XI,XF,NX,IX)
      IF(MX.EQ.0) X=LNF(XI,XF,NX,IX)
      IF(MX.GT.0) X=LTF(XI,XF,NX,IX)
C
      AF=X
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION LSF(XI,XF,NX,IX)
C
C     ARGUMENTS
C
      INTEGER CR,LP,PQ
      REAL    N,D
C
      COMMON/A10/CR,LP,PQ
C
   10 FORMAT("0","ERROR (LSF) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF(IX.LT.1 ) WRITE(LP,10)
      IF(IX.GT.NX) WRITE(LP,10)
C
      N=IX-1
      D=NX-1
      DIF=XF-XI
      X=XI+(N/D)*DIF $LSF=X
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION LNF(XI,XF,NX,IX)
C
C     ARGUMENTS
C
      INTEGER CR,LP,PQ
      REAL    N,D
C
      COMMON/A10/CR,LP,PQ
C
      DATA BASE/2.7182818/
C
   10 FORMAT("0","ERROR (LNF) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF(IX.LT.1 ) WRITE(LP,10)
      IF(IX.GT.NX) WRITE(LP,10)
C
      LNF=0 $IF((IX.EQ.1).AND.(XI.EQ.0)) RETURN
C
      XLI=0 $IF(XI.NE.0) XLI=ALOG(XI)
      XLF=0 $IF(XF.NE.0) XLF=ALOG(XF)
C
      N=IX-1
      D=NX-1
      DLX=XLF-XLI
      XL=XLI+(N/D)*DLX
      X=ALF(XL,BASE) $LNF=X
C
      RETURN
      END
C**************************************** A-34 *************************
      REAL FUNCTION LTF(XI,XF,NX,IX)
```

```
C
C       ARGUMENTS
C
        INTEGER CR,LP,PQ
        REAL    N,D
C
        COMMON/A10/CR,LP,PQ
C
        DATA BASE/10.0/
C
     10 FORMAT("0","ERROR (LTF) : PARAMETER LIMITS NOT SATISFIED"//)
C
        IF(IX.LT.1 ) WRITE(LP,10)
        IF(IX.GT.NX) WRITE(LP,10)
C
        LTF=0 $IF((IX.EQ.1).AND.(XI.EQ.0)) RETURN
C
        XLI=0 $IF(XI.NE.0) XLI=ALOG10(XI)
        XLF=0 $IF(XF.NE.0) XLF=ALOG10(XF)
C
        N=IX-1
        D=NX-1
        DLX=XLF-XLI
        XL=XLI+(N/D)*DLX
        X=ALF(XL,BASE) $LTF=X
C
        RETURN
        END
C*************************************************************************
        REAL FUNCTION ALF(ARG,BASE)
C
C       ANTI-LOG
C
        AL=BASE**ARG $ALF=AL
C
        RETURN
        END
C*************************************************************************
        SUBROUTINE SDB(O,PA,PO,NA,NO,ML,RL,SL)
C
C       SCALE (DB)
C
        DOUBLE PRECISION A
C
        INTEGER PA,PO
        INTEGER CR,LP,PQ
C
        DIMENSION O(PA,PO)
C
        COMMON/A10/CR,LP,PQ
C
     10 FORMAT("0","ERROR (SDB) : PARAMETER LIMITS NOT SATISFIED"//)
C
        IF(NA.GT.PA) WRITE(LP,10)
        IF(NO.GT.PO) WRITE(LP,10)
C
        IF(ML.EQ.0) RETURN
C
        DO 100 IA=1,NA,1
        DO 100 IO=1,NO,1
        AR=O(IA,IO)/RL $A=ABS(AR)
        O(IA,IO)=0 $IF(A.EQ.0) GO TO 100
        IF(ML.LT.0) O(IA,IO)=SL*DLOG  (A)
        IF(ML.GT.0) O(IA,IO)=SL*DLOG10(A)
```

```
 100  CONTINUE
C
      RETURN
      END
C************************************************************************
      SUBROUTINE MNMX(O,PA,PO,NA,NO,XMN,XMX,MIN,MAX,MD)
C
C     MIN/MAX
C
      INTEGER PA,PO
      INTEGER CR,LP,PQ
      REAL    MIN,MAX
C
      DIMENSION O(PA,PO)
C
      COMMON/A10/CR,LP,PQ
C
   10 FORMAT("0","ERROR (MNMX) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF(NA.GT.PA) WRITE(LP,10)
      IF(NO.GT.PO) WRITE(LP,10)
C
      AMN=O(1,1)
      AMX=O(1,1)
      DO 100 IA=1,NA,1
      DO 100 IO=1,NO,1
      AMN=AMIN1(AMN,O(IA,IO))
      AMX=AMAX1(AMX,O(IA,IO))
 100  CONTINUE
C
      IF(MD) 101,102,103
 101  CONTINUE
      XMN=AMN
      XMX=AMX
      GO TO 110
 102  CONTINUE
      XMN=MIN
      XMX=MAX
      GO TO 110
 103  CONTINUE
      XMN=MIN $IF(XMN.GT.AMN) XMN=AMN
      XMX=MAX $IF(XMX.LT.AMX) XMX=AMX
 110  CONTINUE
      IF(XMN.GT.0) XMN=0
      IF(XMX.LT.0) XMX=0
C
      RETURN
      END
C************************************************************************
      SUBROUTINE TBL(A,O,PA,PO,NA,NO)
C
C     TABLE
C
      INTEGER PA,PO
      INTEGER CR,LP,PQ
C
      DIMENSION A(PA),O(PA,PO)
C
      COMMON/A10/CR,LP,PQ
C
   10 FORMAT("0","ERROR (TBL) : PARAMETER LIMITS NOT SATISFIED"//)
   11 FORMAT(" ",I10,10(1PG20.10))
C
      IF(NA.GT.PA) WRITE(LP,10)
```

```
      IF(NO.GT.PO) WRITE(LP,10)
C
      DO 100 IA=1,NA,1
      WRITE(LP,11) IA,A(IA),(O(IA,IO),IO=1,NO,1)
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE PLT(A,O,PA,PO,NA,NO,MIN,MAX)
C
C     PLOT
C
C     PARAMETER NS=9
C     PARAMETER PR=101
C
      INTEGER PA,PO
      INTEGER PR
      INTEGER CR,LP,PQ
      INTEGER ZERO
      INTEGER AXIS,BLNK,SMBL
      REAL MIN,MAX
C
      DIMENSION A(PA),O(PA,PO)
      DIMENSION SMBL(9)
      DIMENSION LINE(101)
C
      COMMON/AIO/CR,LP,PQ
C
      DATA IMN,IMX/1,101/
      DATA ZERO/0/
      DATA AXIS/"+"/
      DATA BLNK/" "/
      DATA SMBL/"1","2","3","4","5","6","7","8","9"/
      DATA NS,PR/9,101/
C
   11 FORMAT("0",10X,8X,1PG10.3,90X,1PG10.3,2X)
   12 FORMAT("+",10X,10X,101A1)
   13 FORMAT("+",I5,5X,1PG9.2,1X)
   14 FORMAT(" ")
C
      SLOPE=0 $IF(MIN.NE.MAX) SLOPE=(IMX-IMN)/(MAX-MIN)
C
      WRITE(LP,11) MIN,MAX
C
      DO 101 IP=1,PR,1
      LINE(IP)=AXIS
 101  CONTINUE
      WRITE(LP,14)
      WRITE(LP,12) (LINE(IP),IP=1,PR,1)
C
      DO 111 IA=1,NA,1
      WRITE(LP,13) IA,A(IA)
      DO 112 IO=1,NO,1
      DO 113 IP=1,PR,1
      LINE(IP)=BLNK
 113  CONTINUE
      IZ=SLOPE*(ZERO     -MIN)+1 $LINE(IZ)=AXIS
      IS=SLOPE*(O(IA,IO)-MIN)+1 $LINE(IS)=SMBL(IO)
      WRITE(LP,12) (LINE(IP),IP=1,PR,1)
 112  CONTINUE
      WRITE(LP,14)
 111  CONTINUE
C
```

```
      RETURN
      END
C************************************************************************
      SUBROUTINE GRF
     +(A,O,PA,PO,NA,NC,MIN,MAX,TT,TX,TV,TH,PM,TS,PN,P,MP,MN,NM,MA,MO,MG)
C
C     CALCOMP
C
C     PARAMETER PB=512
C     PARAMETER PD=102
C     PARAMETER PS=5
C
      INTEGER PA,PO
      INTEGER PM,PN
      INTEGER CR,LP,PQ
      INTEGER PB,PD,PS
      INTEGER TT,TX,TV,TH
      INTEGER TS,ST
      INTEGER BFR
      INTEGER PP
      INTEGER ON,OO
      INTEGER PH,PV
      INTEGER SFC,SPS
      INTEGER SS,CS,SC
      INTEGER BOI,EOI,EOF
      REAL    MIN,MAX
      REAL    MOD
      LOGICAL LIN,LOG
C
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
      DIMENSION TS(PN)
      DIMENSION BFR(512)
      DIMENSION DATA(102)
      DIMENSION SPS(5)
      DIMENSION XM(5),YM(5)
C
      COMMON/A10/CR,LP,PQ
C
      DATA PB/512/
      DATA PD/102/
      DATA PS/5/
      DATA XO,YO/+1.0,+3.5/
      DATA XV,YV/+0.0,+0.0/
      DATA XH,YH/+0.0,+3.0/
      DATA XM/+1.00,+1.00,+1.00,+1.00,+1.00/
      DATA YM/-0.50,-0.75,-1.00,-1.25,-1.50/
      DATA XT,YT/+1.00,-2.00/
      DATA XP,YP/+1.00,-2.25/
      DATA XN,YN/+2.00,-2.25/
      DATA XC,YC/+10.0,+0.0/
      DATA XI,YI/+0.0,+0.0/
      DATA XF,YF/+0.0,+0.0/
      DATA PP/00/
      DATA ON,OO/-3,+3/
      DATA PL/12.0/
      DATA HL,VL/+6.0,+6.0/
      DATA HA,VA/+0.0,+90.0/
      DATA HS,AS/+0.105,+0.0/
      DATA HF,AF/+0.105,+0.0/
      DATA HN,AN/+0.105,+0.0/
      DATA HP,AP/+0.105,+0.0/
      DATA OI/+3.0/
      DATA LW/10/
```

