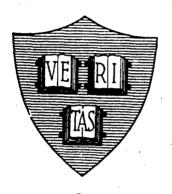
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ELECTRICALLY SMALL LOOP ANTENNA LOADED BY A HOMOGENEOUS AND ISOTROPIC FERRITE CYLINDER-PART II



AD AO 58 527



By

D.V. Giri and R.W. P. King

July 1978

Technical Report No. 868

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1171 (Unclassified SECURITY CLASSIFICATION OF THIS PAGE(When Deta Entered) 20. Abstract (Continued) pole antenna. In the limit $h(\mathcal{P}, \mathcal{P})$ this integral equation is shown to agree with that obtained previously in Part I for the infinite ferrite rod antenna. Continuing to parallel the treatment of the electric dipole antenna, the integral equation is modified by the introduction of an internal impedance per unit length of the magnetic conductor to account for values of $(\hat{\mu}_{\hat{\mathbf{T}}})$ that are large but not infinite, and finally an approximate, three-term expression is derived for the current on an 'imperfectly conducting' magnetic conductor. The second, more rigorous theoretical approach obtains two coupled integral equations in terms of the tangential electric field and the tangential electric surface current from independent treatments of the interior (ferrite) and exterior (free space) problems. The coupled equations are then solved numerically by means of the moment method. Finally the results of the two theories are compared with experimental measurements made on eleven different antenna configurations. The agreement is good. ACCESS off fer n0. Nº iS nt 11 00C C) Uples and JULE P 85 DISCOUPTING PRILING IL CONS CIAL Unclassified SECURITY CLASSIFICATION OF THIS PAGE(When Date Entered)

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By

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Technical Report No. 668

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July 1978

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> Division of Applied Sciences Harvard University · Cambridge, Massachusetts

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ELECTRICALLY SMALL LOOP ANTENNA LOADED BY A HOMOGENEOUS AND ISOTROPIC FERRITE CYLINDER - PART II

By

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ABSTRACT

The problem of a finite, ferrite-rod antenna has been treated theoretically by recognizing an analogy between the ferrite antenna. and the conducting cylindrical dipole antenna which has been studied extensively. Initially the ferrite is idealized to be a perfect magnetic conductor and an Hallén type of integral equation [1] is obtained for the magnetic current. By allowing the antenna height to approach infinity, the formulation is shown to be consistent with previously obtained results for the infinitely long ferrite antenna [2]. Subsequently, the integral equation is modified appropriately to treat the ferrite as an imperfect magnetic conductor, and the curront is obtained in the three-term form of King and Wu [3]. Because this treatment relies rather heavily on a mathematical equivalence of the two problems under idealized driving conditions, an alternative, more rigorous formulation is presented. The result is a pair of coupled integral equations in the tangential electric field (or magnetic current) and the circumferential electric current. The coupled integral equations are solved numerically. An experimental apparatus was fabricated to verify the solutions. Good agreement is obtained for a range of parameters. The experiments were performed for three values of $\Omega = 2 \ln(2h/a) = 8.5534$, 7.4754 and 6.0R9. The electrical radius ak, ranged from .00132 to .01662.

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1. INTRODUCTION

In an earlier report on this subject [2] the magnetic current on a ferrite-rod antenna was derived explicitly in the form of an inverse Fourier integral. The driving loop loaded by an infinitely long, homogeneous and isotropic ferrite rod was assumed to be electrically small so that it carried an essentially constant current I_0^e . When the ferrite rod is assumed to be of infinite length, the magnetic current is equal to a definite integral which is suitable for numerical evaluation. Two values of electrical radii, viz., $ak_0 = 0.05$ and 0.1, were considered and for one of the cases the magnetic current was plotted [2] for several values of the permeability of the ferrite rod ranging from 10 to 200. The total magnetic currents. If u_r and ε_r of the ferrite rod are assumed to be real, the transmission current can be associated with an unattenuated, rotationally symmetric TE surface wave. It was further found that the cutoff condition for this wave is that the electrical radius ak, be greater than 2.405.

In a practical situation, however, the antenna is of necessity finite and electrically short as well, so that a new mathematical formulation along with an experimental investigation is needed for the problem of a finite ferrite-rod antenna. Sections 2 through 8 present the two different theoretical approaches used to determine the magnetic current distribution on the finite ferrite antenna; Section 9 describes the experimental apparatus and results.

2. PROBLEM OF A FINITE FERRITE-ROD ANTENNA

The present formulation is based on the analogy between the cylindrical dipole antenna and the ferrite-rod antenna. The dipole antenna is made up of a wire, rod or tube of high electrical conductivity and may be driven by a

-1-

two-wire line. Equivalently, a monopole antenna fed by a coaxial line corresponds to a dipole antenna through its image in a ground plane. In either configuration, the driving source is represented by an idealized voltage or electric field generator which mathematically takes the form of a delta function. Similarly, the ferrite rod antenna is fabricated from a material of high magnetic permeability and is driven by an electrically small loop antenna carrying a constant current. The loop is, correspondingly, represented by an idealized current or magnetic field generator and takes the form of a delta function. These similarities suggest approaching the problem of the ferrite antenna by treating the ferrite rod as a good magnetic conductor. Initially, however, the ferrite is idealized to be a perfect magnetic conductor ($u_r = \infty$) and, later, appropriate changes are made to account for the finiteness of the value of the permeability of the ferrite material.

3. FERRITE AS A PERFECT MAGNETIC CONDUCTOR

The analogy between the ferrite antenna and the dipole antenna is based on the dual property of electric and magnetic field vectors in Maxwell's equations

$$\mathbf{v} \times \mathbf{\vec{z}} = -\mathbf{\vec{s}}$$

$$\mathbf{v} \times \mathbf{\vec{n}} = \mathbf{J} + \mathbf{\vec{b}}$$

$$\mathbf{v} \cdot \mathbf{\vec{z}} = \mathbf{0}$$

$$\mathbf{v} \cdot \mathbf{\vec{b}} = \mathbf{0}$$

$$(1)$$

Figure 1(a) shows an electrically small loop antenna of diameter 2a. The loop carries a constant current and is assumed to be made up of a wire of infinitesimally small radius. The wire loop is loaded by a ferrite cylinder of height 2h. The ferrite is assumed to have an infinite permeability, in which

-2-

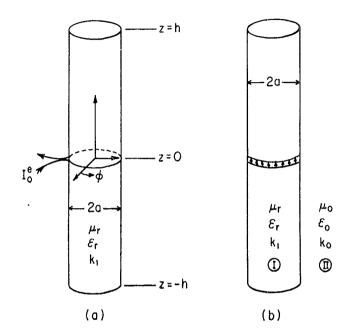


FIG. 1 (a) ELECTRICALLY SMALL LOOP ANTENNA OF DIAMETER '2a' LOADED BY A FERRITE CYLINDER OF HALF HEIGHT 'N' AND SURROUNDED BY FREE SPACE.

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(b) MATHEMATICALLY EQUIVALENT BUT PHYSICALLY UNAVAILABLE MODEL FOR THE ANTENNA SHOW-ING THE IDEALIZED CURRENT GENERATOR $\oint I_0^e$ $\delta(\rho \circ o) \delta(z)$. case the value of its dielectric constant ε_r is immaterial in view of the nature of the driving source. Figure 1(b) shows the mathematical model of the antenna. Region I is the ferrite with parameters μ_r , ε_r , k_1 and region II is free space with constitutive parameters μ_0 , ε_0 and wave number k_0 . Because of the nature of the driving source and azimuthal symmetry, the non-zero components of the fields are μ_z , μ_ρ and E_ϕ . A time dependence of the form exp(-iwt) is assumed. Because of the assumption $\mu_r = \infty$, H_z and H_ρ vanish in region I. The ferrite is also assumed to be homogeneous and isotropic. Thus the idealized driving source is taken into account by setting

$$H_{z} = -I_{0}^{e}\delta(z) \qquad (for \rho = a \text{ and } |z| \leq h) \qquad (2)$$

Since both regions I and II have vanishing electrical conductivity and there is no free charge, Maxwell's equations reduce to

$$\nabla \times \vec{E} = -\vec{B}$$
 (3a)

It is required to solve (3a-d) for the fields subject to the condition (2) which states that the tangential component of $|\dot{I}|$ is discontinuous by the true electric surface current at $\rho = a$ and for $|z| \leq h$. In order to obtain an integral equation for the magnetic current on the antenna, an electric vector potential \vec{A}^{e} and a magnetic scalar potential ϕ^{*} are defined and used.

$$\dot{\mathbf{D}} = -\mathbf{V} \times \dot{\mathbf{A}}^{\mathbf{C}} \tag{4}$$

The definition of $\vec{\Lambda}^{e}$ is incomplete unless its divergence is also specified. Using (4) in (3b) gives $\forall \times (\vec{\eta} + \vec{\Lambda}^{e}) = 0$, from which the scalar magnetic potential is defined by setting

$$\vec{l} + \vec{A}^{e} = -\nabla \phi^{*}$$
(5)

In terms of the potentials, the fields are now given by

$$\vec{E} = (-1/\epsilon) \nabla \times \vec{A}^e$$
 (6a)

$$\vec{X} = -V\phi^* - \vec{A}$$
 (6b)

Substitution of (Ga, b) into Maxwell's equations (3c) and (3a) gives

$$v^2 \phi^* + v \cdot \dot{A}^e = 0 \tag{7a}$$

$$\nabla^{2} \dot{\Lambda}^{e} - \mu \epsilon \dot{\Lambda}^{e} = \nabla [\nabla \cdot \dot{\Lambda}^{e} + \mu \epsilon \dot{\phi}^{*}]$$
(7b)

Equation (7) is a set of coupled equations for the potentials which may be decoupled by defining the dual Lorentz gauge

$$v \cdot \vec{\lambda}^{e} + u\epsilon \phi^{*} = 0 \tag{8}$$

Upon using (8), (7) becomes

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$$r^{2}\phi^{*} = \mu c \dot{\phi}^{*} = 0 \tag{9a}$$

$$v^2 \dot{\Lambda}^0 - u c \dot{\Lambda}^0 = 0 \tag{9b}$$

If (9) is solved for the potentials, subject to suitable boundary conditions, then the electromagnetic field is known everywhere by making use of (6). Nowever, for the problem at hand, a \hat{z} -component of electric vector potential is adequate for a complete solution so that $\hat{\Lambda}^{0} = \hat{z}\Lambda_{\underline{z}}^{0}$. On the surface (e = a, $|z| \leq h$) of the antenna, (6b) then becomes

$$H_{z} = -I_{0}^{e}\delta(z) = -(\partial\phi^{*}/\partial z) + i\omega\lambda_{z}^{e}$$
(10)

Using (8), one can rewrite (10) as

-5-

$$\left(\frac{d^{2}A_{z}^{e}}{dz^{2}} + k_{0}^{2}A_{z}^{e}\right) = i(k_{0}^{\prime}/v_{0})I_{0}^{e}\delta(z)$$
(11)

where k_0 is the free space wave number and v_0 the velocity of light in free space. This equation is identical to that for the z-component of the magnetic vector potential in the case of the dipole antenna [1, eq.(3.2.4)] and, therefore, has a complete solution - like [1, eq.(3.2.12)] - which is given by

$$A_{z}^{e}(z) = (i/v_{0}) \{ C \cos k_{0} z + (I_{0}^{e}/2) \sin k_{0} | z_{1} \}$$
(12)

Equation (12) is an expression for the z-cuaponent of electric vector potential in terms of the driving current I_0^e . However, the general formula for $\vec{A}^e(\vec{r})$ due to an arbitrary distribution of magnetic surface current $\vec{K}^*(\vec{r})$ can be written as

$$\vec{\mathbf{A}}^{\mathbf{c}}(\vec{\mathbf{r}}) = (\epsilon_0/4\pi) \int_{\mathbf{S}_1} \vec{\mathbf{k}}^{\mathbf{t}}(\vec{\mathbf{r}}') (\mathbf{e}^{\mathbf{k}_0^R}/\mathbf{R}) dS_1'$$

In general, $\vec{k}^*(\vec{r}) = \vec{k}^*(\vec{r}) + \vec{n} + \vec{p}(\vec{r})$, but because of the nature of the driving source $\vec{p}(\vec{r}) = 0$, so that $\vec{k}^*(\vec{r}) = \vec{k}^*(\vec{r}) = (\vec{n} + \vec{k}) =$ magnetic surface current. Since rotational symmetry obtains, the total axial magnetic current can be introduced with thin antenna approximation so that $I_z^*(z) = 2\pi a k_z^*(\vec{r})$

$$\Lambda_{z}^{e}(z) = \Lambda_{z}^{e}(z) = (c_{0}^{2}/4\pi) \int_{-h}^{h} I_{z}^{A}(z') dz' \int_{-\pi}^{\pi} (e^{ik_{0}P_{B}}/R_{s}) d\theta'/2\pi$$

where

$$R_{g} = [(z - z^{\dagger})^{2} + (2a \sin \theta^{\dagger}/2)^{2}]^{1/2}$$

Letting.

$$K_{s}(z,z') = \int_{-\pi}^{\pi} (e^{ik_0R_s}/R_s) d\theta'/2\pi$$

gives

$$A_{z}^{c}(z) = (c_{0}/4\tau) \int_{-h}^{h} \frac{i_{z}^{*}(z')K_{s}(z, z') dz'}{(z')}$$
(13)

-6-

 $A_z^e(z)$ was previously obtained in (12). Equations (12) and (13) together lead to the required integral equation,

$$\int_{-h}^{h} I_{z}^{*}(z') K_{s}(z,z') dz' = 14\pi \zeta_{0} [C \cos k_{0} z + (I_{0}^{e}/2) \sin k_{0} |z|]$$
(14)

with $\zeta_0 = (\mu_0/\epsilon_0)^{1/2}$ = the free space characteristic impedance.

The integral equation (14) for the magnetic current on a finite, infinitcly permeable, ferrite rod antenna can be identified formally with the similar integral equation [1, eq.(3.2.23)] for the electric current on a finite dipole antenna made up of a perfect metallic conductor. Comparing the integral equations for the two cases, one finds that the driving voltage V_0^e and the free space characteristic impedance $\boldsymbol{\zeta}_0$ in the electric dipole case are replaced by the driving current I_0^e and the free space characteristic admittance $(1/\xi_0)$ in the magnetic case. Commonly used metals like copper and brass are found to have sufficiently large electrical conductivities to justify the assumption of vanishing electric field inside the material of the dipole antenna so that an integral equation of the form (14) is adequate and has been used to obtain the electric current distributions. Furthermore, if more accuracy is required, theories de exist for imperfectly conducting cylindrical transmitting antennas. However, it is substionable whether the integral equation (16) is directly applicable to the practical ferrite rod antenna due to the relative permeability ranges of available ferrites. Whereas the treatment of the imperfectly conducting dipole antenna is done for reasons of improved accuracy, a similar treatment (ν_r large but not infinite) for the ferrite antanna appears to be a necessity. This forms the subject of Section 5.

4. MACNETIC CURRENT ON AN INFINITE ANTENNA

The magnetic current $I_z^*(z)$ obtained by solving the integral equation (14) may be called a zeroth-order solution because of the assumption $\mu_r = \infty$. The integral equation (14) is for a finite antenna from which the zeroth-order solution $I_{\infty}^*(z)$ for an antenna of infinite length may be obtained. For the sake of convenience, the integral equation is rewritten as

$$\int_{-h}^{h} I_{z}^{*}(z') K_{s}(|z - z'|) dz' = (4\pi/\epsilon_{0}) A_{z}^{e}(z) = i4\pi \epsilon_{0} [C \cos k_{0} z + \frac{I_{0}^{e}}{2} \sin k_{0}|z|]$$

As $h \neq \infty$, the vector potential $\Lambda_z^e(z)$ is a traveling wave which may be obtained by setting C = $I_0^e/2i$. In this case,

$$\int_{-\infty}^{\infty} I_{\infty}^{*}(z') K_{g}(|z-z'|) dz' = 2\pi \zeta_{0} I_{0}^{e} e^{ik_{0}|z|}$$
(15)

Taking Fourier transforms of both sides of (15), one obtains

$$\int_{-\infty}^{\infty} e^{-i\xi z} dz \int_{-\infty}^{\infty} I_{\infty}^{*}(z') K_{s}(|z - z'|) dz' = 2\pi\zeta_{0} I_{0}^{e} \int_{-\infty}^{\infty} e^{-i\xi z} e^{ik_{0}|z|} dz$$

The left side of the above equation is a convolution integral and on the right side, the integration may be performed to obtain

$$\vec{k}(\xi) \vec{1}_{\omega}^{*}(\xi) = 2\pi \zeta_{0} I_{0}^{0} [2ik_{0}^{2} / (k_{0}^{2} - \xi^{2})]$$
With $\gamma_{0}^{2} = k_{0}^{2} - \xi^{2}$

$$\vec{1}_{\omega}^{*}(\xi) = 4i\pi \zeta_{0} I_{0}^{0} k_{0}^{2} / \gamma_{0}^{2} \vec{k}(\xi) \qquad (16)$$

By recalling

$$K_{g}(|z - z^{i}|) = \int_{-\pi}^{\pi} (e^{ik_{0}R_{g}}/R_{g}) d\theta^{i}/2\pi$$

with $R_g = [(z - z^1)^2 + (2a \sin \theta'/2)^2]^{1/2}$, it can be shown [3] that the Pourier transform $\tilde{K}(\xi)$ of the kernel $K_g(z,z^1)$ is given by

-8-

$$\bar{K}(\xi) = \int_{-\infty}^{\infty} e^{-i\xi z} K_{g}(z) dz = i\pi J_{0}(a\gamma_{0}) H_{0}^{(1)}(a\gamma_{0})$$
(17)

Using (17) in (16), one obtains

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$$\bar{I}_{\infty}^{*}(\xi) = 4\zeta_0 I_0^{e_k} k_0 / \gamma_0^2 J_0(a\gamma_0) H_0^{(1)}(a\gamma_0)$$

The inverse Fourier transform may now be taken.

$$I_{\omega}^{*}(z) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \bar{I}_{\omega}^{*}(\xi) e^{i\xi z} d\xi$$

$$I_{\omega}^{*}(z) = \frac{2}{\pi} I_{0}^{0} \zeta_{0} k_{0} \int_{-\frac{2}{3}}^{\infty} \frac{e^{i\xi z} d\xi}{\zeta_{0}^{0} I_{0}(a\gamma_{0})H_{0}^{(1)}(a\gamma_{0})} \quad \text{volts}$$
(18)

Equation (18) is thus an explicit expression in the form of an infinite integral for the current on an infinitely long, infinitely permeable, ferrite rod antenna.

The problem of infinitely long ferrite rod antennas was formulated previously [2] in terms of differential equations and the Fourier transform of this current was obtained, from [2, eq. (23)], to be

$$I_{\omega}^{*}(\xi) = \frac{-i\omega_{a}(u_{r} - 1)I_{0}^{0}u_{0}2\pi aH_{1}^{(1)}(a\gamma_{1})J_{1}(a\gamma_{1})}{a[\gamma_{1}J_{0}(a\gamma_{1})H_{1}^{(1)}(a\gamma_{0}) - \gamma_{0}u_{r}J_{1}(a\gamma_{1})H_{0}^{(1)}(a\gamma_{0})]}$$
(19)

where $y_1^2 = k_1^2 - \xi^2$ and $y_0^2 = k_0^2 - \xi^2$, ξ is the Fourier transform variable, and k_1 and k_0 are the wave numbers in the ferrite and the surrounding free space medium, respectively. The zeroth-order current on the infinite antenna may be obtained from (19) by taking the limit $v_p \rightarrow \infty$.

First, (19) may be rewritten as

$$\bar{I}_{\omega}^{A}(\xi) = (-i\omega a I_{0}^{a} \nu_{0}^{2} \pi) \left[\frac{\gamma_{1} J_{0}(a \gamma_{1})}{(\nu_{r} - 1) J_{1}(a \gamma_{1})} - \frac{\gamma_{0} \nu_{r} H_{0}^{(1)}(a \gamma_{0})}{(\nu_{r} - 1) H_{1}^{(1)}(a \gamma_{0})} \right]^{-1}$$

-9-

As $\mu_r \rightarrow \infty$, the ratio $[J_0(a\gamma_1)/J_1(a\gamma_1)]$ is finite so that the first term within the brackets approaches zero. In this case

$$\bar{I}_{\infty}^{\star}(\xi) = \frac{4\zeta_0 I_0^{e_k} 0}{\gamma_0^2 J_0(a\gamma_0) H_0^{(1)}(a\gamma_0)} [a\gamma_0 \frac{\pi i}{2} H_1^{(1)}(a\gamma_0) J_0(a\gamma_0)]$$

Furthermore, for a thin antenna, a small argument approximation may be used for the Bessel functions in the numerator so that $\tilde{I}_{\infty}^{*}(\xi)$ reduces to

$$\tilde{I}_{\infty}^{*}(\xi) = \frac{4\zeta_{0}I_{0}^{e_{k_{0}}}}{\gamma_{0}^{2}J_{0}(a\gamma_{0})H_{0}^{(1)}(a\gamma_{0})}$$

from which

$$I_{\omega}^{*}(z) = \frac{2}{\pi} I_{0}^{e} \zeta_{0} k_{0} \int_{-\infty}^{\infty} \frac{e^{i\xi_{z}} d\xi}{\gamma_{0}^{2} J_{0}(a\gamma_{0})H_{0}^{(1)}(a\gamma_{0})} \quad \text{volts}$$
(20)

Thus, equations (20) and (18) are both independently derived explicit expressions for the zeroth-order ($\mu_r = \infty$) magnetic currents on an infinitely long ferrite rod antenna. In the limit of infinite permeability the two formulations give the same result. This limit is, however, physically unrealizable since a magnetic material with $\mu_r = \infty$ does not exist and, hence, a modification of the formulation which treats the forrite as an imperfect magnetic conductor is required. This modification has, once again, an analogue in the electric case in the treatment of the imperfectly conducting cylindrical transmitting antenna [3], [4].

5. FERRITE AS AN IMPERFECT MAGNETIC CONDUCTOR

In order to account for the fact that the relative permeability is large but not infinite, the concept of 'internal impedance' is useful and sufficient. With reference to Fig.2, the internal impedance per unit length of a cylindrical magnetic conductor of circular cross section of radius a with its axis along the z-axis of a system of cylindrical coordinates (o, ϕ, z) may be defined by

$$z_{m}^{i} = (r_{m}^{i} - ix_{m}^{i}) = H_{z}(\rho = a)/I_{z}^{*}$$
 (21)

where $H_{z}(\rho = a)$ is the tangential magnetic field at the surface, $\rho = a$, of the cond ctor and I_{z}^{*} is the total axial magnetic current. Recalling the expressions of electric and magnetic fields in terms of the potentials

$$\dot{H} = -V\phi^* - \dot{A}^2$$
(22a)

$$\vec{D} = -\nabla \times \vec{\Lambda}^{e}$$
 (22b)

$$v \cdot \dot{A}^{e} + \nu \varepsilon \dot{\phi}^{*} = 0 \tag{22c}$$

che electric vector potential satisfies

$$(v^2 + k^2)\dot{A}^e = 0$$
 (23)

where k is replaced by k_1 and k_0 for the two regions I and II shown in Fig. 2. For the problem of a thin cylindrical conductor, the axial component of electric potential is sufficient to satisfy Maxwell's equations and the relevant boundary conditions. Thus, the electromagnetic fields everywhere can be obtained by satting $\vec{\Lambda}^0 = \hat{z}\Lambda_z^0$. With the vector potential being entirely axial and also because of azimuthal symmetry, (23) becomes

$$\left[\frac{\partial^2}{\partial z^2} + \frac{1}{\rho}\frac{\partial}{\partial \rho}(\rho,\frac{\partial}{\partial \rho}) + k^2\right]\Lambda_z^{\alpha}(\rho,z) = 0$$
(24)

A product solution to (24) is sought in the following form:

$$A_{z}^{e}(\rho,z) = f_{z}(z)R_{z}(\rho)$$
(25)

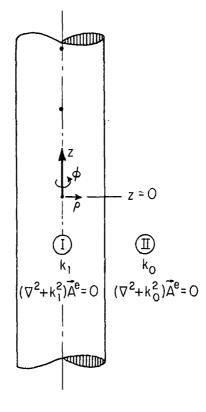


FIG.2 A CYLINDRICAL MAGNETIC CONDUCTOR CARRYING A TOTAL AXIAL MAGNETIC CURRENT OF I^{*}_z AND IMMERSED IN FREE SPACE.