```
      DATA LC/80/
      DATA NT/8/
      DATA SS/+1/
      DATA CS,SC/-1,+10/
      DATA SD/+1.0/
      DATA ND/+2/
      DATA NS/+5/
      DATA SPS/0,1,2,3,4/
      DATA BOI,EOI,EOF/1,-999,+999/
C
      IF(MIN.EQ.MAX) RETURN
C
      LIN=.FALSE. $IF((MA.EQ.0).AND.(MO.EQ.0)) LIN=.TRUE.
      LOG=.FALSE. $IF((MA.NE.0). OR.(MO.NE.0)) LOG=.TRUE.
C
      IF((MA.NE.0).AND.(MO.EQ.0)) LT=-1
      IF((MA.NE.0).AND.(MO.NE.0)) LT= 0
      IF((MA.EQ.0).AND.(MO.NE.0)) LT=+1
C
      MB=MG $IF(MG.EQ.EOI) MB=BOI
      IF(MB.EQ.BOI) CALL PLOTS(BFR,PB,FQ,PP)
      IF(MB.EQ.BOI) CALL PLOT(XO,YO,ON)
C
      CALL PLOTMX(PL)
      IF(MA.EQ.0) CALL  SCALE(A,HL,NA,SS)
      IF(MA.NE.0) CALL LGSCAL(A,HL,NA,SS)
      NC=NM*LW $IF(NC.GT.LC) NC=LC
      PH=-NC $PV=+NC
      AMN=ABS(MIN) $AMX=ABS(MAX) $MOD=AMAX1(AMN,AMX)
      VTM=-MOD     $HTM=A(NA*SS+1)
      VDY=+MOD/DI $HDX=A(NA*SS+2)
      IF(MO.EQ.0) CALL   AXIS(XV,YV,TV,PV,VL,VA,VTM,VDY)
      IF(MO.NE.0) CALL LGAXIS(XV,YV,TV,PV,VL,VA,VTM,VDY)
      IF(MA.EQ.0) CALL   AXIS(XH,YH,TH,PH,HL,HA,HTM,HDX)
      IF(MA.NE.0) CALL LGAXIS(XH,YH,TH,PH,HL,HA,HTM,HDX)
      CALL PLOT(XI,YI,OO)
      DO 101 IO=1,NO,1
      DO 102 IA=1,NA,1
      DATA(IA)=O(IA,IO)
 102  CONTINUE
      DATA(NA+1)=VTM
      DATA(NA+2)=VDY
      SPC=SPS(IO)
      IF(LIN) CALL   LINE(A,DATA,NA,SS,NS,SPC)
      IF(LOG) CALL LGLINE(A,DATA,NA,SS,NS,SPC,LT)
      XS=XM(IO) $XD=XS+SD
      YS=YM(IO) $YD=YS
      ST=TS(IO)
      NK=MN*LW $IF(NK.GT.LC) NK=LC
      CALL SYMBOL(XS,YS,HS,SPC,AS,CS)
      CALL SYMBOL(XD,YD,HS,ST ,AS,SC)
 101  CONTINUE
      CALL SYMBOL(XT,YT,HF,TT,AF,NK)
      IF(MP.NE.0) CALL NUMBER(XN,YN,HN,F ,AN,ND)
      IF(MP.NE.0) CALL SYMBOL(XP,YP,HF,TX,AP,NK)
      CALL PLOT(XC,YC,ON)
C
      ME=MG $IF(MG.EQ.EOI) ME=EOF
      IF(ME.EQ.EOF) CALL PLOT(XF,YF,EOF)
C
      RETURN
      END
C*************************************  A-39 ****************************
      SUBROUTINE TPGX
```

```
     +(A,O,PA,PO,TT,TX,TV,TH,PM,DATA,PD,XI,XF,NX,MX,IXI,IXF,NXI)
C
C      TABLE/PLOT/GRAPH DATA
C
C      PARAMETER PN=5
C
      INTEGER PD
      INTEGER PM,PN
      INTEGER PA,PO
      INTEGER CR,LP,PQ
      INTEGER TT,TX,TV,TH
      INTEGER TS
      REAL    MIN,MAX
      COMPLEX DATA
C
      DIMENSION DATA(PD)
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
      DIMENSION TS(5)
C
      COMMON/A10/CR,LP,PQ
      COMMON/B12/ML,RL,SL
      COMMON/B13/MIN,MAX,MD
      COMMON/B20/IN,NM
C
    1 FORMAT(8A10)
    2 FORMAT("0",8A10)
    3 FORMAT(10I10)
    4 FORMAT(2G10.0,I10)
   11 FORMAT("0","       INDEX"
     +          ,"                ARGUMENT"
     +          ,"                    REAL"
     +          ,"               IMAGINARY"
     +          ,"               MAGNITUDE"
     +          ,"         ANGLE (RADIANS)"
     +          ,"         ANGLE (DEGREES)"//)
   12 FORMAT("0","1 -> REAL           "/
     +       " ","2 -> IMAGINARY      "/
     +       " ","3 -> MAGNITUDE      "/
     +       " ","4 -> ANGLE (RADIANS)"/
     +       " ","5 -> ANGLE (DEGREES)"//)
C
      DATA PN/5/
      DATA TS
     +/"REAL      ","IMAGINARY ","MAGNITUDE ","ANGLE     ","ANGLE     "/
      DATA P,MQ/0.0,0/
C
      READ(CR, 1) (TT(IT),IT=1,PM,1)
      READ(CR, 1) (TX(IT),IT=1,PM,1)
      READ(CR, 1) (TV(IT),IT=1,PM,1)
      READ(CR, 1) (TH(IT),IT=1,PM,1)
      READ(CR, 3)  MA,MO,MT,MP,MG
      READ(CR, 4)  MIN,MAX,MD
C
      IF((MT.EQ.0).AND.(MP.EQ.0).AND.(MG.EQ.0)) RETURN
      IF((MT.NE.0).OR.(MP.NE.0)) WRITE(LP, 2) (TT(IT),IT=1,PM,1)
C
      CALL AOZ(A,O,PA,PO,DATA,PD,ND,XI,XF,NX,MX,IXI,IXF,NXI)
C
      NA=ND $NO=5
      IF(MO.NE.0) CALL SDB(O,PA,PO,NA,NO,ML,RL,SL)
      NA=ND $NO=5
      IF(MT.NE.0) WRITE(LP,11)
      IF(MT.NE.0) CALL TBL(A,O,PA,PO,NA,NO)
```

```
      NA=ND $NO=3
      CALL MNMX(O,PA,PO,NA,NO,XMN,XMX,MIN,MAX,MD)
      NA=ND $NO=3
      IF(MP.NE.0) WRITE(LP,12)
      IF(MP.NE.0) CALL PLT(A,O,PA,PO,NA,NO,XMN,XMX)
      NA=ND $NO=3
      IF(MG.NE.0) CALL GRF
     +(A,O,PA,PO,NA,NO,XMN,XMX,TT,TX,TV,TH,PM,TS,PN,P,MQ,MN,NM,MA,MO,MG)
C
      RETURN
      END
C****************************************************************
      SUBROUTINE TPGK
     +(A,O,PA,PO,TT,TX,TV,TH,PM,DATA,PX,PY,
     + XI,XF,NX,MX,IXI,IXF,NXI,YI,YF,NY,MY,IYI,IYF,NYI)
C
C     GRAPH (TABLE/PLOT) (FREQUENCY DOMAIN)
C
      INTEGER PX,PY
      INTEGER PA,PO
      INTEGER PM
      INTEGER TT,TX,TV,TH
      COMPLEX DATA
C
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
      DIMENSION DATA(PX,PY)
C
      DATA NQ/2/
C
      DO 100 IP=1,NQ,1
      IF(IP.EQ.1) CALL VPXY
     +(VI,VF,NV,MV,IVI,IVF,NVI,PI,PF,NP,MP,IPI,IPF,NPI,
     + XI,XF,NX,MX,IXI,IXF,NXI,YI,YF,NY,MY,IYI,IYF,NYI)
      IF(IP.EQ.2) CALL VPXY
     +(VI,VF,NV,MV,IVI,IVF,NVI,PI,PF,NP,MP,IPI,IPF,NPI,
     + YI,YF,NY,MY,IYI,IYF,NYI,XI,XF,NX,MX,IXI,IXF,NXI)
      CALL TPGC
     +(A,O,PA,PO,TT,TX,TV,TH,PM,DATA,PX,PY,IP,
     + VI,VF,NV,MV,IVI,IVF,NVI,PI,PF,NP,MP,IPI,IPF,NPI)
 100  CONTINUE
C
      RETURN
      END
C****************************************************************
      SUBROUTINE TPGC
     +(A,O,PA,PO,TT,TX,TV,TH,PM,DATA,PX,PY,MZ,
     + XI,XF,NX,MX,IXI,IXF,NXI,YI,YF,NY,MY,IYI,IYF,NYI)
C
C     TABLE/PLOT/GRAPH DATA VS X OR Y
C
C     PARMETER PN=5
C
      INTEGER PX,PY
      INTEGER PM
      INTEGER PA,PO
      INTEGER CH,LP,PQ
      INTEGER TT,TX,TV,TH
      INTEGER TS
      INTEGER BOI,COI,EOI,ECF
      REAL    MIN,MAX
      COMPLEX DATA
C
      DIMENSION DATA(PX,PY)
```

```
      DIMENSION A(PA),O(PA,PO)
      DIMENSION TT(PM),TX(PM),TV(PM),TH(PM)
      DIMENSION TS(5)
C
      COMMON/A10/CR.LP,PO
      COMMON/B12/ML,RL,SL
      COMMON/B13/MIN,MAX,MD
      COMMON/B20/MN,NM
C
      DATA PN/5/
      DATA TS
     +/"REAL      ","IMAGINARY ","MAGNITUDE ","ANGLE     ","ANGLE     "/
      DATA MQ/1/
      DATA BOI,COI.EOI,EOF/1,2,-999,+999/
C
    1 FORMAT(8A10)
    2 FORMAT("0",8A10)
    3 FORMAT(10I10)
    4 FORMAT(2G10.0.I10)
   11 FORMAT("0","     INDEX"
     +          ,"                ARGUMENT"
     +          ,"                    REAL"
     +          ,"               IMAGINARY"
     +          ,"               MAGNITUDE"
     +          ,"     ANGLE  (RADIANS)"
     +          ,"     ANGLE  (DEGREES)"//)
   12 FORMAT("0","1 -> REAL            "/
     +        " ","2 -> IMAGINARY       "/
     +        " ","3 -> MAGNITUDE       "/
     +        " ","4 -> ANGLE (RADIANS)"/
     +        " ","5 -> ANGLE (DEGREES)"//)
   13 FORMAT("0","PARAMETER :",1PG20.10)
C
      READ(CR, 1) (TT(IT),IT=1,PM,1)
      READ(CR, 1) (TX(IT),IT=1,PM,1)
      READ(CR, 1) (TV(IT),IT=1,PM,1)
      READ(CR, 1) (TH(IT),IT=1,PM,1)
      READ(CR, 3)  MA,MO,MT,MP,MG
      READ(CR, 4)  MIN,MAX,MD
C
      IF((MT.EQ.0).AND.(MP.EQ.0).AND.(MG.EQ.0)) RETURN
      IF((MT.NE.0).OR.(MP.NE.0)) WRITE(LP, 2) (TT(IT),IT=1,PM,1)
C
      DO 100 IP=IYI,IYF.NYI
      MC=COI
      IF((MG.EQ.BOI).AND.(IP .EQ.IYI)) MC=BOI
      IF((MG.EQ.EOF).AND.(IP .EQ.IYF)) MC=EOF
      IF((MG.EQ.EOI).AND.(IP .EQ.IYI)) MC=BOI
      IF((MG.EQ.EOI).AND.(IP .EQ.IYF)) MC=EOF
      IF((MG.EQ.EOI).AND.(IYI.EQ.IYF)) MC=EOI
      CALL AOXY
     +(A,O,PA,PO,DATA,PX,PY,NZ,P,IP,MZ,
     + XI,XF,NX,MX,IXI,IXF,NXI,YI,YF,NY,MY,IYI,IYF,NYI)
      NA=NZ $NO=5
      IF(MO.NE.0) CALL SDB(O,PA,PO.NA,NC,ML,RL,SL)
      IF((MT.NE.0).OR.(MP.NE.0)) WRITE(LP,13) P
      NA=NZ $NO=5
      IF(MT.NE.0) WRITE(LP,11)
      IF(MT.NE.0) CALL TBL(A,O,PA,PO,NA,NO)
      NA=NZ $NO=3
      CALL MNMX(O,PA,PO,NA,NO,XMN,XMX,MIN,MAX,MD)
      NA=NZ $NO=3
      IF(MP.NE.0) WRITE(LP,12)
      IF(MP.NE.0) CALL PLT(A,O,PA,PO,NA,NO,XMN,XMX)
```

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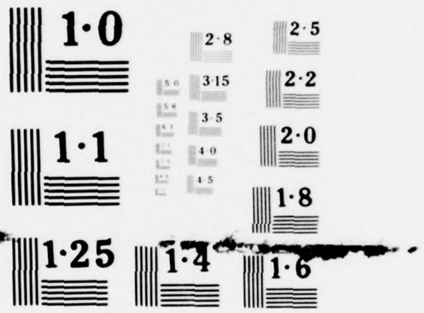

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```
      NA=NZ $NO=3
      IF(MG.NE.0) CALL GRF
     +(A,O,PA,PO,NA,NO,XMN,XMX,TT,TX,TV,TH,PM,TS,PN,P,MQ,MN,NM,MA,MO,MC)
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE AOZ(A,O,PA,PO,DATA,PD,ND,XI,XF,NX,MX,IXI,IXF,NXI)
C
C     AESICCA/ORDINATE
C
      INTEGER PD
      INTEGER PA,PO
      INTEGER CR,LP,PQ
      COMPLEX DATA
C
      DIMENSION DATA(PD)
      DIMENSION A(PA),O(PA,PO)
C
      COMMON/A10/CR,LP,PQ
C
   10 FORMAT("0","ERROR (AOZ) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF((NX.GT.PO).OR.(NX.GT.PA)) WRITE(LP,10)
C
      ID=IXF-IXI
      ND=ID/NXI+1
C
      IA=1
      DO 100 IX=IXI,IXF,NXI
      A(IA)=AF(XI,XF,NX,IX,MX)
      O(IA,1)= REAL(DATA(IX))
      O(IA,2)=AIMAG(DATA(IX))
      O(IA,3)= CABS(DATA(IX))
      AR=CANG(DATA(IX)) $AD=RDF(AR)
      O(IA,4)=AR
      O(IA,5)=AD
      IA=IA+1
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE AOXY
     +(A,O,PA,PO,DATA,PX,PY,NZ,P,IP,MZ,
     + VI,VF,NV,MV,IVI,IVF,NVI,PI,PF,NP,MP,IPI,IPF,NPI)
C
C     AESICCA/ORDINATE
C
      INTEGER PX,PY
      INTEGER PA,PO
      INTEGER CR,LP,PQ
      COMPLEX DATA
      LOGICAL LVX,LPY
      LOGICAL LVY,LPX
      LOGICAL LVA
C
      DIMENSION DATA(PX,PY)
      DIMENSION A(PA),O(PA,PO)
C
      COMMON/A10/CR,LP,PQ
C
   10 FORMAT("0","ERROR (TPGC) : PARAMETER LIMITS NOT SATISFIED"//)
```

```
C
      LVX=(MZ.EQ.1).AND.(NV.GT.PX)
      LPY=(MZ.EQ.1).AND.(NP.GT.PY)
      LVY=(MZ.EQ.2).AND.(NP.GT.PX)
      LPX=(MZ.EQ.2).AND.(NV.GT.PY)
      LVA=(NV.GT.PA).OR.(NP.GT.PA)
C
      IF(LVX.OR.LPY) WRITE(LP,10)
      IF(LVY.OR.LPX) WRITE(LP,10)
      IF(LVA) WRITE(LP,10)
C
      ID=IVF-IVI
      NZ=ID/NVI+1
C
      P=AF(PI,PF,NP,IP,MP)
C
      IA=1
      DO 100 IV=IVI,IVF,NVI
      A(IA)=AF(VI,VF,NV,IV,MV)
      CALL XYVP(IX,IY,IV,IP,MZ)
      O(IA,1)= REAL(DATA(IX,IY))
      O(IA,2)=AIMAG(DATA(IX,IY))
      O(IA,3)= CABS(DATA(IX,IY))
      AR=CANG(DATA(IX,IY)) $AD=RDF(AR)
      O(IA,4)=AR
      O(IA,5)=AD
      IA=IA+1
 100  CONTINUE
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE VPXY
     +(VI,VF,NV,MV,IVI,IVF,NVI,PI,PF,NP,MP,IPI,IPF,NPI,
     + AI,AF,NA,MA,IAI,IAF,NAI,OI,OF,NO,MO,IOI,IOF,NOI)
C
C     VARIABLE/PARAMETER
C
      VI=AI $IVI=1  $PI=OI $IPI=IOI
      VF=AF $IVF=NA $PF=OF $IPF=IOF
      NV=NA $NVI=1  $NP=NO $NPI=NOI
      MV=MA         $MP=MO
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE XYVP(IX,IY,IV,IP,MP)
C
C     INDEX
C
      IF(MP.EQ.1) IX=IV $IF(MP.EQ.2) IX=IP
      IF(MP.EQ.1) IY=IP $IF(MP.EQ.2) IY=IV
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE TLU(TX,TY,PT,NT,ND,X,Y,YD,MD,MX)
C
C     TABLE LOOK UP (INTERPOLATION/EXTRAPOLATION/DIFFERENTIATION)
C
C     PARAMETER DP=10
C
      INTEGER DP
      INTEGER PT
```

```
      INTEGER CR,LP,PQ
      COMPLEX TY
      COMPLEX QKMJ
      COMPLEX Q,QD
      COMPLEX Y,YD
C
      DIMENSION TX(PT),TY(PT)
      DIMENSION P(10),Q(10),QD(10)
C
      COMMON/A10/CR,LF,PQ
C
      DATA DP/10/
C
   10 FORMAT("0","ERROR (TLU) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF(NT.GT.PT) WRITE(LF,10)
      IF(ND.GT.NT) WRITE(LP,10)
      IF(ND.GT.10) WRITE(LP,10)
      IF(ND.LE. 1) WRITE(LP,10)
C
      YD=0
      NTL=1