Substitution of (25) into (24) leads to

$$R_{z} \frac{d^{2}f_{z}}{dz^{2}} + f_{z} \frac{1}{\rho} \frac{d}{d\rho} \left(\rho \frac{dR_{z}}{d\rho}\right) + k^{2}f_{z}R_{z} = 0$$
(26)

Equation (26) may be rewritten as

$$\frac{1}{f_z}\frac{d^2f}{dz^2} + k^2 = -\frac{1}{R_z}\frac{1}{\rho}\frac{d}{d\rho}\left(\rho\frac{dR_z}{d\rho}\right)$$
(27)

The left side of (27) is a function of z alone, while the right side is a function of ρ alone. Hence, they can be equal to each other for all possible values of ρ and z only if they are both equal to a constant (say ζ^2) which may, however, be multivalued. Therefore,

$$\frac{d^2 f_z}{dz^2} + (k^2 - \zeta^2) f_z = 0 \quad \text{and} \quad \frac{1}{\rho} \frac{d}{d\rho} \left(\rho \frac{dR_z}{d\rho}\right) + \zeta^2 R_z = 0$$

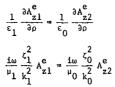
After solving the foregoing differential equations for f_z and R_z , the axial vector potential in the two regions can be written down as

$$A_{z1}^{e}(\rho,z) = C_{1}J_{0}(\zeta_{1}\rho)\exp(i\sqrt{k_{1}^{2}-\zeta_{1}^{2}}z)$$
 in region I

$$A_{z2}^{e}(\rho,z) = C_{2}H_{0}^{(1)}(\zeta_{0}\rho)\exp(i\sqrt{k_{0}^{2}-\zeta_{0}^{2}}z)$$
 in region II

Boundary conditions that are useful in determining the unknown constants in the solution require the continuity of tangential \vec{E} and \vec{R} across the surface $\rho = a$; that is

In terms of the vector potential, the boundary conditions at the surface p = a are



Application of the boundary conditions yields

$$\frac{1}{\varepsilon_1} C_1 \zeta_1 J_0^{\dagger}(\zeta_1 a) \exp(i\sqrt{k_1^2 - \zeta_1^2} z) = \frac{1}{\varepsilon_0} C_2 \zeta_0 H_0^{(1)}(\zeta_0 a) \exp(i\sqrt{k_0^2 - \zeta_0^2} z)$$
(28)

$$\frac{i\omega}{\mu_1} \frac{\zeta_1^2}{k_1^2} c_1 J_0(\zeta_1 a) \exp(i\sqrt{k_1^2 - \zeta_1^2} z) = \frac{i\omega}{\mu_0} \frac{\zeta_0^2}{k_0^2} c_2 H_0^{(1)}(\zeta_0 a) \exp(i\sqrt{k_0^2 - \zeta_0^2} z)$$
(29)

Since (28) and (29) are valid for all values of z at all times, it follows that

$$\sqrt{k_1^2 - \zeta_1^2} = \sqrt{k_0^2 - \zeta_0^2} = q$$
 (say) (30)

so that $\zeta_1 = \sqrt{k_1^2 - q^2}$ and $\zeta_0 = \sqrt{k_0^2 - q^2}$. Dividing (29) by (28) and rearranging, one obtains

$$\zeta_{0}^{a} \frac{\mathfrak{n}_{0}^{(1)}(\zeta_{0}^{a})}{\mathfrak{n}_{0}^{(1)}(\zeta_{0}^{a})} = \frac{\varepsilon_{1}^{\mu_{0}}}{\varepsilon_{0}^{\mu_{1}}} \frac{k_{0}^{2}}{k_{1}^{2}} \zeta_{1}^{a} \frac{J_{0}(\zeta_{1}^{a})}{J_{0}(\zeta_{1}^{a})}$$
(31)

Although, in general, an explicit solution is not possible, equations (30) and (31) are theoretically sufficient to determine the unknowns c_1 and c_0 . The two unknowns will be determined here by two methods.

Method 1:

An approximate solution is possible by allowing k_1 to become very large. Since q is finite, $c_1 + k_1$ and, therefore, c_1 is also large. Using this on the right side of (31) gives

$$i \frac{\varepsilon_1^{\mu_0}}{\varepsilon_0^{\mu_1}} \frac{k_0^2}{k_1^2} \zeta_1^{a} \neq 0$$

Therefore,

$$\tau_{0}^{a} \frac{H_{0}^{(1)}(\tau_{0}^{a})}{H_{0}^{(1)}(\tau_{0}^{a})} \stackrel{\sim}{=} 0$$
(32)

Equation (32) is satisfied by $\zeta_0 = 0$ since it can be shown that the ratio $H_0^{(1)}(\zeta_0^a)/H_0^{(1)}'(\zeta_0^a)$ remains finite as ζ_0 approaches the value of zero. It then follows from (30) that

$$\zeta_1 = \sqrt{k_1^2 - k_0^2} = k_1 \sqrt{1 - (1/\mu_r \varepsilon_r)} \sim k_1$$

Thus the solutions are $\zeta_1 \stackrel{\sim}{_{\sim}} \stackrel{k_1}{_{\sim}}$ and $\zeta_0 \stackrel{\sim}{_{\sim}} 0$.

Nethod 2:

Method 1 may seem to be an oversimplification and hence, a slightly more rigorous method may be needed in some cases. It is observed that (31) may be identified with a similar equation obtained by Sommerfeld [5] in the problem on 'waves on wires.' Sommerfeld has developed an iterative form of solution which may be used here.

In the limit of large z_1 , the right side of (31) becomes

$$i \frac{\epsilon_1 \nu_0}{\epsilon_0 \nu_1} \frac{k_0^2}{k_1^2} \zeta_1 a = i \frac{\epsilon_r}{\nu_r} \frac{k_0^2}{k_1^2} a \sqrt{k_1^2 - q^2} \sum_{i=1}^{n} \frac{\epsilon_r}{\nu_r} \frac{k_0^2}{k_1} a = i \frac{ak_0}{\nu_r} \sqrt{\epsilon_r / \nu_r}$$

and is small. Since the left side of (31) also has to be small, we have

$$(c_0 a)^2 \ln(\gamma c_0 a/2i) = -\frac{2}{\gamma^2} u \ln u$$
 with $u = (\gamma c_0 a/2i)^2$

where y = 1.781.

Equation (31) finally becomes

u in u = v with
$$v = -\frac{i\gamma^2}{2} \frac{ak_0}{\mu_r} \sqrt{\epsilon_r/\mu_r}$$

Since in u varies slowly in comparison with u, it is possible to write

where u_n is the nth approximation to u. The method is best illustrated by an example. In the later part of this report, eleven different antenna configurations were used in the experimental determination of the magnetic current. The example chosen here (antenna *f*1) corresponds to the lowest value of the $|r_r e_r|$ product for the eleven cases.

Example: $ak_0 = 0.00166$, $\mu_r = (18 + i.036)$, $\epsilon_r = 11.0$.

Let
$$u_0 = v = -\frac{i\gamma^2}{2} \frac{ak_0}{\mu_r} \sqrt{\epsilon_r/\mu_r} \simeq -i(1.1 \times 10^{-4})$$

This gives

$$u_1 = \frac{v}{\ln u_0} = \frac{-11.1 \times 10^{-4}}{(-9.115 + 14.712)} = -10^{-4} (.049 - 1.095)$$

$$u_2 = \frac{v}{i_n u_1} = \frac{-11.1 \times 10^{-4}}{(-11.445 + 12.047)} = -10^{-4} (.0167 - 1.0931)$$

Continuing the iteration

$$u_3 = \frac{v}{\ln u_2} = \frac{-i1.1 \times 10^{-4}}{(-11.5684 + i1.7478)} = -10^{-4} (.0140 - i.0930)$$

$$u_4 = \frac{v}{\ln u_3} = \frac{-11.1 \times 10^{-4}}{(-11.5748 + 11.7208)} = -10^{-4} (.0138 - 1.0930)$$

and finally

$$u_5 = \frac{v}{\ln u_A} = \frac{-11.1 \times 10^{-4}}{(-11.5748 + 11.7184)} = -10^{-4} (.0138 - 1.0930)$$

It is seen that this iterative procedure is rapidly converging and using the above value of u.

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$$(\zeta_0 a)^2 = -\frac{4}{\chi^2} u^2 = 10^{-10} (1.062 + 1.3225)$$

Furthermore, from (30)

$$(aq)^2 = (ak_0)^2 - (ar_0)^2$$

= 2,7556 × 10⁻⁶ - 10⁻¹⁰(1.062 + 1.3225)

from which $a\zeta_1$ may be calculated using

$$(a\zeta_{1})^{2} = (ak_{1})^{2} - (aq)^{2} = (ak_{1})^{2} - (ak_{0})^{2} + (a\zeta_{0})^{2}$$
$$= ak_{1}^{2} \left[1 - \frac{1}{\nu_{r}c_{r}} + \left(\frac{a\zeta_{0}}{ak_{1}}\right)^{2} \right]$$
$$= ak_{1}^{2} [1 - (.0056 - 1.00001) + 10^{-7} (2.159 + 1.651)]$$

From the calculated values of $(a_{\zeta_0})^2$ and $(a_{\zeta_1})^2$, it is seen that the approximate solutions, i.e., $\zeta_0 = 0$ and $\zeta_1 \geq k_1$, are quite satisfactory even when $|u_{\mu}c_{\nu}|$ is as low as 180.

Therefore, the vector potential in the interior of the conductor is given by

$$\Lambda^{\rm e}_{z1}(\rho,z) = \Lambda^{\rm e}_{z1}(\rho)\Lambda^{\rm e}_{z1}(z) = C_1 J_0(k_1\rho) \exp(i\sqrt{k_1^2 - \zeta_1^2} z)$$

where ζ_1 in the argument of the Bessel function is replaced by k_1 in view of the calculations of "Method 2." The constant C_1 can be written in terms of the potential on the surface so that

$$\Lambda_{z1}^{e}(\rho) = \Lambda_{z1}^{e}(a) J_{0}(k_{1}\rho)/J_{0}(k_{1}a)$$

Since H_z is proportional to A_z ,

$$H_{z1}(\rho) = H_{z1}(a)J_0(k_1\rho)/J_0(k_1a)$$

The magnetization is then given by

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$$\hat{\mathbb{M}}_{z}(\rho) = (\mu_{r} - 1)\hat{\mathbb{H}}_{z1}(\rho) = (\mu_{r} - 1)\hat{\mathbb{H}}_{z1}(a)J_{0}(k_{1}\rho)/J_{0}(k_{1}a)$$

from which the magnetic current can be obtained as

$$I_{z}^{*}(\rho) = 2\pi \int_{0}^{\rho} \mu_{0}\dot{M}_{z}(\rho')\rho' d\rho'$$

$$= 2\pi\mu_{0}(\mu_{r} - 1) \frac{\dot{H}_{z1}(a)}{J_{0}(k_{1}a)} \int_{0}^{\rho} J_{0}(k_{1}\rho') \rho' d\rho'$$

Performing the integration gives

$$I_{z}^{*}(\rho) = \frac{2\pi\nu_{0}(\nu_{r} - 1)\dot{H}_{z1}(a)}{J_{0}(k_{1}a)} \frac{\rho}{k_{1}} J_{1}(k_{1}\rho)$$
(33)

The total magnetic current carried by the conductor is, however, given by

$$I_{z}^{*}(a) = 2\pi \int_{0}^{a} \mu_{0}\dot{M}_{z}(p) \rho dp$$

which becomes

$$I_{z}^{*}(a) = \frac{2\pi\nu_{0}(\mu_{r} - 1)\tilde{H}_{z1}(a)}{J_{0}(k_{1}a) - \frac{k_{1}}{k_{1}} J_{1}(k_{1}a)}$$
(34)

From (33) and (34) the radial distribution of the magnetic current in the interior of the conductor is given by

$$I_{z}^{*}(\rho) = I_{z}^{*}(a) \frac{\rho}{a} \frac{J_{1}(k_{1}\rho)}{J_{1}(k_{1}a)}$$
(35)

Furthermore, having obtained the total axial magnetic current of (34), the

internal impedance per unit length defined in (21) can be written as

$$z_{m}^{i} = r_{m}^{i} - ix_{m}^{i} = H_{z1}(\rho = a)/I_{z}^{*}(a)$$
$$= \left[\frac{i}{2\omega} \frac{1}{\mu_{0}\chi^{m}} \frac{1}{\pi a^{2}} k_{1}a \frac{J_{0}(k_{1}a)}{J_{1}(k_{1}a)}\right] U/m$$
(36)

where

 $\chi^{m} = (\mu_{r} - 1) = magnetic susceptibility;$ ω = radian frequency; $\mu_0 = 4\pi \times 10^{-7}$ h/m = permeability of free space; $\pi a^2 = cross-sectional area of the conductor;$ $k_1 = \beta_1 + i\alpha_1 = k_0(\beta_{1N} + i\alpha_{1N}) = wave number in the material of the$ conductor. $\begin{array}{c} i\theta \\ i\theta \\ \text{With } u_r = (u_r^{'} + iu_r^{''}) = |u_r|e^{-\mu} \text{ and } e_r = (e_r^{'} + ie_r^{''}) = |e_r|e^{-\mu}, \end{array}$

 $k_1 = k_0 |v_r \epsilon_r|^{1/2} \exp[i(\theta_\mu + \theta_\epsilon)/2]$

so that

$$\theta_1 = k_0 [v_r e_r [\frac{1/2}{cos[(\theta_u + \theta_r)/2]}]$$
 (37a)

and

$$s_{1} = k_{0} |u_{r} c_{r}|^{1/2} \sin[(\theta_{u} + \theta_{c})/2]$$
(37b)

One may now use the internal impedance per unit length of a magnetic conductor carrying an axial magnetic current to find an integral equation for the magnetic current on a finite ferrite rod antenna. The axial component $\Lambda^0_z(z)$ on the surface of a cylindrical antenna that has an internal impedance por unit length z_m^i , carries an exial current $I_z^*(z)$, and is driven at z = 0by a delta-function generator with an musi of I_0^α , satisfies the following differential equation:

$$\left(\frac{d^2}{dz^2} + k_0^2\right) A_z^e(z) = -\frac{ik_0^2}{\omega} \left[z_m^{1} I_z^{\star}(z) - I_0^e \delta(z) \right]$$
(38)

If the antenna were made of a perfect magnetic conductor, $z_m^i = 0$ because $\chi^m =$ infinity so that (38) will reduce to (11). If the radius a of the antenna and the free-space wave number $k_0 = \omega/v_0 = 2\pi/\lambda_0$ satisfy the inequality

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then the vector potential is given approximately by

$$A_{z}^{e}(z) \sim \frac{\varepsilon_{0}}{4\pi} \int_{-h}^{h} I_{z}^{*}(z') K(z,z') dz'$$
(39)

If the equations (38) and (39) are formally identified with those for the imperfectly conducting, electric dipole antenna [3, eqs. (7) and (9)], it is observed that μ_0 and I_0^e play the roles of ε_0 and V_0^e . King and Wu [3] have developed a three-term solution for the electric current on the imperfectly conducting dipole antenna which can be well applied to the present problem of the ferrite as an imperfect magnetic conductor. The procedure used to obtain the three-term solution will be described here briefly; for a detailed analysis the reader is referred to [3].

The approximate kernel in (39) may be separated into real and imaginary parts,

$$K(z,z') = K_{R}(z,z') - iK_{I}(z,z') = e^{ik_{0}r}/r$$

so that

$$K_{R}(z,z') = \frac{\cos k_{O}r}{r}$$
, $K_{I}(z,z') = -\frac{\sin k_{O}r}{r}$

with $r = [(z - z')^2 + a^2]^{1/2}$. The vector potential may also be divided into two parts,

$$\Lambda_{z}^{e}(z) = \Lambda_{R}^{e}(z) - i\Lambda_{I}^{e}(z)$$

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where

$$A_{R}^{e}(z) = \frac{k_{0}c_{0}}{4\pi} \int_{-h}^{h} I_{z}^{*}(z^{*}) \frac{\cos k_{0}r}{k_{0}r} dz^{*}$$
(40)

$$A_{I}^{e}(z) = -\frac{k_{0}\varepsilon_{0}}{4\pi} \int_{-h}^{h} I_{z}^{*}(z') \frac{\sin k_{0}r}{k_{0}r} dz'$$
(41)

The properties of the two integrals are quite different. The kernel in (40) has a sharp peak at $k_0|z - z'| = 0$ and thus greatly magnifies the contribution to the integral due to current elements near z = z'. The current vanishes at the end but the vector potential $\Lambda_R^e(h)$ has a small finite value so that the difference in vector potential should vary closely like $T_z^*(z)$. Therefore,

$$(4\pi/\epsilon_0)[\Lambda_R^{e}(z) - \Lambda_R^{e}(h)] = \forall (z)I_z^{*}(z) \triangleq \forall I_z^{*}(z)$$
(42)

where Ψ is the approximately constant value of $\Psi(z)$ defined at a suitable reference value of z. However, in the second integral in (41) the rather flat behavior of (sin $k_0 r$)/ $k_0 r$ with $k_0 r$ allows the following approximation:

$$\frac{\sin k_0 r}{k_0 r} = \frac{2 \sin \frac{k_0 r}{2} \cos \frac{k_0 r}{2}}{k_0 r} = \frac{\cos \frac{k_0 r}{2}}{\cos \frac{k_0 r}{2}}$$

which is useful over a range $k_0 r \leq \pi$. This approximation leads to

$$A_{1}^{e}(z) = A_{1}^{e}(0) \cos \frac{k_{0}z}{2}$$
(43)

where $\Lambda_{I}^{P}(0)$ is a constant given by

$$\Lambda_{1}^{e}(0) = \frac{k_{0}r_{0}}{4\pi} \int_{-h}^{h} I_{z}^{*}(z') \cos \frac{k_{0}z'}{2} dz'$$
(44)

If equation (42), rearranged in the form $I_z^*(z) = i4\pi/\Psi r_0) [A_R^e(z) - A_R^e(h)]$, is substituted in the differential equation (38), one obtains:

$$\left(\frac{d^{2}}{dz^{2}} + k_{0}^{2}\right) \left[A_{z}^{e}(z) - A_{z}^{e}(h)\right] = -i4\pi\zeta_{0}k_{0}z_{m}^{i_{\psi}-1}[A_{R}^{e}(z) - A_{R}^{e}(h)] - k_{0}^{2}A_{z}^{e}(h) + \frac{i}{\omega}k_{0}^{2}I_{0}^{e}\delta(z)$$
(45)

A complex constant k may now be defined by

$$k^{2} = (\beta + i\alpha)^{2} = k_{0}^{2} \left(1 + \frac{i4\pi z_{m}^{1} \zeta_{0}}{k_{0}^{\Psi}} \right)$$
(46)

Using (43) and (46), (45) becomes

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$$\left(\frac{d^{2}}{dz^{2}} \div k^{2}\right) \left[A_{z}^{e}(z) - A_{z}^{e}(h)\right] = -i(k^{2} - k_{0}^{2})A_{I}^{e}(z) - \left[k_{0}^{2}A_{R}^{e}(h) - ik^{2}A_{I}^{e}(h)\right] + \frac{i}{\omega}k_{0}^{2}I_{0}^{e}\delta(z)$$
$$= -i(k^{2} - k_{0}^{2})A_{I}^{e}(0)\cos\frac{k_{0}z}{2} - \left[k_{0}^{2}A_{R}^{e}(h) - ik^{2}A_{I}^{e}(h)\right] + \frac{i}{\omega}k_{0}^{2}I_{0}^{e}\delta(z)$$
(47)

The integral equation of (39) may now be written in the form

$$[\Lambda_{z}^{e}(z) - \Lambda_{z}^{e}(h)] = \frac{\varepsilon_{0}}{4\pi} \int_{-h}^{h} I_{z}^{*}(z')K_{d}(z,z') dz'$$
(48)

where the difference kernel K_d is given by

$$K_{d}(z,z') = K(z,z') - K(h,z') = \frac{ik_{0}r}{r} - \frac{ik_{0}r_{h}}{r_{h}}$$

with $r = [(z - z')^2 + a^2]^{1/2}$ and $r_h = [(h - z')^2 + a^2]^{1/2}$. If the differential equation (47) is solved for the vector potential difference and the solution is substituted for the left-hand side of (48), an integral equation for the magnetic current on the ferrite antenna is obtained, viz.,

$$\int_{-h}^{h} I_{z}^{*}(z') K_{d}(z,z') dz' = \frac{-i4\pi k_{0} c_{0}}{k \cos kh} [(1/2) I_{0}^{0} M_{kz} + V_{k}^{\dagger} F_{kz} - D \cos kh F_{0z}^{\dagger}]$$
(40)

where for ease of reference, the same notation as in King and Wu [3] is employed and the various factors on the right side are given by

$$M_{b_{\phi}} = \sin k(h - |z|)$$

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$$u_{k}' = u_{k} + D \cos \frac{k_{0}h}{2}$$

$$u_{k} = (i\omega k/k_{0}^{2}) [(k_{0}^{2}/k^{2})A_{R}^{e}(h) - iA_{I}^{e}(h)]$$

$$D = -\frac{\omega k}{k_{0}^{2}} \left[\frac{k^{2} - k_{0}^{2}}{k^{2} - k_{0}^{2}/4}\right] A_{I}^{e}(0)$$

$$F_{kz} = \cos kz - \cos kh$$

$$F_{0z}' = \cos \frac{k_{0}z}{2} - \cos \frac{k_{0}h}{2}$$

Following the procedure as in [3], an approximate formal solution to the integral equation may be written in the form

$$I_{z}^{*}(z) = I_{V}^{*}M_{kz} + I_{U}^{*}F_{kz} + I_{D}^{*}F_{0z}^{\dagger}$$
(50)

where the coefficients I_V^* , I_U^* and I_D^* are obtained by a numerical procedure. Letting $T_U^* = I_U^*/I_V^*$, $T_D^* = I_D^*/I_V^*$ and evaluating I_V^* , one may write (50) as

$$I_{z}^{*}(z) = \frac{-i2\pi k_{0}\zeta_{0}I_{0}^{e}}{k^{\Psi}_{dR}\cos kh} \left[\sin k(h - |z|) + T_{U}^{*}(\cos kz - \cos kh) + T_{D}^{*}(\cos \frac{k_{0}z}{2} - \cos \frac{k_{0}h}{2}) \right]$$
(51)

where k is redefined by

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$$k^{2} = (\beta + i\alpha)^{2} = k_{0}^{2} \left(1 + \frac{i4\pi z_{m}^{2} \zeta_{0}}{k_{0} \gamma_{dR}} \right)$$
(52)

and Ψ_{dR} is given by the integral expression

$$\int_{-h}^{h} \sin k(h - |z'|) K_{dR}(z,z') dz' = \sin k(h - |z|) \Psi_{dR}$$
(53)

Thus, equation (51) is the required expression for the total magnetic current on the antenna from which the admittance can be obtained to be

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$$Y = G - iB = I_z^*(0)/I_0^e$$
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$$= \frac{-i2\pi k_0 \zeta_0}{k_{\text{dR}}^{\text{cos } \text{kh}}} \left[\sin \text{kh} + T_{\text{U}}^{\text{*}} (1 - \cos \text{kh}) + T_{\text{D}}^{\text{*}} (1 - \cos \frac{k_0 h}{2}) \right]$$
 (54)

Note that, because of an earlier approximation of the imaginary part of the kernel, equations (51) and (54) are valid representations for the magnetic current and admittance only when $k_0h \leq 5\pi/4$.