      NTU=NT
      NDH=ND/2
  100 CONTINUE
      NTD=NTU-NTL $IF(NTD.LE.1) GO TO 110
      NTA=(NTL+NTU)/2
      IF(MX.LT.0) ASSIGN 101 TO IX
      IF(MX.GT.0) ASSIGN 102 TO IX
      GO TO IX,(101,102)
  101 CONTINUE
      IF(X-TX(NTA)) 113,111,112
  102 CONTINUE
      IF(X-TX(NTA)) 112,111,113
  113 CONTINUE
      NTL=NTA $GO TO 100
  112 CONTINUE
      NTU=NTA $GO TO 100
  111 CONTINUE
      Y=TY(NTA) $IF(MD.EQ.0) RETURN
      NTL=NTA
  110 CONTINUE
      NDL=NTL-NDH+1 $IF(NDU.GT.NT) NDL=NT-ND+1
      NDU=NTL+NDH+1 $IF(NDL.LT. 1) NDL=1
      DO 131 J=1,ND $K=NDL+J-1
      P (J)=TX(K)
      Q (J)=TY(K)
      QD(J)=0
  131 CONTINUE
      I=ND-1
      DO 141 J=1,I $L=J+1
      DO 141 K=L,ND
      PKMJ=P(K)-P(J)
      QKMJ=Q(K)-Q(J)
      XMPJ=X    -P(J)
      XMPK=X    -P(K)
      Q (K)=(XMPJ*Q(K)-XMPK*Q(J))/PKMJ
      QD(K)=(QKMJ+XMPJ*QD(K)-XMPK*QD(J))/PKMJ
  141 CONTINUE
      Y =Q (ND) $IF(X.EQ.TX(NTA)) Y=TY(NTA)
      YD=QD(ND)
C
      RETURN
      END
```

```
C**********************************************************************
      COMPLEX FUNCTION IF(XI,XF,NX,MX,NP,FNCTN,X,Y,PW)
C
C     NEWTON/COTES PARABOLIC RULE
C
      INTEGER PW
      INTEGER CR,LP,PQ
      COMPLEX Y
      COMPLEX EVEN,ODD
      COMPLEX YI,YF
      COMPLEX YE,YO
      COMPLEX FNCTN
      COMPLEX I
      LOGICAL TEST
C
      DIMENSION X(PW),Y(PW)
C
      COMMON/A10/CR,LP,PQ
      COMMON/D21/XX,XXX
C
   10 FORMAT("0","ERROR (IF) : PARAMETER LIMITS NOT SATISFIED"//)
C
      CALL PARITY(NP,TEST)
C
      IF(NP.LT.5) WRITE(LP,10) $IF(TEST) WRITE(LP,10)
C
      I=0
      ML=-1
      NXM1=NX-1
      NPM1=NP-1
      NPM2=NP-2
      DO 100 IX=1,NXM1,1
      IM=IX
      IP=IX+1
      XM=AF(XI,XF,NX,IM,MX)
      XP=AF(XI,XF,NX,IP,MX)
      XD=(XP-XM)/NPM1
      YI=FNCTN(XX,XM,X,Y,PW)
      YF=FNCTN(XX,XP,X,Y,PW)
      EVEN=0
      ODD =0
      DO 101 IE=2,NPM1,2
      XE=AF(XM,XP,NP,IE,ML)
      YE=FNCTN(XX,XE,X,Y,PW)
      EVEN=EVEN+YE
  101 CONTINUE
      DO 102 IO=3,NPM2,2
      XO=AF(XM,XP,NP,IO,ML)
      YO=FNCTN(XX,XO,X,Y,PW)
      ODD=ODD+YO
  102 CONTINUE
      I=I+(XD/3)*(YI+4*EVEN+2*ODD+YF)
  100 CONTINUE
      IF=I
C
      RETURN
      END
C**********************************************************************
      SUBROUTINE PARITY(IT,TEST)
C
C     ODD/EVEN
C
      LOGICAL TEST
C
```

```
      IC=(IT/2)*2
      IF(IC.EQ.IT) TEST=.TRUE.
      IF(IC.NE.IT) TEST=.FALSE.
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION QF(XI,XF,NX,MX,NQ,FNCTN,X,Y,PW)
C
C     GAUSS/LEGENDRE QUADRATURE
C
C     PARAMETER GL=5
C
      INTEGER GL
      INTEGER PW
      INTEGER CR,LP,PQ
      COMPLEX Y
      COMPLEX I
      COMPLEX TERM,SUM
      COMPLEX FNCTN
C
      DIMENSION X(PW),Y(PW)
      DIMENSION RL(5,5)
      DIMENSION WL(5,5)
C
      COMMON/A10/CR,LF,PQ
      COMMON/D21/XX,XXX
C
      DATA GL/5/
      DATA RL
     +/+0.00000000,-0.57735027,-0.77459667,-0.86113631,-0.90617984,
     + +0.00000000,+0.57735027,+0.00000000,-0.33998104,-0.53846931,
     + +0.00000000,+0.00000000,+0.77459667,+0.33998104,+0.00000000,
     + +0.00000000,+0.00000000,+0.00000000,+0.86113631,+0.53846931,
     + +0.00000000,+0.00000000,+0.00000000,+0.00000000,+0.90617984/
      DATA WL
     +/+2.00000000,+1.00000000,+0.55555556,+0.34785484,+0.23692689,
     + +0.00000000,+1.00000000,+0.88888889,+0.65214514,+0.47862869,
     + +0.00000000,+0.00000000,+0.55555556,+0.65214514,+0.56888889,
     + +0.00000000,+0.00000000,+0.00000000,+0.34785484,+0.47862869,
     + +0.00000000,+0.00000000,+0.00000000,+0.00000000,+0.23692689/
C
   10 FORMAT("0","ERROR (QF) : PARAMETER LIMITS NOT SATISFIED"//)
C
      IF(NQ.GT.GL) WRITE(LP,10)
C
      I=0
      NXM1=NX-1
      DO 101 IX=1,NXM1,1
      IM=IX
      IP=IX+1
      XM=AF(XI,XF,NX,IM,MX)
      XP=AF(XI,XF,NX,IP,MX)
      XA=(XP-XM)/2
      XC=(XP+XM)/2
      SUM=0
      DO 102 IQ=1,NQ,1
      XS=XC+RL(NQ,IQ)*XA
      TERM=WL(NQ,IQ)*FNCTN(XX,XS,X,Y,PW)
      SUM=SUM+TERM
  102 CONTINUE
      I=I+XA*SUM
  101 CONTINUE
      QF=I
```

```
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION NRF(X,FF,FDF)
C
C     NEWTON/RAPHSON
C
      INTEGER CR,LP,PQ
C
      COMMON/A10/CR,LP,PQ
      COMMON/B11/IMX,EMX
C
   10 FORMAT("0","ERROR (NRF) : MAXIMUM ITERATION LIMIT EXCEEDED"//)
C
      XM=X
      DO 101 II=1,IMX,1
      F=FF(XM)
      FD=FDF(XM)
      XP=XM/2 $IF(FD.NE.0) XP=XM-F/FD
      DIF=ABS(XP-XM)
      ERR=DIF $IF(XM.NE.0) ERR=DIF/XM
      IF(ERR.LT.EMX) GO TO 100
      XM=XP
  101 CONTINUE
      WRITE(LP,10)
  100 CONTINUE
      NRF=XP
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE SRM(KN,N,RTS,MAXIT,EP1,EP2,FN,FNREAL)
C
C     MULLER METHOD
C     HENRICI,"ELEMENTS OF NUMERICAL ANALYSIS",PP. 198-2
C     MULLER,"A METHOD OF SOLVING ALGEBRAIC EQUATIONS"
C     MATH TABLES AND AIDS TO COMFUTATION 10 (1956), PP. 208-215
C
      COMPLEX RTS(1)
      LOGICAL FNREAL
      COMPLEX X0,X1,X2,FX0,FX1,FX2,RT,FRT,FPRT,DEN
      COMPLEX A2,B2,C2,D2,E2,F2,H2,Q2,Q21
      EPS1=EP1
      EPS2=EP2
      IF(EPS1.LE.0.0) EPS1=1.0E-12
      IF(EPS2.LE.0.0) EPS2=1.0E-20
      KNL=KN
      NL=KN+N
   10 CONTINUE
      IF(KNL.LT.NL) GO TO 20
      RETURN
   20 KNL=KNL+1
      KOUNT=0
   30 X0=RTS(KNL)-0.5
      ASSIGN 40 TO NN
      RT=X0
      GO TO 80
   40 FX0=FPRT
      X1=RTS(KNL)+0.5
      ASSIGN 50 TO NN
      RT=X1
      GO TO 80
   50 FX1=FPRT
```

```
      X2=RTS(KNL)
      ASSIGN 60 TO NN
      RT=X2
      GO TO 80
   60 FX2=FPRT
      H2=X2-X1
      Q2=(X2-X1)/(X1-X0)
   65 CONTINUE
      Q21=Q2+1.0
      A2=Q2*(FX2-Q21*FX1+Q2*FX0)
      B2=(Q21+Q2)*FX2-Q21*Q21*FX1+Q2*Q2*FX0
      C2=Q21*FX2
      D2=B2*B2-4.0*A2*C2
      IF((FNREAL).AND.(REAL(D2).LT.0.0)) D2=0.0
      D2=CSQRT(D2)
      E2=B2+D2
      F2=B2-D2
      IF(CABS(F2).GT.CABS(E2)) E2=F2
      IF(CABS(E2).GT.0.0) GO TO 70
      E2=1.0
   70 CONTINUE
      Q2=-2.0*C2/E2
      FX0=FX1
      FX1=FX2
      H2=H2*Q2
      RT=RT+H2
      ASSIGN 75 TO NN
      GO TO 80
   75 CONTINUE
      FX2=FPRT
      IF(CABS(H2).LT.EPS1*CABS(RT)) GO TO 100
      IF((CABS(FRT).LT.EPS2).AND.(CABS(FPRT).LT.EPS2)) GO TO 100
      IF(KOUNT.GT.MAXIT) GO TO 100
      IF(CABS(FX2).LT.10.0*CABS(FX1)) GO TO 65
      H2=0.5*H2
      Q2=0.5*Q2
      TR=TR-H2
   80 CONTINUE
      KOUNT=KOUNT+1
      CALL FN(RT,FRT)
      FPRT=FRT
      IF(KNL.LT.2) GO TO 91
      DO 90 I=2,KNL
      DEN=RT-RTS(I-1)
      IF(CABS(DEN).LT.EPS2) GO TO 92
   90 FPRT=FPRT/DEN
   91 CONTINUE
      GO TO NN,(40,50,60,75)
  100 CONTINUE
      RTS(KNL)=RT
      GO TO 10
   92 RT=RT+0.001
      GO TO 80
      END
C***********************************************************************
      SUBROUTINE BNHF(ORD,ARG,BF,NF,HFM,HFP)
C
C     BESSEL  FUNCTIONS
C     NEUMANN FUNCTIONS
C     HANKEL  FUNCTIONS
C
      INTEGER ORD,OA
      REAL    MOD
      COMPLEX CI
```

```
      COMPLEX ARG
      COMPLEX BF,NF,HFM,HFP
C
      DATA POLE/1.0E+38/
      DATA BPL/0.001/
      DATA BPU/10.0/
C
      CI=CMPLX(0.0,1.0)
C
      OA=IABS(ORD)
      MOD=CABS(ARG)
C
      BF=+0 $IF(OA.EQ.0) BF=+1
      NF=-POLE
      HFM=BF-CI*NF
      HFP=BF+CI*NF
C
      IF (MOD.EQ.0)                     RETURN
      IF (MOD.LT.BPL)                   CALL SRAS(OA,ARG,BF,NF,HFM,HFP)
      IF((MOD.GE.BPL).AND.(MOD.LE.BPU)) CALL SRRS(OA,ARG,BF,NF,HFM,HFP)
      IF                  (MOD.GT.BPU)  CALL SRAL(OA,ARG,BF,NF,HFM,HFP)
C
      IF(ORD.GT.0) RETURN
C
      BF=((-1)**OA)*BF
      NF=((-1)**OA)*NF
      HFM=BF-CI*NF
      HFP=BF+CI*NF
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE SRAS(ORD,ARG,BF,NF,HFM,HFP)
C
C     ASYMPTOTIC EXPANSION (SMALL ARGUMENTS)
C
      INTEGER ORD
      COMPLEX CI
      COMPLEX ARG,AD2
      COMPLEX BF,NF,HFM,HFP
C
      DATA PI/3.14159263/
C
      CI=CMPLX(0.0,1.0)
C
      AD2=ARG/2
C
      FP=FF(ORD)
      FM=FF(ORD-1)
C
      BF=+(AD2**(+ORD))/FP
      NF=-(AD2**(-ORD))*(FM/PI) $IF(ORD.EQ.0) NF=(2/PI)*CLOG(ARG)
      HFM=BF-CI*NF
      HFP=BF+CI*NF
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE SRRS(ORD,ARG,BF,NF,HFM,HFP)
C
C     ASCENDING SERIES
C
      INTEGER ORD,OM1,OP1
      COMPLEX CI
```

```
      COMPLEX ARG,AD2
      COMPLEX TM,TP
      COMPLEX SB,SN,SY
      COMPLEX BSF,NSF,YSF
      COMPLEX YF,NFM,NFP
      COMPLEX BF,NF,HFM,HFP
C
      COMMON/B11/IMX,EMX
C
      DATA PI/3.14159263/
C
      CI=CMPLX(0.0,1.0)
C
      OM1=ORD-1
      OP1=ORD+1
C
      AD2=ARG/2 $TM=AD2**(-ORD) $TP=AD2**(+ORD)
C
      FO  =FF(ORD) $G1  =GF(  1)
      FOM1=FF(OM1) $GOP1=GF(OP1)
                    GO=G1+GOP1
C
      SB=BSF(ORD,ARG)
      SN=NSF(ORD,ARG,GO)
      SY=YSF(ORD,ARG)
C
      BF=(TP/FO)*SB
      YF=(2/PI)*CLOG(AD2)*BF
      NFM=-(TM/PI)*FOM1*SY
      NFP=-(TP/PI)*(1/FO)*SN
      NF=YF+NFM+NFP
      HFM=BF-CI*NF
      HFP=BF+CI*NF
C
      RETURN
      END
C**********************************************************************
      SUBROUTINE SRAL(ORD,ARG,BF,NF,HFM,HFP)
C
C     ASYMPTOTIC EXPANSION (LARGE ARGUMENTS)
C
      INTEGER ORD
      COMPLEX ARG
      COMPLEX CI
      COMPLEX CC
      COMPLEX X,C
      COMPLEX CX,SX
      COMPLEX AMX,APX
      COMPLEX EMX,EPX
      COMPLEX P,Q
      COMPLEX BF,NF,HFM,HFP
      COMPLEX DCEXP
C
      DATA PI/3.14159263/
C
      CI=CMPLX(0.0,1.0)
C
      X=ARG-(2*ORD+1)*(PI/4) $CX=CCOS(X) $SX=CSIN(X)
      CC=2/(PI*ARG) $C=CSQRT(CC)
C
      AMX=-CI*X $EMX=DCEXP(AMX)
      APX=+CI*X $EPX=DCEXP(APX)
C
      CALL SRPQ(ORD,ARG,P,Q)
```

```
C
      BF=C*(P*CX-Q*SX)
      NF=C*(P*SX+Q*CX)
      HFM=C*(P-CI*Q)*EMX
      HFP=C*(P+CI*Q)*EPX
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE SRPQ(ORD,ARG,P,Q)
C
C     HANKEL ASYMPTOTIC EXPANSIONS
C
      INTEGER CR,LP,PQ
      INTEGER ORD,OM
      INTEGER SGN
      COMPLEX ARG,AT8
      COMPLEX T,S
      COMPLEX P,Q
C
      COMMON/A10/CR,LP,PQ
      COMMON/B11/IMX,EMX
C
   10 FORMAT("0","ERROR (SRPQ) : MAXIMUM ITERATION LIMIT EXCEEDED"//)
C
      P=1 $EP=1
      Q=0 $EQ=1
      T=1
C
      OM=4*ORD*ORD
      AT8=8*ARG
C
      DO 101 IX=1,IMX,2 $IXP1=IX+1
      DO 102 IY=IX,IXP1,1
      SGN=-(-1)**IY
      IO=2*IY-1 $IS=IO*IO
      S=SGN*((OM-IS)/(IY*AT8))
      T=T*S
      IF(SGN.EQ.-1) P=P+T
      IF(SGN.EQ.+1) Q=Q+T
 102  CONTINUE
      IF(CABS(P).NE.0) EP=CABS(T/P)
      IF(CABS(Q).NE.0) EQ=CABS(T/Q)
      ERR=AMAX1(EP,EQ) $IF(ERR.LT.EMX) GO TO 100
 101  CONTINUE
      WRITE(LP,10)
 100  CONTINUE
C
      RETURN
      END
C*********************************************************************
      SUBROUTINE MBNHF(ORD,ARG,MBF,MNF,MHFM,MHFP)
C
C     MODIFIED BESSEL  FUNCTIONS
C     MODIFIED NEUMANN FUNCTIONS
C     MODIFIED HANKEL  FUNCTIONS
C
      INTEGER ORD
      COMPLEX CI
      COMPLEX ARG,CA
      COMPLEX BF,NF,HFM,HFP
      COMPLEX MBF,MNF,MHFM,MHFP
C
      DATA PI/3.14159263/
```

```
C
      CI=CMPLX(0.0,1.0)
C
      CA=CI*ARG $CALL BNHF(ORD,CA,BF,NF,HFM,HFP)
C
      MBF=(CI**(-ORD))*BF
      MNF=NF