The existing computer programs for the imperfectly conducting dipole antenna due to King, Harrison and Aronson [4] have been modified for use on the IBM 370/155 computer system of the Joint Harvard/M.I.T. Ratch Processing Center. Appendix B includes a listing of the Fortran IV programs that compute the magnetic current distribution and the admittance of the finite ferriterod antenna when the ferrite is treated as an imperfect magnetic conductor.

6. THE LIMITATIONS OF THE THEORETICAL FORMULATION

The present formulation is based on an analogy between the ferrite-rod antenna and the conducting cylindrical dipole antenna. Because of the symmetry in Maxwell's equations, a set of scalar magnetic (ϕ^*) and electric vector ($\vec{\Lambda}^6$) potentials was defined and used in formulating the finite ferrite-rod antenna problem. It is considered useful to determine the existence of these potentials for the infinite antenna and thus provide some justification for their use in the finite antenna problem.

The electromagnetic fields in both regions for the case of the infinitely long antenna were determined previously [2] to be:

Region I, $0 \le \rho \le a$:

 $\tilde{\tilde{E}}_{\phi1}(\rho,\xi) = i_{\omega\nu_1} a I_0^{e} H_1^{(1)}(\gamma_0 a) J_1(\gamma_1 \rho) / D(\xi)$

-24-

$$\begin{split} \vec{H}_{z1}(\rho,\xi) &= \frac{1}{i\omega u_{1}} \left[\partial \vec{E}_{\phi1}(\rho,\xi) / \partial \rho + \vec{E}_{\phi1}(\rho,\xi) / \rho \right] = a I_{0}^{e} \gamma_{1} H_{1}^{(1)}(\gamma_{0} a) J_{0}(\gamma_{1} \rho) / D(\xi) \\ \vec{H}_{\rho1}(\rho,\xi) &= (\xi / \omega u_{1}) \vec{E}_{\phi1}(\rho,\xi) = i a I_{0}^{e} \xi H_{1}^{(1)}(\gamma_{0} a) J_{1}(\gamma_{1} \rho) / D(\xi) \\ \vec{H}_{\phi1}(\rho,\xi) &= \vec{E}_{\rho1}(\rho,\xi) = \vec{E}_{z1}(\rho,\xi) = 0 \end{split}$$
(55)

Region II, $\rho > a$:

.

$$\begin{split} \bar{E}_{\phi2}(\rho,\xi) &= i\omega\mu_{1}aI_{0}^{e}J_{1}(\gamma_{1}a)H_{1}^{(1)}(\gamma_{0}\rho)/D(\xi) \\ \bar{H}_{z2}(\rho,\xi) &= aI_{0}^{e}\gamma_{0}\mu_{z}J_{1}(\gamma_{1}a)H_{0}^{(1)}(\gamma_{0}\rho)/D(\xi) \\ \bar{H}_{\nu2}(\rho,\xi) &= iaI_{0}^{e}\mu_{z}\xi J_{1}(\gamma_{1}a)H_{1}^{(1)}(\gamma_{0}\rho)/D(\xi) \\ \bar{H}_{\phi2}(\rho,\xi) &= \bar{E}_{\rho2}(\rho,\xi) = \bar{E}_{z2}(\rho,\xi) = 0 \end{split}$$
(56)

where

$$\mathbb{D}(\xi) = \mathfrak{a}[\gamma_1 J_0(\gamma_1 \mathfrak{a}) \mathbb{H}_1^{(1)}(\gamma_0 \mathfrak{a}) - \gamma_0 \mu_r J_1(\gamma_1 \mathfrak{a}) \mathbb{U}_0^{(1)}(\gamma_0 \mathfrak{a})]$$

The actual field quantities may be obtained by applying the Fourier inverse formula to the above transformed fields. It can be verified easily that the above field quantities satisfy the following transformed boundary conditions:

i) Tangential \vec{E}_{i} $\vec{E}_{\phi 2}(a^{+},\xi) = \vec{E}_{\phi 1}(a^{-},\xi)$ (57a)

ii) Taugential
$$\vec{H}_{z2}(a^{+},\xi) - \vec{H}_{z1}(a^{-},\xi) = -T_{0}^{e}$$
 (57b)

iii) Normal
$$\vec{B}$$
: $\vec{B}_{\rho 2}(a^{\dagger},\xi) = \vec{B}_{\rho 1}(a^{\bullet},\xi)$ (S7c)

 ϕ^* is a scalar magnetic potential and has a non-zero value in both regions. For the infinitely long antenna, the only non-zero component of \vec{A}^e is ж

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the z-component so that $\vec{A}^e = \hat{z}A_z^e$. The potentials may be derived either from the already known electromagnetic fields or from an independent solution of the following wave equations with suitable boundary conditions:

$$(\nabla^2 + k^2) \dot{A}^e(\rho, z) = 0$$
 , $(\nabla^2 + k^2) \phi^*(\rho, z) = 0$

The equations reduce to

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<u>Region I</u>, $0 \le \rho \le a$:

$$\left[\frac{\partial^2}{\partial z^2} + \frac{1}{\rho}\frac{\partial}{\partial \rho}\rho \frac{\partial}{\partial \rho} + k_1^2\right] A_{z1}^e(\rho,z) = 0$$

Region II, $\rho > a$:

$$\left[\frac{\partial^2}{\partial z^2} + \frac{1}{\rho} \frac{\partial}{\partial \rho} \rho \frac{\partial}{\partial \rho} + k_0^2\right] A_{z2}^{\rm e}(\rho, z) = 0$$

Using a Fourier transform pair, the above equations become

 $\left[\frac{\partial^2}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial}{\partial \rho} + (k_1^2 - \xi^2)\right] \bar{\lambda}_{21}^{\rm e}(\rho,\xi) = 0$

$$\left[\frac{\partial^2}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial}{\partial \rho} + (k_0^2 - \xi^2)\right]\bar{\lambda}_{z2}^{\rm e}(\rho,\xi) = 0$$

With a change of variable the above equations can be recognized as Bessel equations with the following solutions,

$$\overline{A}_{21}^{e}(\rho,\xi) = PJ_{0}(\gamma_{1}\rho) \qquad \text{for } 0 \le \rho \le a$$

$$\overline{A}_{22}^{e}(\rho,\xi) = QH_{0}^{(1)}(\gamma_{0}\rho) \qquad \text{for } \rho \ge a$$

where
$$Y_0 = (k_0^2 - \xi^2)^{1/2}$$
 and $Y_1 = (k_1^2 - \xi^2)^{1/2}$

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The boundary conditions (57a,b), expressed in terms of the electric vector potential, become

$$(1/\varepsilon_1)\partial\bar{A}_{z1}^{e}(\bar{a},\xi)/\partial\rho = (1/\varepsilon_0)\partial\bar{A}_{z2}^{e}(\bar{a},\xi)/\partial\rho$$
(58a)

$$(i\omega\gamma_0^2/k_0^2)\bar{A}_{z2}^{e}(a^{\dagger},\xi) - (i\omega\gamma_1^2/k_1^2)\bar{A}_{z1}^{e}(a^{-},\xi) = -I_0^{e}$$
(58b)

By applying the boundary conditions and determining P and Q, the electric vector potential can be written as:

$$\overline{A}_{z1}^{e}(\rho,\xi) = -i\omega\mu_{1}\varepsilon_{1}aI_{0}^{e}H_{1}^{(1)}(\gamma_{0}a)J_{0}(\gamma_{1}\rho)/\gamma_{1}D(\xi) \qquad \text{for } 0 \leq \rho \leq a$$

$$\overline{A}_{z2}^{e}(\rho,\xi) = -i\omega\mu_{1}\varepsilon_{0}aI_{0}^{e}J_{1}(\gamma_{1}a)H_{0}^{(1)}(\gamma_{0}\rho)/\gamma_{0}D(\xi) \qquad \text{for } \rho \geq a$$
(59)

Similarly, by solving the wave equation for the scalar magnetic potential ϕ^* , the solution can be obtained as:

$$\overline{\phi}_{1}^{\star}(\rho,\xi) = ia\xi I_{0}^{e}H_{1}^{(1)}(\gamma_{0}a)J_{0}(\gamma_{1}\rho)/\gamma_{1}D(\xi) \qquad \text{for } 0 \leq \rho \leq a$$
(60)

$$\vec{\phi}_2^*(\rho,\xi) = ia\xi I_0^e \mu_r J_1(\gamma_1 a) H_0^{(1)}(\gamma_0 \rho) / \gamma_0 D(\xi) \qquad \text{for } \rho \ge a$$

The boundary conditions satisfied by $\overline{\phi}^{*}(\rho,\xi)$ at the surface $\rho = a$ are:

$$(\omega \mu_1 / \xi) \partial \overline{\phi}_1^* (\overline{a}, \xi) / \partial \rho = (\omega \mu_0 / \xi) \partial \overline{\phi}_2^* (\overline{a}, \xi) / \partial \rho$$
(61a)

$$\gamma_0^2 \bar{\phi}_2^*(a^+,\xi) - \gamma_1^2 \bar{\phi}_1^*(a^-,\xi) = -i\xi I_0^e$$
 (61b)

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It can also be verified that the potentials satisfy the gauge condition,

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$$\partial \Lambda_z^{e}(\rho,z)/\partial z = i\omega\mu \epsilon \phi^{*}(\rho,z) = 0$$
 in both regions

The potentials of (59) and (60) can also be obtained from the electromagnetic fields of (55) and (56) by making use of the following relationships in both regions:

 $E_{\phi}(\rho,z) = (1/\varepsilon) \partial A_{z}^{e}(\rho,z) / \partial z \quad ; \quad H_{z}(\rho,z) = -\partial \phi^{*}(\rho,z) / \partial z + i \omega A_{z}^{e}(\rho,z)$ and

$$\partial A_z^e(\rho,z)/\partial z - i\omega\mu\varepsilon\phi^*(\rho,z) = 0$$

The above analysis verifies that when the antenna is infinitely long, both the scalar magnetic and electric vector potentials exist. They are both discontinuous across the antenna surface and satisfy respective wave equations, appropriate boundary conditions, and the gauge condition.

In the case of the finite antenna, however, a precise knowledge of the vector potential in the two regions is not necessary to derive an approximate integral equation for the magnetic current. What is required is the electric vector potential on the surface of the antenna. To determine this, an internal impedance per unit length is defined and used to obtain the three-term solution for the magnetic current. Using the computer programs described and listed in Appendix B, the magnetic current was evaluated for a range of parameters. The current distribution was studied as a function of the four independent parameters, viz., μ'_r ; μ''_r or $Q = \mu'_r/\mu''_r$; h/λ_0 or k_0h ; and ak_0 or $\Omega = 2 \ln(2h/a)$. In this study the value of the dielectric constant of the ferrite was fixed at 10.

The ranges of the four parameters were as follows: $\mu_r^i = 10$, 100, 1000; Q = 1 to Q = 100; $h/\lambda_0 = .1$ to $h/\lambda_0 = .5$; and $ak_0 = .001$ to $ak_0 = .1$. Typical results of the computations are shown plotted in Fig. 3. The quantities μ_r^i , ak_0 , h/λ_0 and Q are varied, respectively, in Fig. 3a-d, while in each case the remaining three parameters are kept constant.

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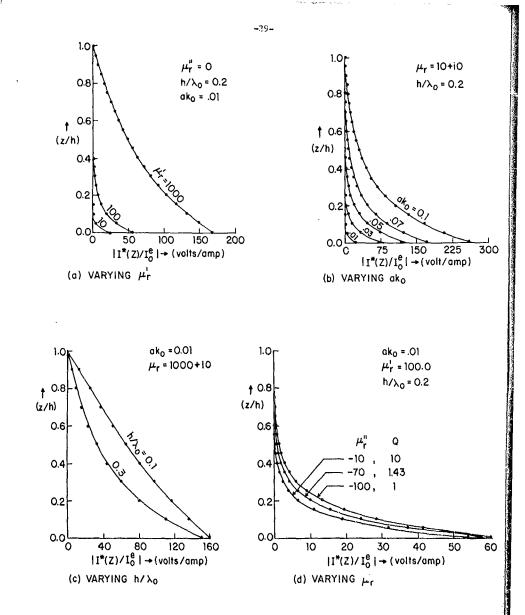


FIG. 3 PLOT OF THE MAGNITUDE OF NORMALIZED MAGNETIC CURRENT (11*(Z)/1°)1) AS A FUNCTION OF NORMALIZED DISTANCE (z/h) FOR VARIOUS PARAMETER RANGES. (Er=10+10 FOR ALL THE CASES)

In Fig. 3a for fixed height, radius, and ratio 0, the magnetic current on the antenna is seen to increase with the real part of the relative permeability. A similar behavior is observed in Fig. 3h for increasing antenna radius and fixed height, permeability and 0. A comparison between Fig. 3a and Fig. 3d shows that a large value of μ_r^{\dagger} produces a greater increase in the magnetic current than a high Q ratio; in fact, an increase in Q for Q < 50 is seen to reduce the magnitude of the magnetic current. To interpret Fig. 3c, it is useful to examine the behavior of the propagation constant k on the antenna, given by

$$k = \beta + i\alpha = k_0 [1 + i(4\pi z_m^i \zeta_0 / k_0 \Psi_{dR})]^{1/2}$$

If the dimensionless parameter $\phi_i = (4\pi z_m^i \zeta_0/k_0)$ is introduced, this expression becomes

$$k = \beta + i\alpha = k_0 (1 + i\phi_1/\Psi_{dR})^{1/2}$$

Despite the fact that Ψ_{dR} is itself a function of k, an efficient iterative method can be used to determine the value of the propagation constant. By substituting for z_m^i from (36) the following expression for ϕ_i is obtained:

$$\phi_{i} = \frac{2iak_{1}}{(ak_{0})^{2}\chi^{m}} \frac{J_{0}(ak_{1})}{J_{1}(ak_{1})}$$

 Φ_i becomes positive imaginary for the cases plotted in Fig. 3c where ak_1 is real. This makes the propagation constant k on the antenna pure imaginary which leads to an exponentially decreasing magnetic current. For most practical ferrites the positive imaginary part of Φ_i dominates, which makes the attenuation constant a significantly larger than the phase constant β . This can also be seen in the experimental results reported in Section 9.

At this stage it is considered useful to summarize all the approximations and assumptions involved in the derivation of the integral equation in (38) with (39). The ferrite was first treated as a perfect magnetic conductor (μ_{μ} = infinity) and the integral equation in (14) was obtained. This expression was later modified by adding an intrinsic impedance per unit length for a practical ferrite that is an imperfect magnetic conductor and finite. The basic assumption that the radius he small, i.e., ak, << 1, was made. An implied approximation was introduced when the impedance per unit length z_m^1 , derived originally for the infinitely long magnetic conductor, was used for the finite antenna. Its use can be justified as follows. For an infinitely long magnetic conductor, the transverse distribution of electric vector potential is independent of the axial distribution. It is reasonable to assume that this remains the case when the conductor length is large compared to the radius, so that the intrinsic impedance per unit length derived for the infinitely long conductor can be used directly for antennas of finite length. A further question arises concerning the discontinuity of the electric vector potential across the antenna surface. It has been established that the electric vector potential is discontinuous across the antenna surface when the antenna is infinitely long. It is reasonable to conclude that the discontinuity exists even when the length of the antenna is finite. The derivation of the integral equation for the magnetic current or the tangential electric field requires a knowledge of the electric vector potential on the surface $\rho = a$, which has apparently two values. This problem is not peculiar to the ferrite-rod antenna but also exists in the analogous resistive electric dipole antenna. In either case, the value of the vector potential used is that obtained by approaching the antenna surface from the surrounding medium. It is believed, however, that the discontinuity in the vector potential is a

consequence of the way in which the vector potential was defined and can be overcome with the introduction of a suitable scale factor in the definition.

The approach of treating the ferrite as an imperfect magnetic conductor relies on the mathematical equivalence of the two analogous problems. One cannot escape the fact, however, that while there are two pieces of conductor separated by a slice voltage or electric field generator in the case of an electric dipole, the magnetic conductor in the ferrite problem is a single continuous rod driven on the outside surface. A delta function, although unphysical, is a mathematical convenience in either case.

In view of the above discussion, a more rigorous analysis which does not invoke the analogy with the electric dipole is developed and presented in the following section.

7. A MORE RIGOROUS TREATMENT OF THE FINITE ANTENNA

Since the total magnetic current $I_z^*(z)$ is linearly related to the tangential electric field $E_{\phi}(a,z)$ by the relation

$$I_z^*(z) = -2\pi a E_\phi(a,z)$$

the following procedure seeks to derive an integral equation for $E_{\phi}(a,z)$ by solving the ferrite-interior and free space-exterior problems.

Interior Problem. The interior problem consists of a ferrite cylinder of height 2h driven at the center by a constant-current loop. The driving condition will be accounted for after the interior and exterior problems are solved. The diameter of the rod and of the loop is 2a and the restriction $ak_0 << 1$ is satisfied in order to maintain a constant current I_0^e in the driving loop. Given a cylindrical coordinate system (ρ, ϕ, z) and after eliminating \vec{h} from Maxwell's curl equation and imposing azimuthal symmetry, one obtains for the electric field

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$$\left[\frac{\partial^2}{\partial\rho^2} + \frac{1}{\rho}\frac{\partial}{\partial\rho} + (k_1^2 - \frac{1}{\rho^2}) + \frac{\partial^2}{\partial z^2}\right] E_{\phi}(\rho, z) = 0$$
(62)

with $k_1 = k_0 (\mu_r c_r)^{1/2}$, $|z| \le h$, $0 \le \rho \le a$, and $E_{\phi}(\rho, z) = E_{\phi}(\rho, -z)$. Solving (62) by a separation-of-variables technique gives

$$E_{\phi}(\rho,z) = \sum_{n=-\infty}^{\infty} A_n \cos[(n+1/2)\pi z/h] J_1(\rho [k_1^2 - (n+1/2)^2 \pi^2/h^2]^{1/2})$$
(63)

with the coefficients A_n given by

$$A_{n} = \frac{1}{hJ_{1}\{a[(n+1/2)^{2}\pi^{2}/h^{2}]^{1/2}\}} \int_{-h}^{h} E_{\phi}(a,z') \cos[(n+1/2)\pi z'/h] dz'$$

This procedure aims to determine the tangential magnetic field $H_z(a,z)$ from independent treatments of both the interior and exterior problems and then to require that their difference equal $-I_0^e\delta(z)$, the true electric surface current. Thus, $H_z(a,z)$ can be obtained from the above by using

$$H_{z}(\rho,z) = (1/i\omega \mu_{1}) \left[\partial E_{\phi}(\rho,z)/\partial \rho + E_{\phi}(\rho,z)/\rho \right]$$

= $(1/i\omega \mu_{1}h) \left[\sum_{n=-\infty}^{\infty} \left(\int_{-h}^{h} dz' E_{\phi}(a,z') \cos[(n + 1/2)\pi z'/h] \right) \right]$
$$\times \cos[(n + 1/2)\pi z/h] \frac{J_{0}(\rho[k_{1}^{2} - (n + 1/2)^{2}\pi^{2}/h^{2}]^{1/2}}{J_{1}(a[k_{1}^{2} - (n + 1/2)^{2}\pi^{2}/h^{2}]^{1/2}}$$

$$\times [k_{1}^{2} - (n + 1/2)^{2}\pi^{2}/h^{2}]^{1/2} \left]$$
(64)

It should be pointed out that, as a first approximation, $E_{\mu}(a, z)$ is made

to vanish on the top and bottom surfaces defined by |z| = h and $0 \le \rho \le a$, thus neglecting all the fringing fields at the ends of the antenna. In practice, this condition nearly prevails for antennas with heights large compared to the radius (h >> a).