      MHFM=(PI/2)*(CI**(ORD+1))*HFM
      MHFP=(PI/2)*(CI**(ORD+1))*HFP
C
      RETURN
      END
C**********************************************************************
      COMPLEX FUNCTION BSF(ORD,ARG)
C
C     BESSEL SERIES
C
      INTEGER CR,LP,PQ
      INTEGER ORD
      COMPLEX ARG,AD2
      COMPLEX TC,TR,TB,SB
C
      COMMON/A10/CR,LP,PQ
      COMMON/B11/IMX,EMX
C
   10 FORMAT("0","ERROR (BSF) : MAXIMUM ITERATION LIMIT EXCEEDED"//)
C
      AD2=ARG/2 $TC=AD2**2
C
      TB=1 $SB=1 $EB=1
C
      DO 101 IX=1,IMX,1
      TR=-TC/(IX*(IX+ORD))
      TB=TB*TR
      SB=SB+TB
      IF(CABS(SB).NE.0) EB=CABS(TB/SB) $IF(EB.LT.EMX) GO TO 100
 101  CONTINUE
      WRITE(LP,10)
 100  CONTINUE
      BSF=SB
C
      RETURN
      END
C**********************************************************************
      COMPLEX FUNCTION NSF(ORD,ARG,GO)
C
C     NEUMAN SERIES
C
      INTEGER CR,LP,PQ
      INTEGER ORD
      COMPLEX ARG,AD2
      COMPLEX TS,TP
      COMPLEX TC,TR,TX,TN,SN
C
      COMMON/A10/CR,LP,PQ
      COMMON/B11/IMX,EMX
C
   10 FORMAT("0","ERROR (NSF) : MAXIMUM ITERATION LIMIT EXCEEDEC "//)
C
      AD2=ARG/2 $TC=AD2**2
C
      TS=GO $SN=TS $EN=1
      TP=1
      TN=TP
```

```
C
      DO 101 IX=1,IMX,1
      TX=+FLOAT(1)/IX+FLOAT(1)/(IX+ORD)
      TS=TS+TX
      TR=-TC/(IX*(IX+ORD))
      TP=TP*TR
      TN=TS*TP
      SN=SN+TN
      IF(CABS(SN).NE.0) EN=CABS(TN/SN) $IF(EN.LT.EMX) GO TO 100
  101 CONTINUE
      WRITE(LP,10)
  100 CONTINUE
      NSF=SN
C
      RETURN
      END
C***********************************************************************
      COMPLEX FUNCTION YSF(ORD,ARG)
C
C     NEUMANN SERIES
C
      INTEGER ORD,OM1
      COMPLEX ARG,AD2
      COMPLEX TC,TR,TY,SY
C
      YSF=0 $IF(ORD.EQ.0) RETURN
      YSF=1 $IF(ORD.EQ.1) RETURN
C
      OM1=ORD-1
C
      AD2=ARG/2 $TC=AD2**2
C
      TY=1 $SY=1
C
      DO 100 IX=1,OM1,1
      TR=+TC/(IX*(ORD-IX))
      TY=TY*TR
      SY=SY+TY
  100 CONTINUE
      YSF=SY
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION FF(IR)
C
C     FACTORIAL
C
      FF=1 $IF(IR.LT.1) RETURN
C
      F=1
      DO 111 IX=1,IR,1
      F=F*IX
  111 CONTINUE
      FF=F
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION GF(IR)
C
C     GAMMA
C
      DATA GAMMA/0.577215664901533/
```

```
C
      GF=-GAMMA $IF(IR.EQ.1) RETURN
C
      SUM=0
      IRM1=IR-1
      DO 100 IX=1,IRM1,1
      TERM=FLOAT(1)/IX
      SUM=SUM+TERM
 100  CONTINUE
      GF=-GAMMA+SUM
C
      RETURN
      END
C****************************************************************
      REAL FUNCTION CANG(C)
C
C     COMPLEX ANGLE
C
      REAL    R.I
      COMPLEX C
C
      CANG=0
      R= REAL(C) $IF(R.EQ.0) RETURN
      I=AIMAG(C)
      CANG=ATAN2(I,R)
C
      RETURN
      END
C****************************************************************
      COMPLEX FUNCTION DCEXP(C)
C
C     DOUBLE PRECISION COMPLEX EXPONENTIAL
C
      DOUBLE PRECISION DR,DI
      DOUBLE PRECISION DE,DC.DS
C
      COMPLEX CC
      COMPLEX C
      COMPLEX EXP
C
      CC=CMPLX(0.0,1.0)
C
      CR= REAL(C) $DR=DBLE(CR)
      CI=AIMAG(C) $DI=DBLE(CI)
C
      DE=DEXP(DR) $SE=SNGL(DE)
      DC=DCOS(DI) $SC=SNGL(DC)
      DS=DSIN(DI) $SS=SNGL(DS)
C
      EXP=SE*(SC+CC*SS) $DCEXP=EXP
C
      RETURN
      END
C****************************************************************
      SUBROUTINE FTDR(DU,DATA,PX.PY)
C
C     FASTRAN DRUM READ
C
      INTEGER PX.PY
      INTEGER CK,LP,PD
      INTEGER DU
      INTEGER DMN
      INTEGER RD
      INTEGER END.EOF
```

```
      INTEGER RWND.WAIT
      COMPLEX DATA
C
      DIMENSION DATA(PX,PY)
C
      COMMON/A10/CR,LP,PQ
C
      DATA RWND/10/
      DATA RD  / 2/
      DATA WAIT/22/
C
   10 FORMAT("0","READ  TRANSFER COMPLETE / DRUM :",I10)
   11 FORMAT("0","READ  TRANSFER ERROR    / UNIT :",I10/
     +         " ","                      / END  :",I10/
     +         " ","                      / EOF  :",I10)
C
      DMN=PX*PY $END=DMN $EOF=DMN
C
C     CALL NTRAN(DU,RWND)
C     CALL NTRAN(DU,RD ,END,DATA,EOF)
C     CALL NTRAN(DU,WAIT)
C
      READ(DU) DATA
C
      IF(EOF.EQ.END) WRITE(LP,10) DU
      IF(EOF.NE.END) WRITE(LP,11) DU,END,EOF
C
      RETURN
      END
C***************************************************************************
      SUBROUTINE FTDW(DU,DATA,PX,PY)
C
C     FASTRAN DRUM WRITE
C
      INTEGER PX,PY
      INTEGER CR,LP,PQ
      INTEGER DU
      INTEGER DMN
      INTEGER WRT
      INTEGER END,EOF
      INTEGER RWND,WAIT
      COMPLEX DATA
C
      DIMENSION DATA(PX,PY)
C
      COMMON/A10/CR,LP,PQ
C
      DATA RWND/10/
      DATA WRT / 1/
      DATA WAIT/22/
C
   10 FORMAT("0","WRITE TRANSFER COMPLETE / DRUM :",I10)
   11 FORMAT("0","WRITE TRANSFER ERROR    / UNIT :",I10/
     +         " ","                      / END  :",I10/
     +         " ","                      / EOF  :",I10)
C
      DMN=PX*PY $END=DMN $EOF=DMN
C
C     CALL NTRAN(DU,RWND)
C     CALL NTRAN(DU,WRT,END,DATA,EOF)
C     CALL NTRAN(DU,WAIT)
C
      WRITE(DU) DATA
C
```

```
      IF(EOF.EQ.END) WRITE(LP,10) DU
      IF(EOF.NE.END) WRITE(LP,11) DU,END,EOF
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION RDF(AR)
C
C     RADIAN/DEGREE
C
      DATA PI/3.14159265/
C
      AD=AR*(180/PI) $RDF=AD
C
      RETURN
      END
C***********************************************************************
      REAL FUNCTION DRF(AD)
C
C     DEGREE/RADIAN
C
      DATA PI/3.14159265/
C
      AR=AD*(PI/180) $DRF=AR
C
      RETURN
      END
```

APPENDIX B

Sample Input Data Listing

```
       100     1.0E-10                                                  IMX,EMX
         11.0       20.0                                                ML,RL,SL
0.0       1.0               -1                                          MIN,MAX
        +3         0        +1                                          NO,MO,MX
         4         5                                                    NQ,NI
         6         3                                                    MN,NM
         1         1         1         1         1         1            MPS
         0         0         0         0         0         0            RPS
         0         1         1         1         1         1            WPS
         0                                                              MR
         1                                                              MP
 100.0E-06     1.0E+06                                                  TM,WM
        51        51                                                    NK,NC
1000.0    1000.0    1000.0                                              CG
   1.0E+030.5       0.5                0         0                      PS
  20.0E+030.5       0.5                0         1                      RX
   1.0E+030.5       0.5                0         0                      RS
0.0          1.0E-06 100.0E-06   1.0E-06   1.0E-06                      PS
0.0          1.0E-06 100.0E-06   1.0E-06   1.0E-06                      RX
0.0          1.0E-06 100.0E-06  40.0E-03 120.0E-03                      RS
-2.000E+03+2.000E+03        41                                          EI,EF,NE
-0.000E+03+1.000E+03        41                                          XI,XF,NX
-0.000E+03+1.000E+03         3                                          YI,YF,NY
   1.0E+03    +1.0E+06        61                                        WI,WF,NW
   0.0E-03     1.0E-03        61                                        TI,TF,NT
        -1        -1        -1        +1        -1                      MEXYWT
         1        41        10                                          IEIFN
         1        41        10                                          IXIFN
         1         3         1                                          IYIFN
         1        61        20                                          IWIFN
         1        61        10                                          ITIFN
 0.813E-03                                                              RW
 2.953E-03 3.953E-03                                                    RSM,RSP
 4.953E-03 5.953E-03                                                    RAM,RAP
 6.953E-03                                                              RC
1.0                                                                     DO
0.0                                                                     SO
1.0       5.0          1.5E-03                                          RUEOE
1.0       2.26         1.0E-03                                          RUEOI
1.0       1.0          5.7E+07                                          RUEOA
1.0       2.26         1.0E-03                                          RUEO2
1.0       1.0          5.7E+07                                          RUEOS
1.0       2.26         1.0E-03                                          RUEO1
1.0       1.0          5.7E+07                                          RUEOW
50.0      0.0                                                           ZL1
50.0      0.0                                                           ZL2
         1                                                              MIO
         1                                                              MLC
FIGURE 1  : LIGHTNING PULSE (TIME DOMAIN) VS TIME
NA
PULSE (A)
TIME (S)
         0         0         1         1         1                      MTPGK
0.0         20.0E+03        -1
FIGURE 2  : LIGHTNING PULSE (FREQUENCY DOMAIN) VS FREQUENCY
NA
PULSE (A)
FREQUENCY (RAD)
         1         0         1         1         2                      MTPGC
-1.42     +2.86             -1
FIGURE 3A : OUTER EXCITATION (FREQUENCY DOMAIN) VS POSITION
FREQUENCY
EXCITATION (V/M)
POSITION (M)
```

```
         0         0         1         1         2                      MTPGX E
 -1.15E-06 +1.22E-03        -1
FIGURE 3B : OUTER EXCITATION (FREQUENCY DOMAIN) VS FREQUENCY
POSITION
EXCITATION (V/M)
FREQUENCY (RAD)
         1         0         0         0         0                      MTPGW E
 -1.15E-06 +1.22E-03        -1
FIGURE 4A : OUTER CURRENT (FREQUENCY DOMAIN) VS POSITION
FREQUENCY
CURRENT (A)
POSITION (M)
         0         0         1         1         2                      MTPGX O
-0.0396   +0.146            -1
FIGURE 4B : OUTER CURRENT (FREQUENCY DOMAIN) VS FREQUENCY
POSITION
CURRENT (A)
FREQUENCY (RAD)
         1         0         0         0         0                      MTPGW O
-0.0395   +0.146            -1
FIGURE 5  : TRANSFER RATIO (FREQUENCY DOMAIN) VS FREQUENCY
NA
TRANSFER RATIO
FREQUENCY (RAD)
         1         0         1         1         2                      MTPGW T
-0.0290   +0.0358           -1
FIGURE 6A : INNER EXCITATION (FREQUENCY DOMAIN) VS POSITION
FREQUENCY
EXCITATION (V/M)
POSITION (M)
         0         0         1         1         2                      MTPGX E
 -1.15E-06 +1.22E-03        -1
FIGURE 6B : INNER EXCITATION (FREQUENCY DOMAIN) VS FREQUENCY
POSITION
EXCITATION (V/M)
FREQUENCY (RAD)
         1         0         0         0         0                      MTPGW E
 -1.15E-06 +1.22E-03        -1
FIGURE 7A : INNER CURRENT (FREQUENCY DOMAIN) VS POSITION
FREQUENCY
CURRENT (A)
POSITION (M)
         0         0         0         0         0                      MTPGX I
-0.00189  +0.00522          -1
FIGURE 7B : INNER CURRENT (FREQUENCY DOMAIN) VS FREQUENCY
POSITION
CURRENT (A)
FREQUENCY (RAD)
         1         0         1         1         2                      MTPGW I
-0.00189  +0.00522          -1
FIGURE 7C : INNER VOLTAGE (FREQUENCY DOMAIN) VS POSITION
FREQUENCY
VOLTAGE (V)
POSITION (M)
         0         0         0         0         0                      MTPGX I
-0.00560  +0.0163           -1
FIGURE 7D : INNER VOLTAGE (FREQUENCY DOMAIN) VS FREQUENCY
POSITION
VOLTAGE (V)
FREQUENCY (RAD)
         1         0         1         1         2                      MTPGW I
-0.00560  +0.0163           -1
FIGURE 8A : INNER CURRENT (TIME DOMAIN) VS POSITION
TIME
```

```
CURRENT (A)
POSITION (M)                                                                    MTPGX T
          0          0           0          0          0
                                -1
-0.0       +12.5
FIGURE 8B : INNER CURRENT (TIME DOMAIN) VS TIME
POSITION
CURRENT (A)
TIME (S)                                                                        MTPGT T
          0          0           1          1          2
                                -1
-0.0       +12.3
FIGURE 8C : INNER VOLTAGE (TIME DOMAIN) VS POSITION
TIME
VOLTAGE (V)
POSITION (M)                                                                    MTPGX T
          0          0           0          0          0
                                -1
-0.333     +38.6
FIGURE 8D : INNER VOLTAGE (TIME DOMAIN) VS TIME
POSITION
VOLTAGE (V)
TIME (S)                                                                        MTPGT T
          0          0           1          1       +999
                                -1
-0.333     +38.6
```

APPENDIX C

FAA Lightning Study Participants

Florida Institute of Technology - Cable Testing

Dr. Andrew W. Revay, Jr.
Richard M. Cosel

Lightning and Transient Research Institute - High Voltage Facility

James C. Stahmann

Purdue University - Protective Devices

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Georgia Institute of Technology - Equipment Analysis

Keith Huddleston
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Air Force Institute of Technology - Reliability Aspects

Professor T. L. Regulinski

Augustana Research Institute

Dr. Jerry L. Hanson

Table 1. List of Input Cards and Formats

Card	Label	Format
1	IMX,JMX,EMX	2I10,G10.0
2	ML,RL,SL	I10,2G10.0
3	MIN,MAX,MP	2G10.0,I10
4	ND,MD,MXX	3I10
5	NQ,NI	2I10
6	IFT,JFT	2I10
7	NM,MN	2I10
8	MLS,MCO,MTT,MCI,MTL,MFT	6I10
9	RLS,RCO,RTT,RCI,RTL,RFT	6I10
10	WLS,WCO,WTT,WCI,WTL,WFT	6I10
11	MR,MG	2I10
12	NR,IR	2I10
13	TPK	G10.0
14	EPK	G10.0
15	MQ	I10
16	TM,WM	2G10.0
17	NK,NC	2I10
18	PGPS,PGRX,PGRS	3G10.0
19	PSPS,DCPS,DKPS,MPS,NPS	3G10.0,2I10
20	PSRX,DCRX,DKRX,MRX,NRX	3G10.0,2I10
21	PSRS,DCRS,DKRS,MRS,NRS	3G10.0,2I10
22	TSPS,TRPS,TDPS,TPPS,TCPS	5G10.0
23	TSRX,TRRX,TDRX,TPRX,TCRX	5G10.0
24	TSRS,TRRS,TDRS,TPRS,TCRS	5G10.0
25	SI,SF,NS	2G10.0,I10
26	XI,XF,NX	2G10.0,I10
27	YI,YF,NY	2G10.0,I10
28	WI,WF,NW	2G10.0,I10
29	TI,TF,NT	2G10.0,I10
30	MS,MX,MX,MW,MT	5I10
31	IEI,IEF,NEI	3I10
32	IXI,IXF,NXI	3I10
33	IYI,IYF,NYI	3I10
34	IWI,IWF,NWI	3I10
35	ITI,ITF,NTI	3I10
36	RW	G10.0
37	RSM,RSP	2G10.0
38	RAM,RAP	2G10.0
39	RS	G10.0
40	ZO	G10.0
41	YO	G10.0
42	URE,ERE,OE	3G10.0
43	URI,ERI,OI	3G10.0
44	URA,ERA,OA	3G10.0
45	UR2,ER2,O2	3G10.0
46	URS,ERS,OS	3G10.0
47	UR1,ER1,O1	3G10.0
48	URW,ERW,OW	3G10.0
49	ZLM	2G10.0
50	ZLP	2G10.0