Exterior Problem. The exterior problem is concerned with the free space surrounding the ferrite rod which extends from $(0 \le \rho \le a)$ and $(-h \le z \le h)$ for all ϕ . It is equivalent to solving the problem with the ferrite removed but with the tangential electric field on the surface $E_{\phi}(a,z)$ for $|z| \le h$ required to be the same as that used in the interior problem. With an assumed $e^{-i\omega t}$ time dependence, the governing equations are:

$$\nabla \times \mathbf{H} = -\mathbf{i}\omega \varepsilon_0 \mathbf{E}$$
 (65a)

$$v \cdot \vec{\mathbf{p}} = 0$$
 (65d)

From (65d) in free space, one may define an electric vector potential

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$$t = -(1/c_0) \vee \star t^e$$

This leads to

The exterior problem may be modeled by a cylindrical surface of radius a

that excends from z = -h to z = h. This surface, when immersed in free space, has the following boundary conditions valid for $|z| \le h$:

$$E_{\phi}(a^{\dagger},z) = f^{\dagger}(z) = E_{\phi}(a,z)$$
 (66a)

$$E_{A}(a,z) = f'(z) = 0$$
 (66b)

Substituting for \vec{E} and \vec{H} in (65b), one obtains

$$-\nabla \times \nabla \times \overline{A}^{\mathbf{e}} + i\omega \mu_0 \varepsilon_0 \nabla \phi^* + k_0^2 \overline{A}^{\mathbf{e}} = 0$$
 (67a)

$$(\nabla^2 + k_0^2)\vec{\lambda}^e = \nabla(\nabla \cdot \vec{\lambda}^e + \mu_0 \varepsilon_0 \phi^*) = \nabla_{\chi}$$
(67b)

If the Lorentz gauge is satisfied, the Lorentz factor λ [and the right-hand side of (67b)] is zero. The equations may now be specialized to the problem at hand. There is rotational symmetry in the problem and the non-zero quantities are E_{ϕ} , H_{ρ} , H_{z} , Λ_{z}^{e} and ϕ^{*} . Equations (65a,b) for the different components become

$$(\partial H_{\rho}/\partial z - \partial H_{z}/\partial \rho) = -i\omega \varepsilon_{0} E_{j}$$
(68a)

$$i\omega\mu_0H_0 = -\partial E_{\mu}/\partial z$$
 (68b)

$$i\omega\mu_0 H_z = \frac{1}{\rho} \frac{\partial}{\partial \rho} (\rho E_{\phi})$$
 (68c)

These three equations are true everywhere except on the surface $\rho = 1$ and $|z| \leq h$. To make the equations valid on the surface, one has to introduce the surface conditions into the above equations. In addition to the conditions in (66a,b), there is an electric current $K_{\phi}(z)$ on the surface as well as a large axial magnetic field. Thus, (6da-c) become

$$(\partial H_{\rho}/\partial z - \partial H_{z}/\partial \rho) + \delta(\rho - a)K_{\phi}(z) = -i\omega\varepsilon_{0}E_{\phi}$$
(69a)

$$i\omega\mu_0 H_\rho = -\partial E_\phi / \partial z \tag{69b}$$

$$i\omega\mu_0 H_z + \delta(\rho - a)E_{\phi} = (\partial E_{\phi}/\partial \rho + E_{\phi}/\rho)$$
(69c)

In terms of the potentials, the fields are given by

$$H_{\rho} = -\partial \phi^* / \partial z$$

$$H_{z} = -\partial \phi^* / \partial z + i \omega A_{z}^{e}$$

$$E_{\phi} = (1/\epsilon_{0}) \partial A_{z}^{e} / \partial \rho$$

From the preceding equation,

$$A_{z}^{e}(\rho,z) = c_{0} \int_{\rho}^{\infty} E_{\phi}(\rho',z) d\rho'$$
(70)

It is now required to set up an equation for $\Lambda^e_z({\tt c}\,,z)\,.$

$$(v^{2} + k_{0}^{2})A_{z}^{e}(\rho, z) = \left[\frac{\partial^{2}}{\partial\rho^{2}} + \frac{1}{\rho}\frac{\partial}{\partial\rho} + \frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right]\epsilon_{0}\int_{\rho}^{\infty}F_{\phi}(\rho', z) d\rho'$$
$$= \epsilon_{0}[\partial E_{\phi}(\rho, z)/\partial\rho + E_{\phi}(\rho, z)/\rho] + \epsilon_{0}\frac{\partial}{\partial z}\int_{\rho}^{\infty}\partial E_{\phi}(\rho', z)/\partial z d\rho'$$
$$+ \epsilon_{0}k_{0}^{2}\int_{\rho}^{\infty}E_{\phi}(\rho', z) d\rho'$$

With (69b,c) this becomes

$$(v^{2} + k_{0}^{2})A_{z}^{e}(\rho,z) = c_{0}[i\omega u_{0}H_{z}(\rho,z) + \delta(\rho - \rho)E_{\phi}(\rho,z)]$$
$$- i\omega u_{0}c_{0}\int_{\rho}^{\infty} \partial H_{\rho}(\rho',z)/\partial z d\rho' + c_{0}k_{0}^{2}\int_{\rho}^{\infty} E_{\phi}(\rho',z) d\rho'$$

Using (69a) gives

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$$(\nabla^{2} + k_{0}^{2})A_{z}^{e}(\rho, z)$$

$$= i\omega\mu_{0}\varepsilon_{0}H_{z}(\rho, z) + \varepsilon_{0}\delta(\rho - a)E_{\phi}(\rho, z) - i\omega\mu_{0}\varepsilon_{0}\int_{\rho}^{\infty} [-i\omega\varepsilon_{0}E_{\phi}(\rho', z) + \frac{\partial H_{z}(\rho', z)}{\partial\rho}$$

$$= \delta(\rho' - a)K_{\phi}(z)]d\rho' + \varepsilon_{0}K_{0}^{2}\int_{\rho}^{\infty} E_{\phi}(\rho', z)d\rho'$$

$$= i\omega\mu_{0}\varepsilon_{0}H_{z}(\rho, z) + \varepsilon_{0}\delta(\rho - a)E_{\phi}(\rho, z) - \varepsilon_{0}K_{0}^{2}\int_{\rho}^{\infty} E_{\phi}(\rho', z)d\rho'$$

$$+ i\omega\mu_{0}\varepsilon_{0}K_{\phi}(z)\int_{\rho}^{\infty}\delta(\rho' - a)d\rho' - i\omega\mu_{0}\varepsilon_{0}H_{z}(\rho, z) + \varepsilon_{0}K_{0}^{2}\int_{\rho}^{\infty} E_{\phi}(\rho', z)d\rho'$$

$$= \varepsilon_{0}\delta(\rho - a)E_{\phi}(\rho, z) + i\omega\mu_{0}\varepsilon_{0}K_{\phi}(z)\int_{\rho}^{\infty}\delta(\rho' - a)d\rho'$$

The o' integral may be performed:

$$\int_{\rho}^{\infty} \delta(\rho' - a) d\rho' = H(a - \rho) = \begin{cases} 1 & \text{if } 0 \le \rho \le a \end{cases}$$
$$0 & \text{if } \rho \ge a^{\dagger} \end{cases}$$

Therefore, finally

$$(v^{2} + k_{0}^{2})A_{z}^{e}(\rho,z) = \varepsilon_{0}\delta(\rho - a)E_{\phi}(\rho,z) + i\omega\nu_{0}\varepsilon_{0}K_{\phi}(z)H(a - \rho)$$
(71)

If (71) is formally identified with (67h), it is seen that the second term on the right in (71) corresponds to the Lorentz factor term. The Lorentz gauge is satisfied ($\chi = 0$) in the exterior region ($\rho > a$) but is not satisfied in the interior region. Furthermore, by differentiating with respect to ρ

$$\chi = \nabla \cdot \vec{\Lambda}^{c} + \mu_{0} \varepsilon_{0} \dot{\phi}^{\dagger} = \partial \Lambda_{z}^{c} (\rho, z) / \partial z - i \omega \mu_{0} \varepsilon_{0} \phi^{\dagger} (\rho, z) ,$$

it can be shown that χ is independent of ρ and a function of z only, i.e., $\chi = \chi(z)$, which leads to:

$$\chi(z) = \partial A_{z}^{e}(\rho, z) / \partial z - i \omega \mu_{0} \varepsilon_{0} \phi^{*}(\rho, z) = \begin{cases} i \omega \mu_{0} \varepsilon_{0} \int_{0}^{z} K_{\phi}(z') dz' & \text{if } 0 \leq \rho \leq a \end{cases}$$
$$0 \quad \text{if } \rho \geq a^{+}$$

It is thus seen that the Lorentz condition is satisfied on the exterior but not in the interior. This is because of the presence of the transverse electric current in the ferrite medium. This situation can be contrasted to an electric dipole antenna (thin or thick), where there are no magnetic currents to make the Lorentz condition invalid.

It is now required to solve (71) for the electric vector potential. The equation becomes

$$\left(\frac{\partial^2}{\partial\rho^2} + \frac{1}{\rho}\frac{\partial}{\partial\rho} + \frac{\partial^2}{\partial z^2} + k_0^2\right) A_z^{\rm e}(\rho,z) = \epsilon_0 \delta(\rho - a) E_{\phi}(\rho,z) + i \omega \mu_0 \epsilon_0 K_{\phi}(z) H(a - \rho)$$

This equation can be solved with the use of Green's theorem and the principle of superposition. Thus,

$$A_{z}^{e}(\rho,z) = A_{zE}^{e}(\rho,z) + A_{zK}^{e}(\rho,z)$$

where

$$A_{zE}^{e}(\rho,z) = -(c_{0}/4\pi) \int_{-\pi}^{\pi} d\phi'/2\pi \int_{0}^{\infty} d\rho' 2\pi\rho' \int_{-\infty}^{\infty} dz' E_{\phi}(\rho,z')\delta(\rho'-a)(e^{1k_{0}R}/R)$$
$$= -(ac_{0}/2) \int_{-h}^{h} dz' E_{\phi}(a,z')K(z-z',\rho)$$

with

$$K(z - z', \rho) = \int_{-\pi}^{\pi} \frac{d\phi'}{2\pi} \frac{e}{R}$$
(72)

and R = $((z - z')^2 + \rho^2 + a^2 - 2\rho a \cos \phi')^{1/2}$. $A^{e}_{zF}(\rho, z)$ will be used later

to obtain $A_{z1}^{e}(a,z)$. Similarly, $A_{zK}^{e}(\rho,z) = -(i\omega\mu_{0}\varepsilon_{0}/4\pi) \int_{-\pi}^{\pi} d\phi'/2\pi \int_{0}^{\infty} d\rho' 2\pi\rho' \int_{-\infty}^{\infty} dz' K_{\phi}(z')H(a-\rho)(e^{ik_{0}R_{1}}/R_{1})$ $= -(i\omega\mu_{0}\varepsilon_{0}/2) \int_{-h}^{h} dz' K_{\phi}(z')M_{1}(z-z',\rho)$

where

$$M_{1}(z - z', p) = \int_{-\pi}^{\pi} \frac{d\phi'}{2\pi} \int_{0}^{a} dp' p' \frac{e^{-ik_{0}R_{1}}}{R_{1}}$$
(73)

and
$$R_1 = [(z - z')^2 + \rho^2 + \rho'^2 - 2\rho\rho' \cos \phi']^{1/2}$$
.

Thus, the total electric vector potential is

$$A_{z}^{e}(\rho,z) = -(a\epsilon_{0}/2) \int_{-h}^{h} dz' E_{\phi}(a,z')K(z-z',\rho) -(i\omega\mu_{0}\epsilon_{0}/2) \int_{-h}^{h} dz' K_{\phi}(z')H_{1}(z-z',\rho)$$
(74)

By specializing (74) for $\rho = a^{\dagger}$ and $\rho = a^{-}$ and by making use of (70) and (66a,b), one obtains

$$\varepsilon_{0} \varepsilon_{\phi}(a,z) = -(a\varepsilon_{0}/2) \int_{-h}^{h} dz' \varepsilon_{\phi}(a,z') \frac{\partial K(z-z',p)}{\partial p} \Big|_{p=a}^{p=a^{+}}$$
(75)
- $(i\omega\mu_{0}c_{0}/2) \int_{-h}^{h} dz' K_{\phi}(z') \frac{\partial H_{1}(z-z',p)}{\partial p} \Big|_{p=a^{-}}$

Returning to (74), one may now obtain for the tangential magnetic field

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$$H_{z}(\rho,z) = (i\omega/k_{0}^{2}) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \Lambda_{z}^{e}(\rho,z)$$

.

Thus,

$$H_{z}(\rho,z) = (a/2)(1/i\omega\mu_{0}) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \int_{-h}^{h} dz' E_{\phi}(a,z')K(z-z',\rho) + (1/2) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \int_{-h}^{h} dz' K_{\phi}(z')M_{1}(z-z',\rho)$$
(76)

Once again, on the exterior surface $\rho = a^+$,

$$H_{z}(a^{+},z) = (a/2)(1/i\omega\mu_{0}) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \int_{-h}^{h} dz' E_{\phi}(a,z') K(z-z',a^{+}) + (1/2) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \int_{-h}^{h} dz' K_{\phi}(z')H_{1}(z-z',a^{+})$$
(77)

It now remains to use (77) and (64) to obtain the integral equation.

Integral Equation for $E_{\phi}(a,z)$ and $K_{\phi}(z)$. The required integral equations for the unknown quantities may be obtained from the results of (64) and (77) for the interior and exterior problems by requiring that

$$H_z(a^+,z) - H_z(a^-,z) = -I_0^e \delta(z)$$

This gives

$$\begin{cases} (a/2) (1/i\omega\mu_{(p)}) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \int_{-h}^{h} dz' E_{\phi}(a, z') K(z - z', a) + (1/2) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \\ \times \int_{-h}^{h} dz' K_{\phi}(z') M_{1}(z - z', a) \\ + \left\{ (1/\omega\mu_{1}ah) \left(\sum_{n=-\infty}^{\infty} \left[\int_{-h}^{h} dz' E_{\phi}(a, z') + (1/2) \left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2} \right) \right] \\ \times \cos(pz') \left[\cos(pz) \frac{J_{0}[a(k_{1}^{2} - p^{2})^{1/2}]}{J_{1}[a(k_{1}^{2} - p^{2})^{1/2}]} \left\{ a(k_{1}^{2} - p^{2})^{1/2} \right\} \right\} = -I_{0}^{0}\delta(z)$$
(78a)

with $p = (n + 1/2)\pi/h$.

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The other equation to be satisfied simultaneously is (75), which is reproduced here for convenience:

$$\varepsilon_{0} \mathbb{E}_{\phi}(\mathbf{a}, \mathbf{z}) = -(\mathbf{a}\varepsilon_{0}/2) \int_{-h}^{h} d\mathbf{z}' \mathbb{E}_{\phi}(\mathbf{a}, \mathbf{z}') \left. \partial \mathbb{K}(\mathbf{z} - \mathbf{z}', \rho) \right|_{\rho = a}^{+} - (\mathbf{i}\omega \mu_{0}\varepsilon_{0}/2) \int_{-h}^{h} d\mathbf{z}' \mathbb{K}_{\phi}(\mathbf{z}') \left. \partial \mathbb{M}_{1}(\mathbf{z} - \mathbf{z}', \rho) \right|_{\rho = a}^{-}$$
(78b)

The two kernels $K(z - z', \rho)$ and $M_1(z - z', \rho)$ appearing in the coupled integral equations above are defined by (72) and (73) respectively.

It can be verified easily that in the limit $h \rightarrow \infty$ the integrals in (78a,b) become convolution integrals, that the two equations decouple and that the expression for $E_{\phi}(\rho,z)$ on the surface $\rho = a$ is in complete agreement with the results presented in Part I [2, Eqs. (17) or (18)].

Returning to the coupled integral equations in (78a,b), it is seen that there are three kernels. First of all, the kernel on the right-hand side of (78a) will be examined carefully. The kernel is made up of an infinite series which is clearly divergent since, for large values of n, it behaves like n. Although strictly not valid, the operations of summation and integration will be interchanged for the purpose of examining the series. The interchange is reversed at a later stage so that, in effect, all the steps are valid.

It is convenient to define the kernel $M(z,z^{\dagger})$ on the left-hand side of (78a) as:

$$M(z,z') = \int_{n=-\infty}^{\infty} \cos(pz') \cos(pz) \frac{J_0[a(k_1^2 - p^2)^{1/2}]}{J_1[a(k_1^2 - p^2)^{1/2}]} [a(k_1^2 - p^2)^{1/2}]$$

where $p = (n + 1/2)\pi/h$.

As was pointed out earlier, this series is divergent and, hence, it is useful to write it as the sum of two series, using the first two terms in the asymptotic form. For large values of n, the series behaves like

$$\sum \cos(pz') \cos(pz) \frac{J_0(iap)}{J_1(iap)} (iap) \simeq \sum \cos(pz') \cos(pz) \frac{I_0(ap)}{I_1(ap)} (ap)$$
$$\simeq \sum \cos(pz') \cos(pz) \frac{1 + \frac{1}{8ap}}{1 - \frac{3}{8ap}} (ap) \simeq \sum \cos(pz') \cos(pz) \left[1 + \frac{1}{2ap}\right] (ap)$$

We now write

$$M(z,z') = P(z,z') + Q(z,z')$$
(79)

with

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$$P(z,z') = \sum_{n=-\infty}^{\infty} \left[\frac{J_0[a(k_1^2 - p^2)^{1/2}]}{J_1[a(k_1^2 - p^2)^{1/2}]} [a(k_1^2 - p^2)^{1/2}] - ap - \frac{1}{2} \right] \cos(pz') \cos(pz)$$
(80)

and

$$Q(z,z') = \sum_{n=-\infty}^{\infty} (ap + 1/2) \cos(pz') \cos(pz)$$
 (81)

Equation (79) along with (80) and (81) is exact because it only adds and subtracts the first two terms in the asymptotic form. Now P(z,z') can be written as:

$$P(z,z') = \sum_{n=-\infty}^{\infty} A_n \cos(pz') \cos(pz)$$

with A_n given by the term in the square brackets in (80).

If all the coefficients A_n were equal, P(z,z') would be a delta function; but this is not the case. In view of the differential operator on the lefthand side of (78a), it is helpful to remove a similar factor from P(z,z'). This is easily accomplished by solving an equation of the form:

$$(\partial^2/\partial z^2 + k_0^2)f(z) = \cos(pz)$$

Through the use of Green's function (or by any other method), one can obtain:

$$f(z) = a_1 \cos(k_0 z) + a_2 \sin(k_0 z) + (1/k_0) \int_0^z \sin[k_0 (z - z')] \cos(pz') dz'$$

Note that, without any loss of generality, the constants a_1 and a_2 can be set equal to zero and the integral on the right performed to obtain:

$$f(z) = [\cos(pz) - \cos(k_0 z)]/(k_0^2 - p^2)$$

so that

$$P(z,z^{*}) = \left(\frac{\vartheta^{2}}{\vartheta z^{2}} + k_{0}^{2}\right) \sum_{n=-\infty}^{\infty} A_{n} \left[\frac{\cos(pz) - \cos(k_{0}z)}{k_{0}^{2} - p^{2}}\right] \cos(pz^{*})$$
(82)

In (82) it appears that one of the terms in the series will be equal to infinity if $p = k_0$. This condition is equivalent to $h/\lambda = 1/4$, 3/4, 5/4,..., . This is not the case, however, because of the numerator and the fact that, as $p \rightarrow k_0$, the term in the square brackets in (82) approaches $[z \sin(k_0 z)]/2k_0$.

Returning to (81), it is found that, since Q(z,z') is an odd series, its most divergent part is identically equal to zero, so that

$$Q(z,z') = (1/2) \sum_{n=-\infty}^{\infty} \cos(pz') \cos(pz) = (h/2)\delta(z - z')$$
(83)

Using (82) and (83) with (79) in the integral equation (78a), one obtains

$$\left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \left[\int_{-h}^{h} dz' E_{\phi}(a,z')K(z-z',a) + \frac{i\omega\mu_{0}}{a}\int_{-h}^{h} K_{\phi}(z')M_{1}(z-z',a) dz'\right]$$

- $-\frac{2}{a} \left\{i\omega\mu_{0}I_{0}^{0}\delta(z) - \frac{1}{a\mu_{r}}\frac{1}{2}E_{\phi}(a,z) - \frac{1}{a\mu_{r}}\frac{1}{h}\left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right)\int_{-h}^{h} dz' E_{\phi}(a,z')$ (Continued)

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$$\times \left(\sum_{n=-\infty}^{\infty} A_{n} \left[\frac{\cos(pz) - \cos(k_{0}z)}{k_{0}^{2} - p^{2}}\right] \cos(pz^{*})\right) \right\}$$

Rearranging terms gives

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$$\left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right) \left[\int_{-h}^{h} dz' E_{\phi}(a,z')K_{1}(z-z') + \frac{i\omega\mu_{0}}{a}\int_{-h}^{h} K_{\phi}(z')M_{1}(z-z',a) dz'\right]$$
$$= -\frac{2}{a} \left[i\omega\mu_{0}I_{0}^{0}\delta(z) - \frac{1}{a\mu_{r}}\frac{1}{2}E_{\phi}(a,z)\right]$$
(84)

where the combined kernel $K_1(z - z^{\dagger})$ is defined as

$$K_{1}(z - z') = \int_{-\pi}^{\pi} \frac{d\phi'}{2\pi} \frac{e^{\frac{1k_{0}R_{s}}{R}}}{s} - \frac{2}{a^{2}\mu_{r}h} \int_{n=-\infty}^{\infty} \Lambda_{n} \left[\frac{\cos(pz) - \cos(k_{0}z)}{k_{0}^{2} - p^{2}} \right] \cos(pz')$$
(85)

with the coefficients ${\ensuremath{A}}_n$ given by

$$A_{n} = \frac{J_{0}[a(k_{1}^{2} - p^{2})^{1/2}]}{J_{1}[a(k_{1}^{2} - p^{2})^{1/2}]} [a(k_{1}^{2} - p^{2})^{1/2}] - ap - \frac{1}{2}$$

and $p = (n + 1/2)\pi/h$.

The second integral equation from (78b) is:

$$-\frac{a}{2}\int_{-h}^{h}dz' E_{\phi}(a,z') \frac{\partial}{\partial\rho} K(z-z',\rho)\Big|_{\rho=a^{+}} -\frac{i\omega\mu_{0}}{2}\int_{-h}^{h}dz' K_{\phi}(z') \frac{\partial}{\partial\rho} M_{1}(z-z',\rho)\Big|_{\rho=a^{+}}$$
$$= E_{\phi}(a,z)$$

The coupled integral equations can now be written in a short-hand notation suitable for numerical evaluation:

$$\left(\frac{\partial^{2}}{\partial z^{2}} + k_{0}^{2}\right)\left[\int_{-h}^{h} dz' E_{\phi}(z')K_{1}(z-z') + C_{1}\int_{-h}^{h} dz' I_{\phi}(z')M_{1}(z-z')\right] = C_{2}\delta(z) + C_{3}E_{\phi}(z)$$
(86a)

$$C_{4} \int_{-h}^{h} dz' E_{\phi}(z')K_{2}(z-z') + C_{5} \int_{-h}^{h} dz' I_{\phi}(z')M_{2}(z-z') = \frac{1}{2} E_{\phi}(z)$$
(86b)

where the electric surface current $I_{\phi}(z) = 2\pi a K_{\phi}(z)$. Also, the kernel $K_1(z - z')$ has been defined previously in (85), and

$$C_1 = i\omega\mu_0/2\pi a^2$$
; $C_2 = -2i\omega\mu_0 I_0^{e/a}$; $C_3 = 1/a^2\mu_r$;
 $C_4 = -a/2$; $C_5 = -i\omega\mu_0/4\pi a$

The factor (1/2) on the right-hand side of (86b) comes from the discontinuity in the derivative of the $K_2(z - z')$ kernel, viz.,

$$K_{2}(z - z') = \frac{\partial}{\partial \rho} K(z - z', \rho) \Big|_{\rho=a^{+}} + \frac{\partial}{\partial \rho} K(z - z', \rho) \Big|_{\rho=a^{-}}$$
$$M_{2}(z - z') = \frac{\partial}{\partial \rho} M_{1}(z - z', \rho) \Big|_{\rho=a^{+}} = \frac{\partial}{\partial \rho} M_{1}(z - z', \rho) \Big|_{\rho=a^{-}}$$

8. NUMERICAL SOLUTION BY THE MOMENT METHOD OF THE COUPLED INTEGRAL EQUATIONS The differential equation (86a) can be solved to obtain:

$$\int_{-h}^{h} dz' E_{\phi}(z')K_{1}(z-z') + C_{1} \int_{-h}^{h} dz' I_{\phi}(z')M_{1}(z-z')$$

$$= C_{6} \cos(k_{0}z) + C_{7} \sin(k_{0}|z|) + C_{8} \int_{0}^{z} dz' E_{\phi}(z')\sin[k_{0}(z-z')]$$
(87a)

Similarly, from (86b)

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$$\int_{-h}^{h} dz^{*} E_{\phi}(z^{*}) K_{2}(z - z^{*}) + C_{9} \int_{-h}^{h} dz^{*} I_{\phi}(z^{*}) M_{2}(z - z^{*}) = C_{10} E_{\phi}(z)$$
(87b)

where C_6 is unknown and determined numerically by employing the end condition $I_4(h) = 0$, and

$$c_1 = i\omega\mu_0/2\pi a^2 \quad ; \quad c_7 = c_2/2k_0 = -i\omega\mu_0 I_0^{\text{e}}/ak_0$$
$$c_8 = c_3/k_0 = 1/a^2\mu_r k_0 \quad ; \quad c_9 = c_5/c_4 = i\omega\mu_0/2\pi a^2 \quad ; \quad c_{10} = 1/2c_4 = -1/a$$

It is now considered useful to examine the four kernels in (37s, b) and to obtain their Fourier transforms. Thus,

$$K_1(z - z') = K(z - z') - \frac{2}{a^2 \mu_r h} \sum_{n=-\infty}^{\infty} A_n \left\{ \frac{\cos(pz) - \cos(k_0 z)}{k_0^2 - p^2} \right\} \cos(pz')$$

with $p = (n + 1/2)\pi/h$. The Fourier transform of K(z - z') is given by $\tilde{K}(\xi) = i\pi J_0(a\gamma_0)H_0^{(1)}(a\gamma_0)$ where $\gamma_0^2 = k_0^2 - \xi^2$.

$$M_{1}(z - z', \rho) = \int_{-\pi}^{\pi} \frac{d\phi'}{2\pi} \int_{0}^{a} d\rho' \rho' \frac{e^{(z - z')^{2} + \rho^{2} + \rho'^{2} - 2\rho\rho' \cos \phi'}}{[(z - z')^{2} + \rho^{2} + \rho'^{2} - 2\rho\rho' \cos \phi']^{1/2}}$$

$$\overline{M}_{1}(\xi,\rho) = i\pi \int_{0}^{a} H_{0}^{(1)}(\rho_{>}\gamma_{0}) J_{0}(\rho_{<}\gamma_{0}) \rho' d\rho'$$

n

where

 $\rho_{<} \approx$ smaller of ρ and ρ'

which leads to

$$\widetilde{M}_{1}(\xi,\rho) = \begin{cases} (i\pi a/\gamma_{0})J_{0}(\rho\gamma_{0})H_{1}^{(1)}(a\gamma_{0}) & \text{if } \rho > \rho' \\ \\ (i\pi a/\gamma_{0})H_{0}^{(1)}(\rho\gamma_{0})J_{1}(a\gamma_{0}) & \text{if } \rho < \rho' \end{cases}$$

It is easily seen that

$$\overline{M}_{2}(\xi) = \frac{\partial}{\partial \rho} \overline{M}_{1}(\xi, \rho) \Big|_{\rho=a^{+}} = \frac{\partial}{\partial \rho} \overline{M}_{1}(\xi, \rho) \Big|_{\rho=a^{-}} = -i\pi a J_{1}(a\gamma_{0}) H_{1}^{(1)}(a\gamma_{0})$$

Finally,

$$\widetilde{K}_{2}(\xi) = \frac{\partial}{\partial \rho} \widetilde{K}(\xi, \rho) \Big|_{\rho=a}$$

where

$$\bar{\kappa}(\xi,\rho) = i\pi J_0(\rho_{<}\gamma_0)H_0^{(1)}(\rho_{>}\gamma_0)$$

with

$$\rho_{<} = \text{smaller of } \rho$$
 and a
 $\rho_{>} = \text{larger of } \rho$ and a

so that

$$\tilde{k}(\xi,\rho) = \begin{cases} i\pi J_0(\rho\gamma_0)H_0^{(1)}(a\gamma_0) & \text{for } \rho < a \\ \\ \\ i\pi J_0(a\gamma_0)H_0^{(1)}(\rho\gamma_0) & \text{for } \rho > a \end{cases}$$

Therefore,

$$\bar{k}_{2}(\xi) = -i\pi\gamma_{0}J_{0}(a\gamma_{0})H_{1}^{(1)}(a\gamma_{0})$$

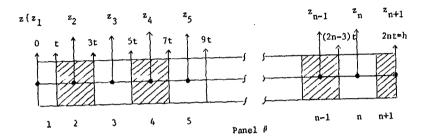
To begin the numerical procedure, it is recognized that, because of the evenness of $E_{\phi}(z)$ and $I_{\phi}(z)$, the integrals ranging from -h to h may be converted as follows:

$$\int_{-h}^{h} E_{\phi}(z') K_{1,2}(z-z') dz' = \int_{0}^{h} E_{\phi}(z') [K_{1,2}(z-z') + K_{1,2}(z+z')] dz'$$

Similarly,

$$\int_{-h}^{h} I_{\phi}(z') M_{1,2}(z-z') dz' = \int_{0}^{h} I_{c}(z') [M_{1,2}(z-z') + M_{1,2}(z+z')] dz'$$

Now the interval from 0 to h can be subdivided into n+1 panels. Within each panel the unknown quantities $E_{\phi}(z)$ and $I_{\phi}(z)$ are approximated by constants and the constant value is assigned to a location z which corresponds to the center of the panel. With the length h = 2nt, each panel is of width 2t except the first and last panels which are of width t.



The locations at which the unknown quantities are determined are given by $z_{I} = (2I - 2)t$ with I = 1, 2, 3, ..., (n+1). Typically,

$$= \begin{cases} t & 3t & 5t \\ 0 & t & 3t & 5t \\ 0 & t & 3t & 5t \\ 0 & t & 3t & 1 & 1 \\ \end{cases} + \begin{cases} t & 3t & 5t \\ 0 & t & 3t & 1 \\ 0 & t & 3t & 1 \\ \end{cases} + \\ \end{cases} + \\ \end{cases} + \\ (2n-1)t & 2nt \\ (2n-1)t \\ (2n-1)t \\ \end{cases} \\ E_{\phi}(z^{\prime}) \{K_{1}(z-z^{\prime}) + K_{1}(z+z^{\prime})\} dz^{\prime}$$

In each of these intervals $E_{\phi}(z)$ is approximated by a constant value so that

$$\begin{aligned} & \kappa_{1}(\mathbf{I},\mathbf{J}) = \int_{\Delta z_{\mathbf{J}}} \left[\kappa_{1}(z_{\mathbf{I}} + z') + \kappa_{1}(z_{\mathbf{I}} - z') \right] dz' = \left\{ \begin{array}{l} (2J-1)t \\ \int_{(2J-3)t} dz' \\ \left\{ \frac{1}{2\pi} \int_{-\infty}^{\infty} \overline{\kappa}(z) e^{i\xi z_{\mathbf{I}}} \left(e^{i\xi z'} + z' \right) \right\} \\ & + e^{-i\xi z'} \\ & + e^{-i\xi z'} \\ & d\xi \\ & - \frac{1}{a^{2}u_{\tau}h} \left(\frac{(2J-1)t}{(2J-3)t} dz' \\ \left\{ \frac{\sum_{n=-\infty}^{\infty} \Lambda_{n}}{n} \left\{ \frac{\cos\left(pz_{\mathbf{I}}\right) - \cos\left(k_{0}z_{\mathbf{I}}\right)}{k_{0}^{2} - p^{2}} \right\} \cos\left(pz'\right) \right\} \end{aligned}$$

By substituting for $\bar{K}(\xi)$ and carrying out the z^{\dagger} integration, one obtains

$$K_1(I,J) = K(I,J) + B(I,J)$$

where

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$$K(I,J) = (4/\pi) \int_{-\infty}^{\infty} [i\pi J_0(a\gamma_0)H_0^{(1)}(a\gamma_0)][(\sin \xi t)/\xi] \{\cos[2\xi(I+J-2)t]$$

+
$$\cos[2\xi(I-J)t]$$
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$$B(I,J) = -\frac{4}{\pi\mu_r} \sum_{n=0}^{\infty} A_n \left[\frac{\cos[2pt(I-1)] - \cos[2k_0t(I-1)]}{a^2(k_0^2 - p^2)} \right]$$

$$+\left[\frac{\sin[\operatorname{pt}(2J-1)] - \sin[\operatorname{pt}(2J-3)]}{(h/\pi)p}\right]$$

The integral in K(1,J) is evaluated by suitably deforming the contour from the real axis to a contour that wraps around the branch cut. When this is done, K(I,J) for I#J can be written in the form

$$K(I,J) = \int_{0}^{\infty} f(x) e^{-x} dx$$

where f(x) is a complex function of a real variable x. The integrals are evaluated using a 10-point Gauss-Laguerre quadrature method. The special case of diagonal elements (I=J) can be written in the form

$$K(I,I) = \frac{1}{\pi} \int_{-\infty}^{\infty} \overline{K}(\xi) \left[(\sin \xi t) / \xi \right] (e^{2i\xi x} I + 1) d\xi = (1/2)K(1,1) + T(I)$$

where

$$T(I) = \frac{1}{\pi} \int_{-\infty}^{\infty} \tilde{K}(\xi) \{(\sin \xi t)/\xi\} e^{2i\xi z_I} d\xi$$

with $z_I = 2(I - 1)t$, I = 1, 2, ..., (n+1). K(1,1) is evaluated as an integral on the real axis because of the absence of the exponential decay factor, using 10-point Gauss quadrature routines. T(I) can once again be put in a form suitable for Gauss-Laguerre quadrature by a deformation of the contour that wraps around the branch cut at $\xi = k_0$. Care is taken in evaluating the first and last panels' integrations because of their half normal width. What is discussed for kernel K(z - z') or $\overline{K}(\xi)$ is essentially true with the calculation of the elements corresponding to the three other kernels.

Referring back now to the three terms on the right-hand side of (87a), viz.,

$$C_{6} \cos(k_{0}z_{1}) + C_{7} \sin(k_{0}|z_{1}|) + C_{8} \int_{0}^{z_{1}} dz' E_{\phi}(z') \sin[k_{0}(z_{1} - z')],$$

the first and last terms, containing respectively the unknowns C_6 and $E_{\phi}(z)$, are moved to the left-hand side. For example,

$$C_6 \cos(k_0 z_1) = C_6 \cos[k_6(21 - 2)t]$$

 $C_{8} \int_{0}^{z} dz' [] = C_{8} \int_{0}^{(2I-2)t} dz' [] = C_{8} \begin{cases} t & 2t \\ f & + f \\ 0 & t \end{cases} + \dots + \begin{pmatrix} (2I-2)t \\ f \\ (2I-3)t \\ (2I-3)t \end{cases} dz' []$

We now define

$$A(I,P) = \int_{(P-1)t}^{Pt} \sin[k_0(z_1 - z^*) dz^* = (1/k_0)(\cos[k_0t(2I - P - 2)] - \cos[k_0t(2I - P - 1)])$$

It is seen that when the term associated with C_8 is moved to the lefthand side, it affects only the lower triangle elements of $K_1(1,J)$ and not the upper triangle elements, thus rendering the $K_1(1,J)$ matrix elements not equal to $K_1(J,I)$. Extending these calculating principles to (87b), and using the fact that $I_{\phi}(h) = I_{\phi}(I=n+1) = 0$, one can finally set up the following matrix equation:

a11	^a 12 ···	^a 1,n+1	^a 1,n+2	•••	^a 1,2n+1	^a 1,2n+2	E ₁		^G 1
:	I	:		11	:	$a^{a}_{1,2n+2}$ v $a^{a}_{n+1,2n+2}$ $a^{a}_{n+2,2n+2}$ $a^{a}_{n+2,2n+2}$ v v v v v $a^{a}_{n+2,2n+2}$	÷		÷
^a n+1,	,1	^a n+1,n+1	^a n+1,n+2	•••	^a n+1,2n+1	 ^a n+1,2n+2	Fn+1	=	6 _{n+1}
^a n+2,	,1	^a n+2,n+1	an+2,n+2	•••	^a n+2,2n+1	^a n+2,2n+2	I1		0 0
:	III	•		IV	•	I I I VI	:		
			l 1			;	I _n		0
^a 2n+2	.,1	^a 2n+2,n+1	^a 2n+2,n+2	2 •••	^a 2n+2,2n+1	^a 2n+2,2n+2	C ₆		0

where the elements on the right-hand side are given by $G(I) = C_7 \sin[k_0(2I-2)t]$ with I = 1, 2, ..., (n+1).

The magnetic current $I_z^*(z)$ is easily obtained from the solution of the system of linear equations by using $I_z^*(z) = -2\pi a E_{\phi}(z)$ volts. The computer programs are included in Appendix C and the results are plotted and discussed in the next section.

The magnetization current is essentially the time rate of change of the magnetization vector (\vec{N}) 'integrated over the antenna cross section. The experimental procedure, however, determines the total axial magnetic flux with the use of a shielded loop placed coaxially over a driven loop which is loaded by a ferrite cylinder. Suitable modifications to the theory have to be made, therefore, before the computations can be compared with the experimental results. These modifications and the assumption of azimuthal symmetry on which they are based are discussed in detail in Appendix D.

Ferrite materials that are available commercially have been used in this experimental investigation. Table 1 lists the initial permeability μ'_r (i.e., the slope of the B-H curve for small H) and the applicable frequency range for a variety of ferrite materials, grouped under their respective suppliers. Ferrites #C-2050 of Ceramic Magnetics, Inc. and #Q-3 of Indiana General were selected for use in the 5-100 MHz frequency range. Toroidal samples of the #C-2050 material were obtained and its properties (μ'_r and Q) measured as a function of frequency by means of a Q-meter. The quality factor Q of the ferrite material is defined by

$$Q = \frac{1}{\log s \ factor} = \mu_r'/\mu_r'' = \frac{2\pi \times stored \ energy}{energy \ dissipated \ per \ period, \ 2\pi/\omega}$$
(88)

The measured values of Q and μ_r^t for the ferrite material \$C-2050 are shown plotted in Fig. 4(a) as a function of frequency together with the values supplied by the manufacturer. Fair agreement is observed between the two. The imaginary part μ_r^u of the relative permeability can be calculated easily using (88) and measured values of μ_r^t and Q. The manufacturer-supplied values of μ_r^t and Q for the ferrite material \$0-3 are shown in Fig. 4(b). The values of the relative permittivity c_r used in the theoretical calculations were

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TABLE 1. List of Commercially Available Ferrite Materials

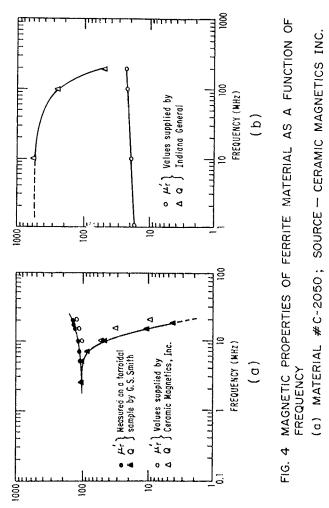
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Source #1:	Ceramic Magnet	ics, Inc., Fairf	ield, N.J.				
Type of Ferrite Material	Manufacturer Code #	Initial Permeability ^µ r	Frequency Range				
Mn-Zn Mn-Zn Ni Ni	MN-31 DC-10 MN-31 DC-20 CN-20 CM-2002	2800 3300 800 1500	Up to 10 MHz Up to 10 MHz 300 KHz - 2 MHz 1 KHz - 1 MHz Up to 500 KHz Up to 600 KHz Below 1 MHz Below 15 MHz				
Mn Mn Mn	MN-30 MN-60 MN-100 C-2010	4000 6000 9500 200–300					
	с-2025 с-2050 с-2075 СМД-5005 N-40	150-200 100-150 25-50 1400 15-20	Below 15 MHz Below 20 MHz Below 50 MHz Up to 10 MHz Up to 100 MHz				
Source #2:	Indiana General	l, Keasbey, N.J.					
Ni-Zn Ni-Zn Ni-Zn	Q-1 Q-2 Q-3	125 40 18	Up to 10 MHz Up to 50 MHz Up to 200 MHz				
	Fair-Rite Products Corp., Wallkill, N.Y.						
N1-Zn	30-61	125	200 KHz - 10 MHz				
Source #4:	Ferroxcube Cor	p., Saugerties,	N.Y.				
Ni-Zn Mn-Zn	4C4 3D3 3B9	125 750 1800	Up to 50 MHz Up to 5 MHz Up to 5 MHz				
Mn-Zn Source #5:	3B7 2300 Up to 1 MHz National Moldite Co., Inc., Newark, N.J.						
	N-Grade						
Source 16:	Stackpole-Carbon Co., St. Marys, Pa.						
	Grade 24 Grade 27A Grade 9 Grade 11 Grade 12 Grade 2285A	2500 1000 190 125 35 7.5	Up to 100 KHz Up to 800 KHz Up to 2 MHz Up to 6 MHz Up to 80 MHz Up to 300 MHz				

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also supplied by the manufacturers. It can be seen from Fig. 4(a) that the value of Q for the ferrite material #C-2050 is nearly constant (2100) up to about 2 MHz and then falls off rapidly to less than 10% of this value at 20 MHz. Similarly for the material #Q-3, Fig. 4(b) indicates a nearly constant value of Q (2500) up to about 15 MHz, beyond which it decays to 250 at 200 MHz.

Three antenna cores were fabricated, as photographed in Fig. 5(a)-(c). Cores (a) and (b) are made of material #C-2050, while core (c) is made of material #Q-3. Cylindrical rods of 5/16'' diameter and 5.25'' height were used along with adhesive tape to fabricate core (a) of 2" overall diameter and 21" height. Core (b) has the same height as core (a) but is comprised of five cylindrical rods of 1" diameter and varying lengths. Core (c) is formed from three cylindrical rods of .625" diameter and 7.5" length for a total height of 22.5". As was pointed out earlier, cores (a) and (b) are useful for frequencies up to about 20 MHz, core (c) up to 200 MHz.

The three cores were used in various antenna configurations in which an electrically small loop antenna is loaded by a finite cylindrical ferrite rod. The antenna parameters for the eleven different cases are tabulated in Table 2. For antennas numbered 1 through 3, measurements were made at frequencies of 10, 50 and 100 MHz, respectively. The electrical radius ak_0 of the driven loop ranges from .00166 to .01662. Antennas numbered 4 through 7 were operated at frequencies of 5, 10, 15 and 20 MHz, respectively; the electrical radius ranged from .00132 to .00531. The operating frequencies for antennas numbered 8 through 11 were the same as for the previous set but the radius was doubled.

It can be seen in Table 2 that the value of ak_0 does not exceed 0.017 for any of the eleven antennas. This ensures the validity of the assumption

FERRITE RODS USED IN THE EXPERIMENT

FIGURE 5

.625", height 2h = 22/5" **9**1 Dia. 2a = 2", height 2h = 21" = $l^{"}$, height $2h = 2l^{"}$ Ward and a state with the second ń .. (a) <u>(</u>9 <u>0</u> il Dia. 2a 2a Dia.

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TABLE 2. Antenna Parameters

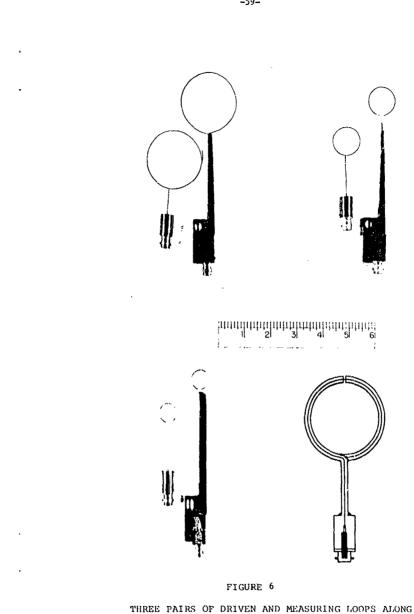
#Q-3 Material (Supplier: Indiana General)									
$2a = 0.625^{"}$, $2h = 22.5^{"}$, $\Omega = 2 \ln(2h/a) = 8.5534$									
• •									
Antenna ∦	$\mu_{\mathbf{r}} = \mu_{\mathbf{r}}^{\dagger} - \mathbf{j}$	$\mu_r^{\mu} = h/\lambda_0$	ak ₀	$z_m^i = r_m^i$	+ jx ⁱ m				
1	18 - j.C	.00952	.00166	.00797 -					
2		.04762	.00831	.00214 -	j.70979				
2 3	20 - j.C	.09525	,01662	.001577 -	j.33443				
	-								
#C-2050 Material (Supplier: Ceramic Magnetics, Inc.)									
43 94	- 18 2h -	21 0 m 2 Pr	(2h/a) = 7	4754					
i) $2a = 1^{n}$, $2h = 21^{n}$, $\Omega = 2 \ln(2h/a) = 7.4754$									
4	100 - j1.0	.00444	.00132	.0051 -					
5	115 - 12.	.00889	.00265		• j.21892				
	125 - 12.5		.00398		j.13270				
6 7	135 - j67.	5.01778	.00531	.03747 -	· j.07394				
(1, 2, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,									
ii) $2a = 2^n$, $2h = 21^n$, $\Omega = 2 \ln(2h/a) = 6.089$									
8	105 - j0.	63 .00444	.00265	.001275 -	1.12611				
9	120 - 12.4		-		•				
10	150 - 115	•			-				
10	130 - 133. 140 - 142.								
22	740 - 1451	.01//0			J.24+42				

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that the driven loop be electrically thin in the theoretical calculation of antenna currents. The height of the monopole antenna (h/λ_0) ranges from .00444 to .09525 so that the longest dipole is nearly (1/5)-wavelength long. The value of the relative permeability $\mu_r = \mu'_r - j\mu''_r$ from Fig. 4 and the internal impedance z_m^i per unit length calculated using equation (36) are also listed in Table 2. In this section an $e^{j\omega t}$ time dependence is implicit and is more convenient. Due account of this change in notation has been taken in using (36) to calculate z_m^i . It is observed that for all antennas considered, the internal impedance is largely reactive.

For each of the three ferrite cylindrical cores described above, a set of driven and measuring loops was fabricated. A photograph and representative line drawing showing the construction of the loops are shown in Fig. 6. The six loops were all constructed from commercially available microcoaxial cables ending in a modified BNC connector. The driven and measuring loops are placed coaxially in the experimental setup, as can be seen in the photograph in Fig. 7 and the block diagram in Fig. 8. The short lengths of microcoaxial transmission lines leading away from the two loops are at right angles to one another in the horizontal plane so that any inductive coupling between the two is minimized. The signal source used in this experiment was either a GR-1001A (5-50 MHz) or an HP-3200B (10-500 MHz) oscillator. When the CR-1001A oscillator was used for measurements with antennas #4 through #11, the power amplifier was not needed. The HP-230B power amplifier was used only in conjunction with the HP-3200B oscillator for measurements on antennas #1 through #3. The source frequency was accurately measured using an HP-5240 electronic counter. A signal proportional to the total axial magnetic field was induced in the receiving loop. An NP-8405A vector voltmater was used to detect and record this signal (B). The reference signal (A) to the



WITH A LINE DIAGRAM SHOWING THE CONSTRUCTIONAL

DETAILS OF A REPRESENTATIVE LOOP.

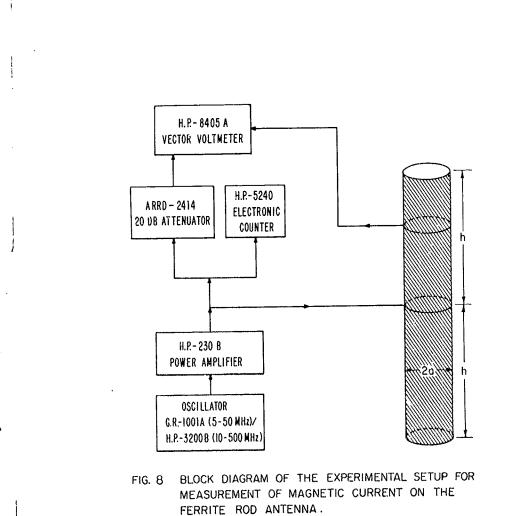
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PHOTOGRAPH OF THE EXPERIMENTAL SET-UP

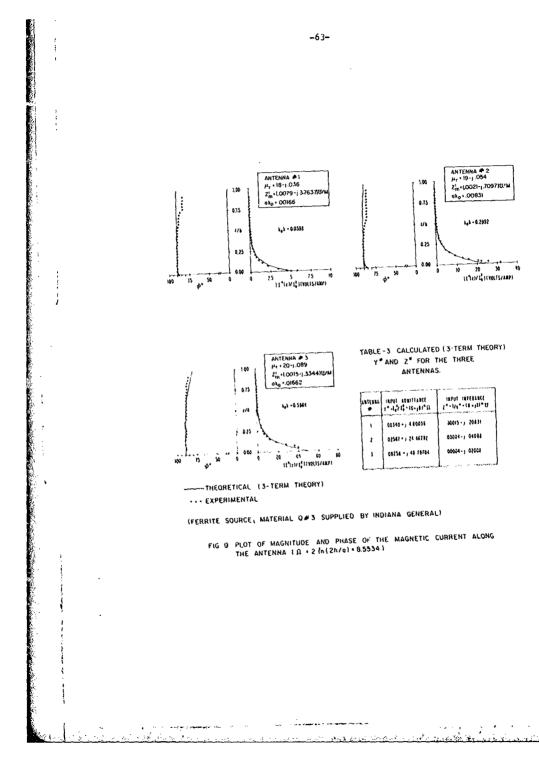
FIGURE 7

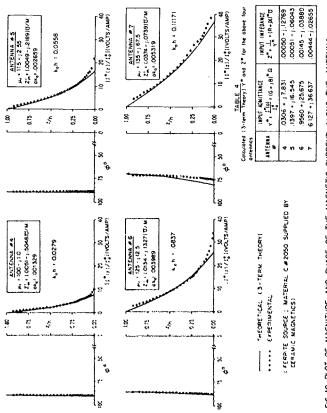


vector voltmeter was provided from a coaxial T. The vector-voltmeter readings were recorded as a function of the axial distance z from the driving loop. In this manner the amplitude and phase of the magnetic current distribution were obtained for the eleven antenna configurations described in Table 2. The unnormalized data are given in Table C-2 of Appendix C.