Numonic	Type	Description	Numonic	Type	Description	
IMX	Integer	MAXIMUM ITERATION	MG	integer	MODE GUESS	
JMX	integer	MAXIMUM DIGITS	NR	integer	ROOT NUMBER	
EMX	real	MAXIMUM ERROR	IR	integer	ROOT INDEX	
ML	integer	LOG MODE	TRK	real	ROOT GUESS	
RL	real	LOG RATIO	ERR	real	ROOT ERROR	
SL	real	LOG SCALE	TM	real	MULTIPLIER	
MTN	real	PLOT MINIMUM	WM	real	MULTIPLIER	
MAX	real	PLOT MAXIMUM	NK	integer	NUMBER OF PULSES	
MP	integer	PLOT MODE	NC	integer	NUMBER OF PULSES	
ND	integer	POLYNOMIAL DEGREE	PGPS	real	PULSE GUESS	PRESTRIKE
MD	integer	CALCULATE DERIVATIVE	PGRX	real	PULSE GUESS	RETURN
MXX	integer	TABLE ORDER	PGRS	real	PULSE GUESS	RESTRIKE
NQ	integer	QUADRATURE GRID	PSPS	real	PULSE PEAK	PRESTRIKE
NI	integer	INTEGRATION INDEX	DCPS	real	DECAY CONSTANT	PRESTRIKE
IFT	integer	INDEX FOURIER TRANSFORM	DKPS	real	DECAY CONSTANT	PRESTRIKE
JFT	integer	INDEX FOURIER TRANSFORM	MPS	integer	MODE DECAY	PRESTRIKE
NM	integer	TITLE NUMBER	NPS	integer	MODE NUMBER	PRESTRIKE
MN	integer	MODE NUMBER	PSRX	real	PULSE PEAK	RETURN
MLS	integer	MODE LIGHTNING STROKE	DCRX	real	DECAY CONSTANT	RETURN
MCO	integer	MODE COUPLE (OUTER)	DKRX	real	DECAY CONSTANT	RETURN
MTT	integer	MODE TRANSFER	MRX	integer	MODE DECAY	RETURN
MCI	integer	MODE COUPLE (INNER)	NRX	integer	MODE NUMBER	RETURN
MTL	integer	MODE TRANSMISSION LINE	PSRS	real	PULSE PEAK	RESTRIKE
TFT	integer	MODE INVERSE	DCRS	real	DECAY CONSTANT	RESTRIKE
RLS	integer	READ STROKE	DKRS	real	DECAY CONSTANT	RESTRIKE
RCO	integer	READ COUPLE (OUTER)	MRS	integer	MODE DECAY	RESTRIKE
RTT	integer	READ TRANSFER	NRS	integer	MODE NUMBER	RESTRIKE
RCI	integer	READ COUPLE (INNER)	TSPS	real	TIME START	PRESTRIKE
RTL	integer	READ TRANSMISSION LINE	TRPS	real	TIME RISE	PRESTRIKE
RFT	integer	READ INVERSE	TDPS	real	TIME DECAY	PRESTRIKE
WLS	integer	WRITE STROKE	TPPS	real	TIME PULSE	PRESTRIKE
WCO	integer	WRITE COUPLE (OUTER)	TCPS	real	TIME CONSTANT	PRESTRIKE
WTT	integer	WRITE TRANSFER	TSRX	real	TIME START	RETURN
WCI	integer	WRITE COUPLE (INNER)	TRRX	real	TIME RISE	RETURN
WTL	integer	WRITE TRANSMISSION LINE	TDRX	real	TIME DECAY	RETURN
WFT	integer	WRITE INVERSE	TPRX	real	TIME PULSE	RETURN
MR	integer	MODE ROUT	TCRX	real	TIME CONSTANT	RETURN

Table 1. (Cont.)

Numonic	Type	Description
TSRS	real	TIME START RESTRIKE
TRRS	real	TIME RISE RESTRIKE
TDRS	real	TIME DECAY RESTRIKE
TPRS	real	TIME PULSE RESTRIKE
TCRS	real	TIME CONSTANT RESTRIKE
SI	real	INITIAL EXCITATION
SF	real	FINAL EXCITATION
NS	integer	NUMBER OF BANDS
XI	real	INITIAL POSITION
XF	real	FINAL POSITION
NX	integer	NUMBER OF BANDS
YI	real	INITIAL POSITION
YF	real	FINAL POSITION
NY	integer	NUMBER OF BANDS
WI	real	INITIAL FREQUENCY
WF	real	FINAL FREQUENCY
NW	integer	NUMBER OF BANDS
TI	real	INITIAL TIME
TF	real	FINAL TIME
NT	integer	NUMBER OF BANDS
MS	integer	MODE EXCITATION
MX	integer	MODE POSITION
MY	integer	MODE POSITION
MW	integer	MODE FREQUENCY
MT	integer	MODE TIME
IEI	integer	INITIAL EXCITATION
IEF	integer	FINAL EXCITATION
NEI	integer	NUMBER OF EXCITATIONS
IXI	integer	INITIAL POSITION
IXF	integer	FINAL POSITION
NXI	integer	NUMBER OF SAMPLES
IYI	integer	INITIAL POSITION
IYF	integer	FINAL POSITION
NYI	integer	NUMBER OF SAMPLES
IWI	integer	INITIAL FREQUENCY
IWF	integer	FINAL FREQUENCY
NWI	integer	NUMBER OF SAMPLES
ITI	integer	INITIAL TIME
ITF	integer	FINAL TIME
NTI	integer	NUMBER OF SAMPLES
RW	real	RADIUS WIRE
RSM	real	RADIUS SHIELD MINUS
RSP	real	RADIUS SHIELD PLUS
RAM	real	RADIUS ARMOR MINUS
RAP	real	RADIUS ARMOR PLUS
RS	real	RADIUS SHEATH
DO	real	DEPTH
SO	real	SEPARATION
URE	real	RELATIVE PERMEABILITY EARTH
ERE	real	RELATIVE PERMITTIVITY EARTH
OE	real	ABSOLUTE CONDUCTIVITY EARTH
URI	real	RELATIVE PERMEABILITY SHEATH
ERI	real	RELATIVE PERMITTIVITY SHEATH
OI	real	ABSOLUTE CONDUCTIVITY SHEATH
URA	real	RELATIVE PERMEABILITY ARMOR
ERA	real	RELATIVE PERMITTIVITY ARMOR
OA	real	ABSOLUTE CONDUCTIVITY ARMOR
UR2	real	RELATIVE PERMEABILITY 2
ER2	real	RELATIVE PERMITTIVITY 2
O2	real	ABSOLUTE CONDUCTIVITY 2
URS	real	RELATIVE PERMEABILITY SHIELD
ERS	real	RELATIVE PERMITTIVITY SHIELD
OS	real	ABSOLUTE CONDUCTIVITY SHIELD
UR1	real	RELATIVE PERMEABILITY 1
ER1	real	RELATIVE PERMITTIVITY 1
O1	real	ABSOLUTE CONDUCTIVITY 1
URW	real	RELATIVE PERMEABILITY WIRE
ERW	real	RELATIVE PERMITTIVITY WIRE
OW	real	ABSOLUTE CONDUCTIVITY WIRE
ZLM	complex	LOAD IMPEDANCE MINUS
ZLP	complex	LOAD IMPEDANCE PLUS

Table 1. (Cont.)

Table 2. Peak current and voltage, rise time, and half-life decay time of the pulses on the inner conductor.

	current (amps)									voltage (volts)								
d	0_m			500_m			1000_m			0_m			500_m			1000_m		
	I_{peak}	t_p	t_d	I_{peak}	t_p	t_d	I_{peak}	t_p	t_d	V_{peak}	t_p	t_d	V_{peak}	t_p	t_d	V_{peak}	t_p	t_d
0	36.5	25μs	85μs	253	45μs	110μs	13.1	50μs	110μs	128	15μs	45μs	674	30μs	90μs	652	50μs	110μs
10	36.2	25μs	85μs	251	45μs	110μs	13.0	50μs	110μs	127	15μs	45μs	669	30μs	90μs	647	50μs	110μs
50	31.3	25μs	85μs	217	45μs	110μs	11.3	50μs	110μs	110	15μs	45μs	579	30μs	90μs	561	50μs	110μs
100	23.9	25μs	85μs	167	45μs	110μs	8.69	50μs	115μs	84.5	15μs	45μs	443	30μs	95μs	432	50μs	115μs
200	15.8	25μs	85μs	112	45μs	110μs	5.81	50μs	115μs	56.0	15μs	45μs	295	30μs	95μs	289	50μs	115μs
500	7.37	25μs	90μs	52.5	45μs	110μs	2.77	45μs	110μs	25.9	15μs	50μs	138	30μs	90μs	137	45μs	110μs
1,000	3.06	25μs	90μs	22.0	45μs	110μs	1.16	45μs	110μs	10.7	15μs	50μs	57.4	30μs	90μs	57.7	45μs	110μs
2,000	0.855	25μs	90μs	6.17	45μs	110μs	.327	45μs	110μs	2.96	15μs	50μs	16.0	30μs	70μs	16.2	45μs	110μs
5,000	0.0848	25μs	90μs	.614	45μs	110μs	0.0325	45μs	110μs	.293	15μs	50μs	1.59	30μs	95μs	1.61	45μs	110μs
10,000	0.0115	25μs	90μs	.0836	45μs	110μs	0.00443	45μs	110μs	0.0397	15μs	50μs	.216	30μs	95μs	.219	45μs	110μs

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