Computer programs, described and listed in Appendices A and B, were utilized in calculating the magnetic current distributions for the eleven cases. As discussed earlier, the theoretical calculations are based on a treatment of the ferrite rod as an imperfect magnetic conductor. The theoretical and experimental current distributions are shown graphically in Figs. 9 through 11. Also appearing in Figs. 9 - 11 are Tables 3, 4 and 5, respectively; these show the calculated values of input admittance $Y^* = I_z^*(0)/I_0^e =$ $(G + jB)^*$ ohms and input impedance $Z^* = 1/Y^*$ mhos. The antenna numbering scheme used in the figures and tables corresponds to that given in Table 2. The values of $\Omega = 2 \ln (2h/a)$ for the antennas in Figs. 9 - 11 are, respectively, 8.5534, 7.4754 and 6.089.

-62-



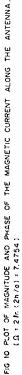


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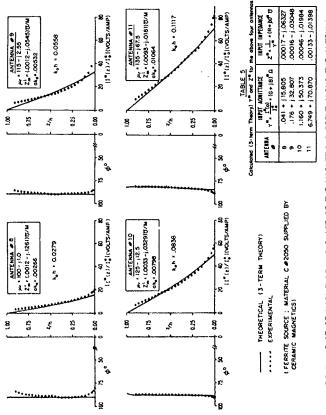
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PLOT OF MAGNITUDE AND PHASE OF THE MAGNETIC CURRENT ALONG THE ANTENNA. [1]: 21n (2h/o) = 6.089] FIG. 11

* **.** . .

curves because of the relatively low magnitude values. The overall agreement of the theory and experiment was used in deciding the point of normalization.

The coupled integral equations in (86a,b) in the two variables, the tangential electric field $E_{\phi}(z)$ and circumferential electric current $I_{\phi}(z)$, were solved numerically by the moment method on a Sigma-7 computer system. The method itself has been discussed in Section 8; the computer programs are listed in Appendix C. Table 6 contains a description of all the subroutines used in this computation. The basic philosophy of this method is to reduce the set of coupled integral equations to a system of linear algebraic equations. The standard routines [6] for solving a system of linear equations were modified to handle complex variables. The results of these computations are plotted in Figs. 12 through 14. As before, the experimental data have been normalized at a point approximately one third the distance from the driving point (z = 0) to the end.

The magnetic current $I_z^*(z)$ is easily obtained from the solution for the tangential electric field using the relation $I_z^*(z) = -2\pi a E_{\phi}(z)$ volts per unit current in the driving loop. The input parameters Y^* and Z^* are also tabulated and the tables are included in the figures showing the magnitude and phase of the magnetic current. In all eleven cases the phase is nearly constant, since the antennas are electrically short in free space, and most of the magnetic current is in phase quadrature. The agroement between the experiment and the theoretical calculations is very good including near the source. This was to be expected because the coupled integral equations (86a,b) in two variables comprise a far more accurate and independent theoretical formulation of the problem than the approximate integral equation (39) which relies rather heavily on an analogy between the ferrite rod antenna and the resistive cylindrical dipole antenna.

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TABLE 6

LIST OF SUBROUTINES USED IN SOLVING THE COUPLED INTEGRAL EQUATIONS (86a,b)

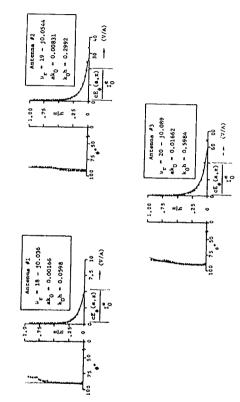
PROGRAM NAME	PURPOSE
MAIN	Computes $E_{\phi}(z)$ and $I_{\phi}(z)$ by solving the coupled integral equations (86a,b).
BSLSML	Computes Bessel functions $J_0(z)$ and $J_1(z)$ for $ z \le 10.0$ with 5 figure accuracy.
BESH	Computes Hankel functions $H_0^{(1)}(z)$, $H_0^{(2)}(z)$, $H_1^{(1)}(z)$ and $H_1^{(2)}(z)$.
QGL10	10-point Gauss-Laguerre quadrature routine.
QG10	10-point Gauss quadrature routine.
FCTK FKIIR, FKIII FKII	Computes the integrand for $K(z - z^{\dagger})$ for $I \neq J$. The same, for $I = J = 1$. The same, for $I = J \neq 1$.
<pre>{ FCTM1, FM111R, FM1111, FM111</pre>	Computes the integrand for $M_1(z - z')$ for $I \neq J$, I = J = 1, and I = J \neq 1, respectively.
{FCTK2, FK211R, FK2111, FK211	Computes the integrand for $K_2(z - z^{\dagger})$ for $I \neq J$, I = J = 1, and I = J \neq 1, respectively.
{ FCTM2, FM211R, FM2111, FM211	Computes the integrand for $M_2(z - z^{\dagger})$ for $I \neq J$, $I = J = 1$, and $I = J \neq 1$, respectively.
AUX	Auxiliary function used in computing the above integrands.
SERIES	Computes the infinite series part of the kernel $K_1(z - z')$.
{ DECOMP, SOLVE, { IMPRUV, SING	Programs used in solving the linear system of algebraic equations.
ANGLE	Computes the phase angle of complex variables $I_{\phi}(z)$ and $E_{\phi}(z)$.

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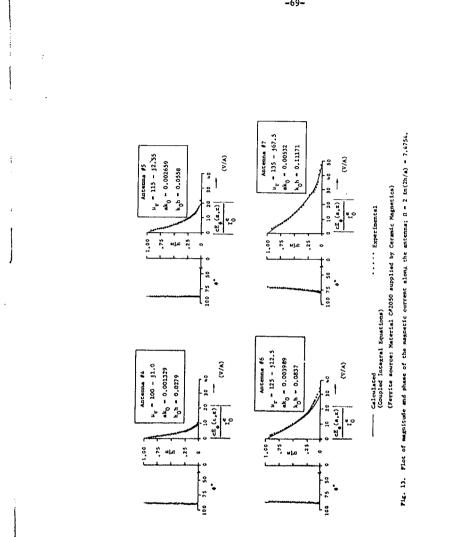
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(Ferrice source: Material Q#3 supplied by Indiana General)

Plot of magnitude and phase of the magnetic current along the antenna; $\Omega = 2 \ln(2h/a) = 0.5534$. (Decorrected: see Appendix D.) F1g. 12.



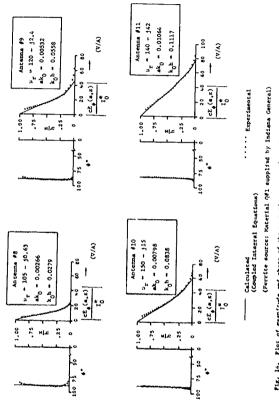
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INPUT ADMITTANCES AND IMPEDANCES OF THE ELEVEN ANTENNAS OBTAINED FROM SOLVING

Antenna #	Input Admittance (ohma)	Input Impedance (mhos)
1	.003 + j 4.99	.00012 - j.20040
2	.03 + j30.22	.00003 - j.03309
3	.10 + j62.32	.00003 - j.01605
4	.03 + j 9.23	.00035 - j.10834
5	.14 + j20.13	.00035 - j.04967
6	.97 + j29.81	.00109 - j.03351
7	6.21 + j45.62	.00293 - j.02152
8	.92 + j23.55	.00004 - j.04246
9	.16 + j44.27	.00008 - j.02259
10	1.06 + j60.02	.00029 - j.01666
11	4.26 + 175.32	.00075 - j.01323

THE COUPLED INTEGRAL EQUATIONS (86a,b)

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TABLE 7

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10. SUMMARY

An electrically small loop that carries a constant current and is loaded by a homogeneous and isotropic ferrite rod has been called the ferrite-rod antenna. In Part I [2] of this report the ferrite rod was assumed to be of infinite length and the problem was treated using a boundary-value approach. In a practical situation, however, the antenna is necessarily finite and often electrically short so that a new mathematical formulation was needed, along with an experimental investigation, for the problem of a finite ferrite rod antenna. With this current distribution known precisely, other quantities of interest can be derived from it.

Although, in terms of physical mechanisms, the ferrite-rod antenna can be compared with the dielectric rod antenna, there exists a complete analogy between the ferrite antenna and the conducting cylindrical dipole antenna. This analogy is based on the dual property of electric and magnetic vectors in Maxwell's equations. The electric dipole antenna has received considerable attention from researchers in the past and, therefore, a treatment of the 'magnetic analog' of the dipole antenna is considered useful. Based on this analogy, an integral equation has been derived for the magnetic current on the finite ferrite-rod antenna. As expected, the integral equation is identical in form to the corresponding equation for the electric current on the dipole antenna. This derivation was based on the assumption that the value of the relative permeability μ_{μ} of the ferrite material equals infinity. In effect, the ferrite is treated as a perfect magnetic conductor as when in the 'electric case' the antenna material is assumed to have an infinite electrical conductivity σ . However, in practice, a material with $\mu_{\rm p}$ equal to infinity does not exist and, furthermore, over a useful frequency range the μ_{μ} value is not high enough to justify using the perfect conductor approximation.

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For this reason, the integral equation had to be modified. The modification was achieved by defining the internal impedance per unit length of the magnetic conductor to be the ratio of the tangential magnetic field to the total magnetic current flowing in the magnetic conductor. An approximate, 3-term expression for the magnetic current was then obtained in a manner paralleling the procedure used by King and Wu to solve for the electric current on the imperfectly conducting dipole antenna. It was found that for commercially available ferrites the internal impedance per unit length was largely reactive so that the propagation constant k (= β + i α) on the antenna had a large imaginary part. The predominance of the attenuation constant α makes the magnetic current very small and, thus, one is led to conclude that the practical ferrite-rod antenna is not a very efficient radiator.

The treatment of the ferrite-rod antenna as an analog of the resistive electric dipole antenna relies rather heavily on the mathematical equivalence of the two problems under idealized driving conditions. For this reason, an alternative derivation of the integral equation for the tangential electric field on the ferrite surface was developed. This derivation led to a pair of coupled integral equations in terms of the tangential electric field and tangential electric surface current. The coupled integral equations were solved numerically by the moment method and the magnetic current obtained from the tangential electric field. It was also verified that in the limit $h + \infty$ the equations decouple and are in complete agruement with the results of the theory for the infinite antenna.

Since the magnetic current is proportional to the total axial magnetic field, a simple experimental apparatus was built to measure the magnetic current distribution on several antenna configurations. A graphical comparison of the theoretical and experimental results has been presented. Although the

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three-term solution has been shown to give good results for antenna lengths $k_0^{h} \leq 5\pi/4$, the antennas used in the experiment were much shorter and the near-triangular distribution of currents was verified. The frequency response of the properties of available ferrite materials and the practical limitations on the size of the ferrite rods made it difficult to construct antennas of longer length.

In conclusion, while ferrites have been used extensively at microwave frequencies and up to several MegaHertz, the fact that ferrites are now becoming commercially available in the range 30 - 300 MHz should lead to useful applications. In situations in which the physical size of the antenna must be kept small, a loop antenna has limited usefulness because of its low efficiency and radiation resistance. The insertion of a suitable ferrite core offers the advantage of both improved efficiency and increased radiation resistance. Although, in theory, an increased radiation resistance should simplify the problem of matching the antenna to its associated circuit, in practice there remains a severe problem. This has been discussed by Dropkin, Metzer and Cacheris [7] who made measurements of the receiving characteristics of a cylindrical ferrite-rod antenna at a frequency of 75 Miz. They conclude that both ferrite-core and air-core loops can be described by similat equivalent circuits. These circuits have resonant properties and each of the lumped circuit elements can be identified with a physical quantity charactorizing the antenna. The improved efficiency and the increased radiation resistance which were determined experimentally can be attributed directly to an increased magnetic flux passing through the loop. They also make the interesting observation that with a dielectric cylinder ($c_r = 10$, $u_r = 1$), the size of the ferrite used had no effect on the air-loop properties. This was because the loop used was small enough to act as a magnetic dipole.

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APPENDIX A.

COMPUTATION OF MAGNETIC CURRENT AND ADMITTANCE OF FERRITE ROD ANTENNA The approximate magnetic current distribution as given by (51) is

$$I_{z}^{*}(z) = \frac{-i2\pi k_{0}\zeta_{0}I_{0}^{e}}{k\Psi_{dR}\cos kh} [\sin k(h - |z|) + T_{U}^{*}(\cos kz - \cos kh) + T_{D}^{*}(\cos \frac{k_{0}z}{2} - \cos \frac{k_{0}h}{2})]$$

where T_U^* and T_D^* are given by

$$\mathbf{x}_{U}^{*} = (\mathbf{c}_{V}\mathbf{E}_{D} - \mathbf{c}_{D}\mathbf{E}_{V})/(\mathbf{c}_{U}\mathbf{E}_{D} - \mathbf{c}_{D}\mathbf{E}_{U})$$
$$\mathbf{x}_{D}^{*} = (\mathbf{c}_{U}\mathbf{E}_{V} - \mathbf{c}_{V}\mathbf{E}_{U})/(\mathbf{c}_{U}\mathbf{E}_{D} - \mathbf{c}_{D}\mathbf{E}_{U})$$

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$$C_{U} = [1 - (k^{2}/k_{0}^{2})](\Psi_{dUR} - \Psi_{dR})(1 - \cos kh) - (k^{2}/k_{0}^{2})\Psi_{dUR} \cos kh$$
$$- i\Psi_{dUI} (\frac{3}{4} - \cos \frac{k_{0}h}{2}) + \Psi_{U}(h)$$

$$C_{D} = \Psi_{dD} \left(\frac{3}{4} - \cos \frac{k_{0}h}{2} \right) - \left[1 - (k^{2}/k_{0}^{2}) \right] \Psi_{dR} \left(1 - \cos \frac{k_{0}h}{2} \right) + \Psi_{D}(h)$$

$$C_{V} = -\left[-i\Psi_{dI} \left(\frac{3}{4} - \cos \frac{k_{0}h}{2} \right) + \Psi_{V}(h) \right]$$

$$E_{U} = -(k^{2}/k_{0}^{2}) \Psi_{dUR} \cos kh + (i/4) \Psi_{dUI} \cos \frac{k_{0}h}{2} + \Psi_{U}(h)$$

$$E_{D} = -(1/4) \Psi_{dD} \cos \frac{k_{0}h}{2} + \Psi_{D}(h)$$

$$E_{V} = -(i/4) \Psi_{dI} \cos \frac{k_{0}h}{2} - \Psi_{V}(h)$$

The Y functions appearing in the above expressions are defined as follows:

$$\Psi_{dR} = \begin{cases} \Psi_{dR}(0) & k_0 h \leq \pi/2 \\ \\ \Psi_{dR}(h - \lambda/4) & \pi/2 \leq k_0 h \leq 3\pi/2 \end{cases}$$

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$$\Psi_{dR}(z) = \csc k(h - |z|) \int_{-h}^{h} \sin k(h - |z^{*}|) \left[\frac{\cos k_{0}r}{r} - \frac{\cos k_{0}r_{h}}{r_{h}} \right] dz'$$

$$\Psi_{dUR} = [1 - \cos kh]^{-1} \int_{-h}^{h} (\cos kz^{*} - \cos kh) \left[\frac{\cos k_{0}r_{0}}{r_{0}} - \frac{\cos k_{0}r_{h}}{r_{h}} \right] dz'$$

$$\Psi_{dD} = [1 - \cos \frac{k_{0}h}{2}]^{-1} \int_{-h}^{h} (\cos \frac{k_{0}z^{*}}{2} - \cos \frac{k_{0}h}{2}) \left[\frac{e^{ik_{0}r_{0}}}{r_{0}} - \frac{e^{ik_{0}r_{h}}}{r_{h}} \right] dz'$$

$$\Psi_{dI} = -[1 - \cos \frac{k_{0}h}{2}]^{-1} \int_{-h}^{h} \sin k(h - |z^{*}|) \left[\frac{\sin k_{0}r_{0}}{r_{0}} - \frac{\sin k_{0}r_{h}}{r_{h}} \right] dz'$$

$$\Psi_{dUI} = -(1 - \cos \frac{k_0 h}{2})^{-1} \int_{-h}^{h} (\cos kz' - \cos kh) \left[\frac{\sin k_0 r_0}{r_0} - \frac{\sin k_0 r_h}{r_h} \right] dz'$$

where the propagation constant k is given by

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$$k = k_0 [1 + (i4\pi\zeta_0 z_m^i/k_0 \psi_{dR})]^{1/2}$$

with $\zeta_0 = 376.7 \ \Omega$ the characteristic impedance of free space. However, since Ψ_{dR} is dependent on k, an iteration procedure is used. To begin with, k_1 as given by

$$k_1 = k_0 [1 + (14\pi \zeta_0 z_m^{1/k_0 \gamma} dR_0)]^{1/2}$$

is determined. With \boldsymbol{k}_1 substituted for $\boldsymbol{k},\;\boldsymbol{\Psi}_{dR1}$ is computed and then \boldsymbol{k} is evaluated using

$$k = k_0 [1 + (14\pi c_0 z_m^i / k_0 Y_{dR1})]^{1/2}$$

This new value of k is used in evaluating all the 7 functions and the current distributions.

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APPENDIX B

This appendix contains a listing of the main program and all associated subroutines. The main program accepts as inputs h/λ_0 , Ω and z_m^i , and computes the input impedance z^* , admittance Y^* , and magnetic current distribution as a function of distance (z/h) along the antenna. Subroutine NINTG employs Simpson's rule for integration to evaluate the functions. The various integrands are calculated using the subroutines FCTH(Y), FCTO(Y) and FCT1(Y).

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0000 10 REPUT (FD) 5.4.00 (FD) 5.5.00 (FD)	0001	CUNNUN A2,H.XKR.Z.CUNNK.CUNHI,SNHHK.SNKHI,LUNZAKI, 2V1.V2.V3.V4.V5.V6.Y7.V8.V9.V10.V11.V12
0000 10 REPUT (FD) 5.4.00 (FD) 5.5.00 (FD)	0002	COMPLEX *8 XK, XKH, CUHH, SKHH, COHHI, U, SYGK, SYDUR, XX21, SYCO, SYDI, ZI,
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0000 NI-NI-23 0001 0172-2012[12:0011[12:02:01]] 0002 0172-2012[12:011][12:02:01]] 0003 0172-2012[12:011][12:02:01]] 0013 2-b 0014 0-117 (CMILTON) 0015 2-b 0016 2-b 0017 2-b 0018 2-b 0019 2-c 0011 2-c 0012	3024	UL01+ULH2 D1 (2+4) (M(H) (H4)
0028 0.12-A.0.601/25081[014941AK2] 029 CALL MURCHARLSONT[014941AK2] 0201 001 0210 001 0211 CALL MURCHARLSONT[014022/241] 0213 0012 0214 CALL MURCHARLSONT[014022/241] 0213 0012 0214 CALL MURCHARLSONT[01402] 0215 CALL MURCHARLSONT[01402] 0216 Arti-Ional Pellosan 0217 CALL MURCHARLSONT[01402] 0218 Arti-Ional Pellosan 0219 Arti-Ional Pellosan 0211 CALL MURCHARLSONT[01402] 0212 Artificial Murcharlsont 0213 Artificial Murcharlsont 0214 Utilican Artificial Murcharlsont </th <th>UU26</th> <th>Ni+1H-21</th>	UU26	Ni+1H-21
0.0.0 0011-CONTRACTANY 0011 2.6 0011 2.6 0011 2.6 0011 00177 0011 0017777 0011 00177777 0011 00177777 0011 00177777 0011 00177777 0011 00177777 0011 00177777 0011 001777777<	0028	UL 22-AL GG(H2+SUAT(H2+H2+A2))
0031 2-b 0032 0.01 0033 0.01 0034 0.01 0035 0.01 0036 0.01 0037 0.01 0038 0.01 0039 0.01 0039 0.01 0039 0.01 0039 0.01 0039 0.01 0039 0.01 0039 0.01 0039 0.01 0039 0.01 0040 0.01 0040 0.01 0040 0.01 0040 0.01 0040 0.01 0040 0.01 0040 0.01 0041 0.01 0041 0.01 0041 0.01 0042 0.01 0043 0.01 0044 0.01 0044 0.01 0045 0.01 0046 <th></th> <th>CALL NINTGIFCT1,GL(1,GL(2,2,2,4)) UV(1)=CMPLX(Y),GL(1,GL(2,2,4))</th>		CALL NINTGIFCT1,GL(1,GL(2,2,2,4)) UV(1)=CMPLX(Y),GL(1,GL(2,2,4))
0012 0012 0014 4.7 0014 4.7 0015 3.4 0016 3.4 0017 3.4 0018 3.4 0019 3.4 0010 3.4 0011 3.4 0012 3.4 0013 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 3.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 0014 4.4 <th>1660</th> <th>2-b</th>	1660	2-b
0055 SYEA-CONTINUEDED 0056 Aut, Lui, 1961/1570 0058 Aut, Lui, 1961/1570 0058 Aut, Lui, 1961/1570 0059 Aut, Lui, 1961/1570 0050 Aut, Lui, 1961/1570 0050 Aut, Lui, 1961/1570 0050 Aut, Lui, 1961/1570 0050 Aut, Lui, 1961/1570 0051 Aut, Lui, 1961/1570 0052 Call, Lui, 1961/1570 0053 Call, Aut, 1961/1570 0054 Call, Aut, 1961/1570 0055 Call, Aut, 1961/1570 0056 Call, Aut, 1961/1570 0057 Call, Aut, 1961/1570	1111	0y(2)=C#FLX(V1+V2)
0038 XA+ALALAX 0074 XA+ALALAX 0074 XA+ALALAX 0074 XA+ALAX 0074 XA+ALAX 0074 VA+ALALAX 0074 VA+ALALAX 0074 VA+ALAX 0074 VA+ALAX <th>0034</th> <th>SYPE=Cov(11-0v(2))/SIR(22)</th>	0034	SYPE=Cov(11-0v(2))/SIR(22)
0038 XA+ALALAX 0074 XA+ALALAX 0074 XA+ALALAX 0074 XA+ALAX 0074 XA+ALAX 0074 VA+ALALAX 0074 VA+ALALAX 0074 VA+ALAX 0074 VA+ALAX <th></th> <th>12+1-10-111+21/570+ 72+15421121</th>		12+1-10-111+21/570+ 72+15421121
UUVU CALL BINUTPETLUL (1,0(1/2/AAB) UUVI CALL DINUTPETLUC (1,0(1/2/AAB) <th>0038</th> <th>288-814L1223</th>	0038	288-814L1223
Unit CH Unit CAR Unit Comparing (CH, CH, CH, CH, CH, CH, CH, CH, CH, CH,	UUNU	CALL MINISTELL
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0010 24.8.4.2.2.2.1 0011 24.8.4.2.2.2.1 0011 24.8.4.2.2.2.1 0011 24.8.4.2.2.2.1 0011 24.8.4.2.2.2.1 0011 24.8.4.2.2.1 0011 24.8.4.2.2.1 0011 24.8.4.2.2.1 0011 24.8.4.2.1.2.1.2.1.2.1.2.1.2.1.2.1.2.1.2.1.2		84+1-~{U.+1.1+71/}TP# 84+(3481188)
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0.153		Ev= 370-0+25#3700#C0H2
2641		LV={U++Q++C5}#SYDL +LUH2~SYY
UU5 8		1u+{CV+E0-LD+EY}/{CU+EC+CC+LU} TD+{LU+EY-LY+LU}/{CU+eu+Ly+EU}
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otau		
eiol uiv.	521	hkl1k (0,951) XK.SYUN FUNKAT (/+10X,°K/K0 → '+F19.5,' +J '+F15.5+5X+
0101		2'SYLK * ',F10.54' + J ',F10.54//}
0303		YU=(UA+{SNHH+TU+UHH}+TG+CH2U)
0104		20=1.0/26
0105		sk11.(o.952) Y0.(d
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		3TENNA (VOLTS/ARP)*,/// +12X+'L/R*+113+'REAL*+111+'IMAG*+12X+
		4'RAG',1UX.'PHAS.'.//)
0107		10H=-0.0>
0108		DO 40 X=1,21
0109		20#=20#+++++5
0110		XX Z=XXH+LUH
0111		CUN=CONVICSIN(XXH-XAZ)+IU+ICCUSIXAZI-CONHI
0112		1+TC+[LL5[U_5+ ZWMM]-CCH2]] CRAUMUNU5[UUF]
0113		CURR-REAL (CUR)
0114		CURL+AIMAGICURI
0:15		CP++5+2Till2{CUx1+CUxF1+1du+0/3+1415926>
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0001 0002		SUBMUUTINE HENIGIFCE.SL.SU.N. AL
0002		UTHENSIUM VAL(12).VAL2(12).VAL3(12),VAL4(12).VAM(12)
0003		LUKHUN BZANA AKRAZA CUHHA ALUHHA ASMHA ASMHI ALUHZAARI AYAR X=AF41,0
4445		A142
0000		LX+136-56 38.25
1000		18 1043 13+5+15
100F	1.0	00 10 3=1.N VAL131=0.0
3304	10	41 10kk
0011	15	. 411 FLT(SL)
J012		LALL FILL(VAL
4 \$ D +		CALL POTISUS
0.014		CALL FILLIVAL 2.H3
1011	11	UU 13 JA214 Wal 2039-31-34 CW2, 6334 Wal 2038
4010	••	31.3-31.401
1010		CALL (CILLE)
4414		CALL FILLIAL MA
0010		
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		to 1+1. M
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3001	STILL TO THE ST THE ST
4342	CUMRUM AZ (+ 1,2 K, 2, CCMHR , CUMH , SMHRY , SMHRY , CUHZ , AK . 19 , VL , V , V + V 5, V 6, V 7, V 8 , V 5, V 10 , V 11 , V 12 E = EP(Y)
1001	1¥1+¥1+¥3+¥4+¥5+¥6+¥7+¥8+¥4+¥10+¥11+¥14 F#FIP(¥1
vud4	£2=1./E
0005	LA=A29E1 R=0.5+{E+EA}
5007	X=0.5/12/24/ X=K==2.4/ x 1= SULT ({X=H}==2.4.2}
100e 0009	n1=SuhT{{\$+}1402+&2} 211=1+/#1
0000	51=51=7=1 5Y=CU5{#,1=6,11=U5{#1]=# C/S=51={N=41=951#{#1]=#
0011	[/S=S1m(k)+K21+S1m(K1)+R
0012	∪#2KK#2 C=Cus(2)
0014	5=51Rf01
0015	5-628f3x61#X3 6]=]=/t
UU17	CH1+0+5+(E+E1)
0313	CH2+CH2+E1) CH2+CH2+E1 SH15+CH1
0014	
UU21	CH 1=C + CH 1 CH 2=C + S + CH 2
0022	CH2=-S#GH2 F#SNHRRHLH2=SHHHT#CH2=CAH4&#SH2#CAH+F#SH2
4500	E « SANKAR UH2 – SANH I #CK2 – CGHIR «S H1 +CGHHI #SH2 SH2 = SANH ↓ H2 + SANH I #CH1 – CUHR # SH2 – CUM H1 #SH1
0025	SH1=t
0027	CH1=CH1=CWHR CH2=CH2=CUHH1
UU28	0*(L)[0.3*X]-(UHZ
1027 V 1050	¥1 «5¥®CH1 ¥2=5¥#CH2
1-60	43 404 SA
2027	A2#2K7#2H1 K##-A#2K?
0033 0034	49=222+241
10.5	48 = 545 = 5H2 47 = 545 = 6H1
اد ∪ ل اد ب ل	V8+SVS+CH2
4t Ú U	¥9=31(}+5¥*3;K2+5¥5 ¥1L+5h2+5¥5;K1+5¥5 ¥{}=1ch1+5¥+61;R2+3¥5
0035	A1 3×CH1+2A-CH1+2A2 A1 1×CH1+2A+CH3+2A2
0040	**************************************
JJ42	eMC
	ι 6
0,001	SUBBLINE FETOEVI
0002	(UNMUN A2,11,3KK,2,CGFHK,CGFHK),3A4066,5A667,CGH2,3Xf, 141,42,41,44,546,41,44,94,41,41,41,41,41,41,41,41,41,41,41,41,41
3343	2 af 12 (V)
4345	t]=1,/c c&+A/4g]
4444	(2442/421 n+0,>4[k+t∆]
100	1-1-1 I
9698 99919	5444.4E051N1
4010	54.5+4.453M(#3 442844
	C+(6)16)
10012	5+5 [nf.ut 6=fa#thaf+a)
4414	21+1+ <i>1</i> +
1015 100	L313+0.54224023 L32-5124+23
1100	201 \$- 54C 10\$
101 A 100	38.+L#L81 [8]=L#L81
2020	L 38 7
4421 11422	5+5Ania 4011-5200114015-0000000000000000000000000000000
0013	894 73 29 214 20 22 22 22 22 22 22 22 22 22 22 22 22 2
0414	x4+3¥3#3HZ
1012	Call-Cal-Calar Cal-Cal-Calar Ca-Cal-Calar V1-Cala-X
uu, 1	x1 -CH1+ 34
du#5 04.7	43+345+141
3310	X4 - >X>+CHU
9.9 41	U+C(110.7*82-LIALC
4012	84+-1418+ 83+0428
0	at the h
4611	(NG
	(«************************************
	Suprolime actions
tyae	CUPPER AZAMAZAKAZACIONA «COURA SHORA SHORA SHORA SHORA SCORE ALE
4043	
U.50 4	
1255 V 16 J K	(A+A2+2)
una t	L+ L , 34 (1 (a) 3+8- ; a ; 2
QuCA	4 L + Sus til sej 1 + + 2 + 4 + 2 +
0001	at +Custates+subtatitat
ww11	F+38++1
9013 9013	8+12718+2813 81+1+78
6412 4412	(H+Q, 1411 at 1)
0413	3H+6(1+2) ¥1+3(H(#{)(#4)
4018	¥1+38#1#5(N+#2) ¥2+6038=}#\$N##43
0014	4E 1UAN
9614	f #0

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APPENDIX C

This appendix opens with two tables containing experimental information. The first, Table C-1, lists the values of the various antenna constants (dimensions, ferrite characteristics, frequency, etc.) for the eleven antenna configurations studied experimentally. Table C-2 gives the raw measured data (unnormalized) for the magnetic current distributions on the eleven antennas as a function of z.

The appendix concludes with a listing of the computer programs used to solve the coupled integral equations in (86a,b). The procedure used, i.e., the moment method, was discussed briefly in Section 8. The coupled integral equations are reduced to a system of linear algebraic equations which are then solved for the unknown variables. An unknown constant in the integral equation is also determined in the numerical procedure by imposing the end condition at z = h. The magnetic current $I_z^*(z)$ is easily computed from the solution of the tangential electric field $F_{\phi}(z)$ by using $I_z^*(z) = -2\pi a E_{\phi}(z)$ volts per unit current in the driving loop.

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Antenna Constants TABIE C-1

5 NU2	sta ⊌	ч а	2a inches	2h inches	ъ/ч	G	ako	۴ ¹ ۴	akı
10	11	18-j.036	-625	22.5	36	8.5534	.00166	.80-j.0008	.022-j.0002
50	11-j.11	19-j.054	.625	22.5	36	8.5534	.00831	4.12-j.0059	.114-j.0002
100	11-j.3	20-j.C89	.625	22.5	36	8.5534	.01662	8.46-j.0188	.235-j.0005
ŝ	τı	100-j.1	-	21	21	7.4754	.00133	, 88-j.0044	.042-j.0002
10	11	115-j2.55	-	21	21	7.4754	.00266	1.89-j.021	100.Č-060.
15	10.5	125-j12.5	н	21	21	7.4754	.00399	2.96-3.1479	.141-j.007
20	10.25	135-j67.5	7	21	21	7.4754	.00532	4.22-j.9970	.201-j.0475
Ś	11	105-j.63	2	21	10.5	6.089	.00266	.90-j.0027	.086-j.0002
10	11	120-j2.4	2	21	10.5	6.089	.00532	1.93-j.0193	.184-j.001
51	11 .	150-j15	м	21	10.5	6.089	.00798	3.25-j.1620	.309-j.015
20	1.11	140-j42	ы	21	10.5	6.089	.01064	4.22-j.6202	.402-j.059

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TABLE	C-2

Unnormalized experimental data (Refer to

Table C-1 for the numbering scheme and antenna constants).

	Ante	enna #1	Ante	nna #2	Ante	enna #3
z cms	Mag	Phase	Mag	Phase	Mag	Phase
0.1	-	-	38	-50	-	-
0.2	130.0	30.4	-		-	-
0.3	100.0	30.2	31.5	-48.8	-	-
0.5	-	-	-	-	-	-
0.6	-	-	25.5	-47.9	-	-
0.8		20	22.0	-47.5	07 F	-
1.0	77.0	30	20.5	-47.2	82.5	
1.5	-	-	16	-47.0	57,0	-
2.0	49.0	30	13	-46.6	44	-169.2
3.0	33.0	30	9.1	-46.4	28.5	-178
4.0	23.0	30	6.4	-46.5	19.0	-182
5.0	17.0	30	4.7	-46.5	13.5	-184
6.0	12.5	30	3.5	-46.5	10.0	-185
7.0	9.25 7.0	30 30	2.65 2.0	-46.5 -46.5	7.7 6.2	-185 -185
8.0 9.0	5.3	30	1.45	-46.3	5.6	-183.5
10.0	4.0	30	1.45	-40.0	?	~103.5
10.0	4.0		1.0	- 4 7	•	·
11.0	3.30	30.5	.8	-47.5	3.1	-184
12.0	2.65	30.6	.63	-48.0	2.35	-185.5
13.0	1.95	30.6	.51	-48.5	1.85	-186
14.0	1.75	30.6	.41	-49	1.45	-186
15.0	1.45	31.2	.34	-50.2	1.20	-186
16.0	1.10	31.6	.285	-51.0	1.02	-186
17.0	.9	32.8	.240	-52	.86	-186
18.0 19.0	.75	32.6 33.0	.205	-52 -52	.70	-186 -186
20.0	.62	33.6	.175	-52	.59	-186
20.0	· JI	22.0	.140	~) X C ~	. 30	-100
21.0	.42	35			.41	-187
22.0	.36	38.2			.35	-186
23.0	.31	38			.30	-186.5
24.0	. 27	38			.26	-188.5
25.0	. 22	38			.23	-188
26.0	.19	38			.205	-190

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ZZ Mag Phase Phase		Ante	enna \$4	Anter	enna #5	Ante	enna #6	Ante	enna #7
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	sus	11	225	Mag	has	N I	has	Mag	ha
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		1	ı	v	129.		12	•	1
5 4.0 -1100 13.5 -129.3 28.5 -130.2 4.9 -700. 6 3.5 -130.4 12.0 -129.4 22.5 -130.6 4.9 -701. 6 2.575 -130.4 10.0 -129.4 22.5 -130.6 3.7 -711. 6 2.75 -130.1 8.3 -129.6 13.5 -711. -711. 6 2.75 -130.1 8.3 -129.6 17.5 -130.6 3.7 -711. 7 2.15 -130 7.9 -129.6 16.5 -131.2 2.9 -721. 7 2.15 -130 7.9 -129.6 15.5 -131.2 2.9 -721. 7 2.159.7 7.1 -129.6 15.5 -131.2 2.9 -721. 7 2.129.7 1.29.6 15.5 -131.2 2.9 -721. 7 1.9 -721. 131.6 1.29.7 131.6 -721. 7 1.9 -721. 131.6 121.6 131.6 -731.		•	ł	.;	129.	5	130.	•	70.
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	•	•	5	m.	129.	 	130.		70.
5 3.2 -130.6 11.0 -129.4 23.5 -130.6 3.7 -711. 5 2.555 -130.4 10.5 -129.4 22.5 -130.6 3.7 -711. 5 2.555 -130.4 10.5 -129.6 17.5 -130.6 3.7 -711. 5 2.555 -130.1 8.7 -129.6 17.5 -131.0 3.3 -721. 5 2.30 -130 7.5 -131.0 8.3 -721. 5 2.30 -130 7.5 -131.0 8.3 -721. 5 2.130 7.5 -129.6 15.5 -131.2 -721. 5 2.155 129.6 15.5 -131.2 2 -721. 6 1.85 -129.6 15.5 -131.2 2 -721. 6 1.85 -129.6 1.5 131.2 2 -721. 6 1.85 -129.6 1.5 131.2 2 -721. 6 1.85 -129.7 13.5 131.2 2 </td <td>•</td> <td></td> <td>130.</td> <td>5</td> <td>129.</td> <td>ς.</td> <td>130.</td> <td>٠</td> <td>70.</td>	•		130.	5	129.	ς.	130.	٠	70.
0 3.05 -1130.4 10.5 -129.4 22.0 -130.6 3.7 -711. 5 2.55 -130.1 9.8 -129.5 19.5 -190.7 3.5 -711. 5 2.55 -130.1 8.7 -129.5 19.5 -190.7 3.5 -711. 5 2.15 -130 7.9 -129.6 15.5 -131.0 3.0 -721. 6 2.15 -139.9 6.8 -129.6 15.5 -131.2 2.9 -721. 6 2.155 -129.9 6.8 -129.7 13.5 -721. -721. 6 1.85 -129.9 6.8 -129.7 13.5 -731.2 -721. 6 1.85 -129.7 13.5 -131.2 2.9 -721. 6 1.85 -129.7 13.5 -131.2 2.9 -721. 7 1.80 -722. 13.5 -131.2 2.9 -721. 7 1.80 -722. 13.5 131.2 2.9 771. 7	۰ ا	•	130.	1	129.	m.	130.	•	1.
5 2.85 -130.4 9.8 -129.5 190.7 3.5 -711. 6 2.45 -130.1 8.7 -129.6 15.5 -131.0 3.15 -771. 7 2.45 -130 7.9 -129.6 15.5 -131.0 3.15 -771. 7 2.15 -130 7.9 -129.6 15.5 -131.2 2.9 -721. 7 2.19.7 7.1 -129.6 15.5 -131.2 2.9 -721. 7 2.19.7 1.29.6 15.5 -131.2 2.9 -721. 7 2.129.7 5.1 -129.6 15.5 -131.2 2.9 -721. 7 1.90 7.1 -129.6 15.5 -131.2 2.9 -721. 7 1.29 129.6 15.5 -131.6 2.75 -721. 7 1.29 13.5 -129.7 13.5 -131.6 774. 7 1.29 13.5 131.6 1.16 -131.6 774. 7 1.29 129.6	•	0	130.	9	129.	2	130.	•	71.
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2 1.15 -129.7 4.0 -129.8 8.5 -131.9 1.60 -74. 5 0.95 -129.6 7.15 -132.0 1.68 -74. 6 0.95 -129.6 7.1 -132.0 1.68 -74. 6 -129.5 3.05 -129.9 5.5 -132.0 1.38 -74. 7 -132.6 1.20 -74. 1.32.0 1.38 -74. 7 -132.6 3.05 -129.9 5.5 -132.0 1.38 -74. 7 -132.6 2.55 -130 5.3 -132.2 1.00 -74. 7 -130.0 2.55 -130 5.3 -132.2 1.00 -74. 7 -130.0 2.5 -130 4.8 -132.2 1.00 -74. 7 -129.5 1.75 -130 4.8 -132.3 3.80 -75 7 -129.2 1.35 1.32 1.32 3.80 -75 7 -129.2 1.35 1.32 1.32 3.80			129.	1.	129.	۱.	131.	5	1
1.05 -129.6 3.60 -129.8 7.8 -132.0 1.48 -74. 6 .99 -129.7 3.30 -129.8 7.1 -132.0 1.48 -74. 6 .99 -129.5 3.30 -129.8 7.1 -132.0 1.35 -74. 6 .129.5 3.30 -129.9 5.3 -132.0 1.35 -74. 7 .74 -130.0 2.5 -130 5.3 -132.2 1.08 -74. 7 .74 -130.0 2.5 -130 5.3 -132.2 1.00 -74. 7 .74 -130.0 2.5 -130 5.3 -132.2 1.00 -74. 7 .74 -130.0 2.5 -130 5.3 -132.2 1.00 -74. 7 .55 -130 3.8 -132.2 1.00 -75. 7 .55 -130 3.8 -132.2 3.9 -75. 7 .55 -130 3.8 -132.2 3.9 -75.		٦.	129.	•	129.		131.	۰	74.
4 99 -129.7 3.30 -129.8 7.1 -132.0 1.35 -74. 5 .89 -129.5 3.05 -129.9 5.5 -132.0 1.35 -74. 6 .81 -129.5 3.05 -129.9 5.5 -132.0 1.35 -74. 7 .74 -130.0 2.5 -130 5.3 -132.2 1.00 -74. 7 .74 -130.0 2.5 -130 5.3 -132.2 1.00 -74. 7 .75 -130 5.3 -132.2 1.00 -74. 7 .52 -130 5.3 -132.2 1.00 -74. 7 .76 .730 5.3 -132.2 1.00 -74. 7 .76 .730 3.2 -130 3.2 1.00 -74. 7 .75 .130 3.2 -130 3.2 1.00 -75. 7 .75 .130		9	129.	۰.	129.	•	132.		74.
5 .89 -125.5 3.05 -129.9 5.5 -132.1 1.20 -74. 7 .74 -1129.5 2.75 -1130 5.9 -132.2 1.00 -74. 8 .66 -129.5 2.75 -130 5.3 -132.2 1.00 -74. 9 .66 -129.5 2.2 -130 5.3 -132.2 1.00 -74. 9 .59 -129.5 2.2 -130 4.8 -132.2 1.00 -74. 9 .59 -129.5 2.2 -130 4.8 -132.2 1.00 -75 9 .59 -129.5 1.75 -130 3.8 -75 -75 1 .66 -129.5 1.3 -130 3.3 -132.3 .66 -75 1 .66 -129.2 1.3 -130 2.4 -132.4 .45 -75 2 .129.2 .19 -130 2.0 -132.5 .37 -75 2 .129.2 1.9 -130 2.0		ŝ	129.	ņ	129.		132.	ņ	74.
6 .81 -120.5 2.75 -130 5.9 -132.2 1.08 -74. 8 .66 -129.5 2.2 -130 5.3 -132.2 1.08 -74. 9 .56 -129.5 2.2 -130 4.8 -132.2 1.00 -74. 9 .59 -129.5 2.2 -130 4.8 -132.2 1.00 -74. 10 .56 -129.5 1.75 -130 3.8 -132.2 .71 -75 11 .66 -130 3.8 -132.2 1.08 -75 2 .33 -132.2 1.33 .66 -75 2 .33 -132.4 .45 -75 3 .123.2 .9 -132.4 .45 -75 2 .129.2 .9 -130 2.0 -132.5 .37 -75		a?	129.	9	129.	٠	132.	?	74.
7 .74 -130.0 2.5 -130 5.3 -132.2 1.00 -74. 8 .66 -129.5 2.2 -130 4.8 -132.2 .89 -75 9 .59 -129.5 2.2 -130 4.8 -132.2 .89 -75 10 .66 -129.5 2.0 -130 4.8 -132.2 .89 -75 10 .66 -129.5 1.55 -130 3.8 -132.3 .71 -75 2 .33 -123.2 1.55 -130 2.4 -75 -75 2 .33 -123.2 1.3 -132.4 .45 -75 2 .129.2 .9 -130 2.4 -75 -75 3 .129.2 .9 .130 2.0 -132.4 .45 -75 2 .129.2 .9 .130 2.0 .132.5 .37 -75		ω	129.	٢.	Å		132.	ę	74.
8 .66 -129.5 2.2 -130 4.8 -132.2 .89 -7 9 .59 -129.5 2.0 -130 4.8 -132.3 89 -7 10 .59 -129.5 1.70 4.2 -132.3 80 -7 10 .46 -1320 3.8 -132.2 71 -7 11 .46 -129.3 1.55 -130 3.8 -132.2 71 -7 11 .46 -1320 3.8 -132.3 .66 -7 12 .35 -130 3.3 -132.3 .66 -7 13 -129.2 1.3 -130 2.9 -132.4 .45 -7 13 .35 -129.2 1.1 -130 2.4 .45 -7 2 .129.2 1.9 .130 2.0 -132.5 .37 -7		5	130.		53		132.	0	74.
9 .59 -129.5 2.0 -136 4.2 -132.3 .80 -7 0 .52 -129.3 1.75 -130 3.8 -132.3 .80 1 .46 -129.2 1.75 -130 3.3 -132.2 .71 -7 2 .39 -129.2 1.3 -130 3.3 -132.3 .66 -7 2 .39 -129.2 1.3 -130 2.9 -132.4 .65 -7 3 .319 -129.2 1.1 -130 2.9 -132.4 .45 -7 4 .26 -129.2 1.1 -130 2.0 -132.4 .45 -7		10	129.	۰ ا	12	14	132.	ω	5
0 .52 -129.3 1.75 -130 3.8 -132.2 .71 -7 1 .46 -129.5 1.55 -130 3.3 -132.3 .66 -7 2 .39 -129.2 1.3 -130 2.9 -132.4 .54 -7 3 -129.2 1.1 -130 2.9 -132.4 .54 -7 3 -129.2 1.1 -130 2.4 -132.4 .45 -7 3 -129.2 1.9 -130 2.4 -132.5 .37 -7 4 .26 -129.2 .9 -130 2.0 -132.5 .37 -7		ŝ	129.	0	24	•	132.	ω	5
1 .46 -129.5 1.55 -130 3.3 -132.3 .66 -7 2 .39 -129.2 1.3 -130 2.4 -132.4 .54 -7 3 .33 -129.2 1.3 -130 2.4 -132.4 .45 -7 4 .26 -129.2 .9 -130 2.0 -132.5 .37 -7		s	129.	5	2	•	132.	7	2
2 .39 -129.2 1.3 -130 2.9 -132.4 .54 -7 3 .32 -129.2 1.1 -130 2.4 -132.4 .45 -7 4 .26 -129.2 3.9 -130 2.0 -132.5 .37 -7		*	129.	ŝ	2		132.	ø	2
3 .33 -129.2 1.1 -130 2.4 -132.4 .45 -7 4 .26 -129.2 .9 -130 2.0 -132.5 .37 -7		m	129.	ņ	2	•	132.	ŝ	2
4 .26 -129.2 .9 -130 2.0 -132.5 .37 -7		m	129.	•	Ξ.	•	132.	4	~
		Ń.	129.		2	•	132.	÷.,	5

TABLE C-2 (Continued)

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6	Anti	Antenna #8	Ante	Antenna #9	Antenna	na #10	Antenna	na #11
CHR	Mag	Phase	Mag	Phase	Mag	Phase	Mag	Phase
	•	-60	1.		68	-80	1	0
ŝ	5.7	-62.8	3.8	-51.8	84	-79.5	170	ъ.
	•	-64.6		ŝ	78	σ	ú	98.
7	•	ъ	٠		71.5	ж.	4	97
ო	٠	-68	•	s	66	~	ŝ	÷.
4	•	-68.6	~		60	. 1.	N	96
ហ	٠	б		ŝ	56	-77.2	~	-95.7
e e		69.	00	(v)	52	-77.2	110	iσ
2	•	σ	5	56.	49	~	105	ഗ
8	۰.	~	9.	ۍ و	46	-77	66	94.
б	2,90	-70	1.50	-56.4	43	-76.8	93	-94.4
10	5	-70	4	÷.	40	-76.8	87	4.
11	ŝ	÷.	e.	56.	37	<u>،</u>	30	-;-
12	٧,	ъ.	2	56.	35	°.	75	93.
13	2	-68.0	٦.	56.	32	<u>ی</u>	. 69	÷
14	4	÷	٩.	è.	30	ۍ. و	64	ë.
15	ς.	.	0	ы. С	28	0	60	÷.
16	ω.	-68.3	.95	55.	6	6	55	93.
.17	•	-68	. 90	ŝ	÷	،	51	
18	9.	-67.8	.84	54.	22	و .	47	63
19	ŝ	~	. 79	*	20	ۍ.	42	93.
20	٣	-67	.73	54.	18	ۍ و	38	3
21	1.26	-66.5	.67	154	16.2	-76.2	33	92
22	٦.	-65.6	.62	ŝ	lą	°	29	3
23	۰.	.,	. 56	m	12	ġ.	25	2.
24	10	6.2	C U		~ ~	ι,	1 () ()	

COMPUTER PROGRAMS USED TO SOLVE THE COUPLED INTEGRAL EQUATIONS (86a,b):

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FORTRAN IN & LEVE	L 21	MAIN	DATE = 75205	14/42/3
ç	THIS POPERA	COMPUTES THE AXIA	NAGNETIC AND AZIMUTHA	LELFCTRIC
	CHREENTS ON	A TINITE FEPKITE P	D ANTENNA DELVEN BY A	LOUP CARR-
ç	YING CONSTAN	NT CUERENT.		
с С				
C .		THE AVENT WETHED I		
c.	INTEGRAL FO	NS # 2.82 CH CHAPTE	· 2.	
C		and the state of the second state		
0001		\$F(FA) 5(C), FALA4(T		CH(30)
02.05	2 CV1010 10	5(20)+1 K(20+20)+C((10),AA(~0,40),CA(10,10))),CK2T(10),CH2(10,10),	TUAL201
2023			(1.TH.T.TKOT.TKJ.1PS	
0004	INTIGER P			
00.)5	CYTE NAL FR	LINGEVELED EXELLECTS	FMILLR.FMILLL.FMITT.	
····	TERTH LAPSENG	TREFT FIRE THE REPORT	, FM2118, IN2111, TM211,	FCTH2
0005 2	PLAD (21,10)	TAKO,CHUE, THUA, TE,	28 P	
		.o.5) or to 150		
0771 17		\$1 X,c(f10,5,1X)}		
2011	10Y= 4, 14155			
0010	TMUG=4.+ [PY			
0011		36.71/17)71.0-07		
2013				· · · · · · · · · · · · · · · · · · ·
3314		TECHUR *CEP 1		
-001.	CAKLECKINTA			· · ·
0014		TAKU, CZUR, THCA, TR	CiP	
0011 15			AND TEASSVERSE FLECTER	C CHRALMIST
			//.5X. AKU	
			°₁F10,5₁//₁5X₁!}≈FQ = !	
			5.//.14x,*{2."PY#A) FPH	
			*PHASE*16X,*RFAL*+6X,*	1446°+12X+*HA
	661,5X, PRAS	THOR STEPAL TOXY TH	46.1 (77.)	
ć	COMPANY THE	CONSTANTS IN THE 1	INTEGRAL FONS. CA IS	THE DRIV
č			MINED AS & COMPANENT O	
ĉ	SCLUTION.			
c				
0014	f1+(C4)+)	[PY+][/[]&++2}		
0019		TPY-TPY/TAKO		
0020	Carl: 101000	***(1917-)		
0021	19-2-161			
00.11	C107-1./TA			
с с	DIVISION IN			
;;		CT PARTY CS		
1321	2+2			
00.4 16	CCE11200			
00.25	KP1+N+1		•	
0926	1+=find=taxd			
0721	1 +11/12.411	CATINII		
JUZH	TROISTROAT			
i c	COMPUTING T	IE PIGHT HAND SIDE		
L				
			-	-
		· ····································		

-86-

FORTPAN IV G	LEVEL	<i>2</i> 1	MAIN	DATE = 15205	14/42/3
00.29		DC 20 1=1.	, NP 1		
0030		TIMIT		· · · · · · · · · · · · · · · · · · ·	
0-331	20	6611)=6705	CIN(2.+111*1KGT)		
0032		62-24NP1			
0031		NP2=NP1+1			
00.34		PE 18 155	NP2 NZ		
0035	18	(1.(?)=(0,,			
0035		1.1	· · · · · · · · · · · · · · · · · · ·		
0037	22	W111 (6.2	21) 1400(1)		
0035	21		X, 46(4,12,4) = 4,624,4	22, 120.51	
0935		1=[+]			
0040	· ~	If ELLER	2) GC 10 22		
	C				
	c	211 TU9Y 1)	THE LEARNING OF PAGE	Pr 1.	
·· · · · · · · · · · · · · · · · · · ·	C C	COMPLETING	*(1,1) (Y 10 PCINT G	USS DUADEATORE.	··· · •-
0.0%1	L.		LC.,5U.,FRIL-97-3	1015 170Mill Alle C.	
- 0742			10.,50.,F¥[[],Y]]		
0213			<=L X { YP , Y] }		
	-r				
	c	COMPOSITIO	¥(1,1) 104 142,8+1		
	¢.	Di	101		
0014	-	-DL 25 1∓2∓ -J≈L	KP1		
6945					
0046		TTTTTTT	0[1,] + [1, 18, 11]		
0049	• /		<(1+1)+.5+CT(1)	•	
0001	2%	1.4121214.4			· · · ·
	ċ	COMPTERS	*(1,J) (OF 1+1,4+1 45	A INTAL PIAL	
	č	CC PROFILED	strat to tettest a		
3-34 4	~	20 30 1+1,	. e e t		
3050		"hn 30 J#(+			
0051			0{[,J,r()x,19,1]}		
0.167			YFE X (TK , T [)		
0051	<u></u>	<u>Chinnijace</u>			
	2	POPIEVIK-	THE LOKEN THIANGLE FL	FRENES TO DREATH THE	
	ċ			FLEMENIS ARE HALVED.	
	è				
0734	*	30 40 1+1.			
0.155	40		5+C×(1,1)		
033/.		PC 45 1+2.			
0957		11*2+2+1-2			
0358		UT 45 P=1.			
0059	45	AA(1,0) +	EL./IX01+(COSETROT+C	* -P-2] -COS{IKUI*(2*1-P	-11)1
	ç				
	<u> </u>	COMPUTING.	0(1, JIFPEN THE STPLET		
	ç				
33-3		00 48 1+1+			
0751 0062		75 48 Jel.			
		1.414 (1.91)	t < (1, J, (6C)		

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FORTRAN	IV G LEVEL	21	HAIN	DATE = 75205	14/42/31
0063	46	C9(1,J)±C8C			
	с — с	THE FIRST COLU	INN ELENENTS		
0064		DC 50 I=2+NP1			
0045	50	<pre>CK(1+1) ≠CK(1+</pre>			
	C	THE DIAGONAL E	LEMENTS		
	С				
0040		Pr 55 1=2.1			
0067	55		1)-^^(1,(?*1-?))+6		
	C			LE BUT NOT IN THE EIEST	
	ç	COLUMN GR THE	DIAGONAL.		
	C		· · ·		
0074		DC 60 1*3 NP1			
0069		[<i>P</i>]=[-]			
0.075		LU 40 7=5*141			
0071	······	"(x(1+2) ±(ki)+	J)- (3*[44[]+2+J-2)+AA(I+Z*J-1))	
	-	CONDUCTING R171			
	(COMPUTING KILL	J) ELEMENTS.		
0272	ų.	00 43 1-1 801			
0073		00 62 1#1,801 00 62 J#1,801			
0015			1146971 11		
0014		CK(1+))*CK(1*1	140 <u>60</u> 1432		
	ć	AV NOV ALL THE	ELEMENTS IN REGIL	ARE COMPLETED	
	<u>_</u>	of you were the	CUPCHED IN PLUIC	A LASE COMPUTERS	
	č	CENDUTING FLEN	TENTS OF PLOTON IL.		
	č				
3075	-	CALL OF THE	OT 11 N 1 1 11 149 1		
0116	-	CALL 20104.5			
0.) /7		C*1(1,1)=(*PL)			
0073		PP 65 142+5		•	
0079		Jej			
6343		าให้เกิดผู้เวินเม	Gestilition (f)		
0041		CP11(1)=CPPLX(
0047	05	(911) 11+(911)			· · · · · · · · · · · · · · · · · · ·
0011	•	DC 70 101.601			
00/14	-	101+1+1			
0115		0C 76 J#191.N			
00800		CALL OCCION.J	1111111111	hand a second	
0087		C41(1, J1+CMPLX	. (78 , 78)		
0084	70	CM101/11+CM101	• J }	•	••
001)		PC 75 1+1-5P1			
ີ່ປຽດປ	75	CF1(1,1)+0.5+C	×1(2,1)		
	<u>,</u>				
	, i	BY NOW ALL THE	LINING IN REGION	11 ARE COMPUTED.	
	c				
	¢.	COMPUTING FLEP	TRUE IN REGION 111.	•	
	¢				
0091		CALL Q61010.15			
0093		CALL 001010.15			
0043		፝፝፝፝፝፝፝፝፝፝፝፝፝፝፝፝፝፝፝ (ሃ2(1ໍລິ1)ຳປັກການ	(Y+,Y1)		
		DU 90 1#5*Phi			
0044					
0094 0095 0095		J=L CALL VGLIA(E_J			

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		21 45 IN DATE = 75205 14/42/3
FURTRAN IV G	Livit	
00.97		CK2T(1)=CMPLX(TR,T])
- 3748	40	<pre>(K2(1,1) =CK2(1,1)+.5+CK2(1)</pre>
_ ')044		nc 85 1=1,NP:
0100		191=1+1
ə191		SC 65 J=1PL,NP1
01.02		CALL OFLIG(1.J.FCTK2.TR.T1)
01.).1		<pre>CK2(1,J)=CPP(X(TF,T1)</pre>
01.34	35	CK2(J,1)=CK2(1,J)
0135	-	DC 40 1=1,xP1
0196	00 0	CK5(1+1)=0*2+CK5(1+1)
	C .	BY NEW ALL THE FIRMINIS IN PEGIUN 111 APE COMPUTED.
	c c	COMPOTING LIPPINTS OF FEETIN IV.
0107	<u></u>	CALL OGIOIG. ,50, , FY211, , Y')
0123		CALL 3613(0.,50.,FM2'11,Y1)
01		('42(1,1)=('MPLX(Y',Y))
0110		60 95 1 = 2 , 1
J111]=]
0112		CALL QGL10(1,J,FP211,19,T1)
011)		C421(1)=CMPLX(14,11)
0111	95	CM2(1,1)>(M2(1,1)),S+CM21(1)
0115		56 160 121,001
0116		1P1=1+1
0117		09 100 J-(PL)
0119		CALL 0611011, J. FCTM2, T4, T11
0114		CH2(1, J)+C+P(x(14, 11)
012:1	105	r = 2 { J , 1 } = (= 2 { 1 , J }
0121		PP 165 1+1+6-P1
0122	105	CP2(1,1)=0.5=CX2(1,0)
	ç	BY NEW ALL THE REPORTS THE FEET & IV AND COMPUTED.
	6 6 5	CEMPUTINE ELEMENTS OF BEGINN V
01.23		1324Z+2+K+2
01.14		an 110 letteret
0125	2 ¹¹⁰	CK(2, 1702)+-COS(1801+(2+1-/1)
	c c	C PROPERTY OF PERSONNEL CONTRACTOR
0126		Markey
017/		m Heresterstable
0124	115	CK11,N/021+10).)
	c c	BY FOR ALL THE ETTRENTS IN PERIOD & AND AT AND ODDE.
	ڊ د	SETTING UP THE FIRME NATELY POR
0127	7	N7P1=24X+1
0119		**************************************
0111		D() 173 J#NPZ+N221
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		DA(F = 75205) 14/42/31
FORTAN IV G	ויערנ	21 MAIN DATE = 75205 14/42/31
11.32	120	CK(1,J)=CK1(1,J-hP1)
	<u>ç</u>	no 125 1=4.02, M222
0133		pr 125 J=1,NP1
0134	1 76	(r(1,J)=C+2(1-NP1,J)
0135	125 C	
01*6		0° 130 1±NP2;N2P1
- 3117		DC-13) J=KP2, X201
0139	130 £	<pre>rk(1,J)=CM2(1-NP1, J=XP1)</pre>
0137	, c	DC 72 1=LiN2P?
	72	
0140		
	c	PROFEDE TO SOLVE THE LINEAR SYSTEM OF FOUNTIONS.
	č	و المحمد المحم
1010		N#22
V142		CALL DECONPENTCK. COLD
0143		" ຮັກມີມີ ຮັດປຸດ ເພິ່ງຄົນປີ ເປັນເທັດ ທີ່ມີ
0144		White 16,661 (CX(1),1=1,N2)
0145	n.h	* FCFPAT (12F10.5)
0144		CALL INPROVINGER CUL, CL, CA, DIGITS)
0147		W311F (6,66) (CX(1),1=1,62)
0143		(Y(A2): (0, ,0,)
		(NVEA) FPUT(2) 10 (+(2)
0149		1Kt + M = (2. + TPY+TAKU/TKO)
01 50		CO +7 1+1+KP1
0151	67	(X(1)+(X(1)+(h)))
•• •	<i>.</i>	
	<	PEINTOUT OF THE SOLUTION.
0151		1+1 ···································
0154	n	TILOUSAL (CX(1))
0154		T TRATFAGICX(I))
0155		T 11. PHE AL (CX1 1+ A+ 1))
0144		THEATPAGE(XHENNED)
10151		TOPATELOATELY-L. PRICATER
Q15n		TI MACAN SECXEDED
0110		ty manage etters tell
01.11		[]H&(&+S((X{{+++1}))
111		T10#496()(())&.1()) **** **** *************************
0167		[[0,1]] (0,1]] (0,1)] X, ([H,1] 0, ([H,1],1],1]H, ([0,1],1]] ((H,1)) ((1), (X,1], ((1,0), (1,0),
31.53		
0164		1=1+1
01.55		1F (1.(F.NP1) 60 10 71
0160		CYSIAR+CX[1]
9161		CISTARE . JCYSTAR
0161		WITT 161 DI CYSTAN, CESTAR
015.	6.	LITE (0. 3) CYSTAC, CCTAR TIMMAT (5x,7/, 2514+ - 1,219,5,3X, YYSTAF - 1,219,5)
	c	
	ć	
0112		GR 10 2
	15	C CONTINUE
0171		
		· · · ·

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 SUBROUTINE BSLSMLINERD,XYO,XYL) C. SUBRBUTINE IRSLSMLINERD,XYO,XYL) C. IBSLSML COMPUTES BESSEL J FUNCTION WITH COMPLEX AR C. AND RREERO AND 1. ACCURACY UPTO 6TH DECIMAL PLACE OR C. OBTAIRED FOR ABS(Z) LESS THAN 20. IMPLICIT COMPLEX #16(D), REAL=8(T) COMPLEX XYO,XYL 8. UZX=XYO 	GUMENTS MORE IS
 2* C SUBROUTINE INSLEMLI 3* C INSLINE INSLEMLI COMPUTES BESSEL J FUNCTION WITH COMPLEX AND 4* C AND ARDERO AND 1. ACCURACY UPTO 6TH DECIMAL PLACE OR 5* C OBTAINED FOR ABS(1) LESS THAN 20* 6* IMPLICIT COMPLEX*(5(0), REAL*8(T) 7* COMPLEX XY0/XYL 	GUMENTS MORE IS
 C AND BRDERO AND 1. ACCURACY UPTB 6TH DECIMAL PLACE OR C OBTAINED FOR ABS(2) LESS THAN 20. IMPLICIT COMPLEX*16(D), REAL+8(T) COMPLEX XY0,XYL 	GUMENTS MORE IS
 GBTAINED FOR ABS(Z) LESS THAN 20+ IMPLICIT COMPLEX*16(D), REAL*8(T) COMPLEX XY0,XYL 	MORE IS
5. C OBTAINED FOR ABS(2) LESS THAN 20. 6. IMPLICIT COMPLEX*16(0), REAL+8(T) 7. COMPLEX XY0JXYL	
 IMPLICIT COMPLEX*16(D), REAL*8(T) COMPLEX XY0,XYL 	
7. COMPLEX XYO, XYL	
8	
9• K=NUKU	
10+ TX#(EAL(022)	
11 • TY*A[MAG(DZZ)	
12• X=TX	
13• Y=TY	
14. TX=0.560xTX	
15+ TY+C+5D2+TY	
16• TR#TX#TX#TY#TY	
17. TF=2.D0+TX+TY	
18• R*N	
19. ETC=10.0	
20+L=(GLHT(R+R+10+0+(X+X+Y+Y))+R)+ETC	
21+ TFH#1+63	
22. TF1.6.00	
23+ 11+(L+1)+(N+L+1)	
24+ JJ++(2+L+N+2)	
25. D9 460 K#11L	
20	
27. TGR=TR/TP	
28. TG1.TE/TP	
29. TOATER	
30. TFR=1.00-TGR+TFR+TQ1+TF1	
31. 400 TF1(T2R+TF1+T01+TC)	
33+ IF (N+GT+0) G8 T8 402	
34. 401 CONTINUE	
35. DCuSLJ+DCMPLX(TFR,TF1)	
36• XYL+6C0SLJ	
37 · PETURK	
39+ 101+3+00	
40. North	
41. 403 TC+TGR	
42. TGK+TGK+TX+TGL+TY	
43. TG1+TC+TY+TG1+Tx	
+5+ IF (N=++++++++++++++++++++++++++++++++++++	
46+ Tk+1+00	
47+ EA 464 MaddaN	
48. AP()+MA	
ayo aqa taotaan"ii	
51. TG1+TJ1/Tw	
62+ TG+TFH	
53+ TFN+TFN+TGR=TF1+T01	
54. TF1=TO=TG1=TF1=TGR	
55· 00 TO 401	

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1		SUBROUTINE RESH(XYC,N,KIND,XYL,IER)
2		JBROUT.INEUFSHL
3		SESHI COMPUTES HANKEL FUNCTION WITH COMPLEX ARGUEMENTS.
4 · 5 ·		IMPLICIT COMPLEX+16(D),REAL+8(T) COMPLEX XY0,XYL
. 6		DIMENSION DT(12),CTT(6),DTX(6)
7		DX+XYC
	·	IF(N+LG+0+AND+KINC+EG+1+_G8-T8-300
9		IF (N+EG+U+At-D+KIND+EG+2) G0 T0 400
. 10		IF (N.EG.1.AND.KINC.EG.1) GO TU 300
11		IF(N+EG+1+AND+KINC+EG+2) 68 T8 400
12 -) 6X=0X+0CMPLX(0+0C/=1+00) G0 TU 500
		-CX*DX*DCKPLX{0+DC+1+D0}
15		6^ 15 500
16		TRX+REAL(DX)
17.	• ·	TIX=AIMAG(D)
18.	,	TMAG=DSCRT(TRX++2+T1X++2)
19		DBK=UCMPLX(0+D0+C+D0)
20.		TP1+3+14159265
21		IF(N) 10,20,20
23) IER=1 KETURN
		1F (TMAG-17G+DC) 22,22,21
25	2:	JER*3
		RETURN
27 •		LIER+O
		1F (THAG+1+DO) 36+36+25
29+		DA+CDEXP(+DX)
30.		08+1+00/CX
31 -		- 1E(ALALICCI)100+101+101
33.) DC*+UC
. 34		CONTINUE
35 -		DT(1)*DU
- 364		06 50 Fa515
37 -		CT(L)=CT(L-1)+OU
		- CTT(1)+(CX/3.7500)++2
39.		60 660 LL+2/6 CTT(LL)+CTT(LL+1)+DTT(;)
41		GTx(1)*(CX/2.)0)**2
42		68 605 LLL+2+6
434		
، فقسب		-1F(N+1) 627,270,627
45.		FITMAG-2+00001 610/610/27
46.		CUMPUTE TO AND THEN KO
47+		010+1+60+3+515622900+011(1)+3+089942400+011(2)
481		1+1+2vo7k920C+011(3)++265973200+011(+)++036076800+011(6)
49. 50+		2++004581300+011(6) 060++6127842000+011(6)
		1++230697560C+0TX(2)++03+8859000+CTX(3)++6026269860+0TX(4)
52		2++0001075000+0TX(5)++000007+000+DTX(6)
53.		1F('') 2016281629
544		C8x=060
55		G0 TØ 200
564		
57		COMPUTE KO USING POLYNOMIAL APPROXIMATION
58 - 59 -		DGU+64+(1+253Ji+1+DC=+15666+1800+DT(1)++688111278C0+DT(2)
60		2**691396954C0+CT(3)++13*4596200+DT(4)++22998503C0+CT(5)
61.		3++3792409760+DT(6)++52472773C0+DT(7)++5575368460+CT(8)
62.		4*************************************

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63.	5++009189383D0+DT(12))+DC
64 .	1F(N)20/28/29
65 •	28 DBK+DGO
66 •	G8 T8 200
67+	C COMPUTE II AND THEN KI
69+	629 DI1+0X+(+5C0++87890594D0+DTT/1)++51498869D0+DTT/2)
70•	1++1508493400+0TT(3)++0265873300+0TT(4)++0030153200+07T(5)
71.	<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>
. 72. 73.	DG1=CCL0G(DX/2+D0)+D11+(1+D0/DX)+(1+D0++1544314+CC+DTX(1)
74	1 - • 6727657900+DTX(2) - • 1815689700+DTX(3) - • 0191940200+DTX(4)
75.	2=+0,110404DU+DTX(5)++00004686D03DTX(6))
. 76.	1F (N-1) 20/630/31 630 DEK-DG1
77.	GB 10 200
76.	
79.	C COMPUTE KI USING POLYNOMIAL APPROXIMATION
81.	29 UG1+UA+(1+25331+1C0++46999270D0+DT(1)++14685830D0+DT(2)
- 62+	2++12804266C0+DT(3)++17364316D0+DT(4)++2847618100+DT(5)
83.	J=+4024J*21CV=D1(6)++62833807n3enT/71e.663229664nnan7/81
. 84•	4++5050238600+DT(9)++2581303800+DT(10)++07880001200+DT(11)
85.	5**010824177U0*DT(12))*DC
87.	30 DBK+DG1
88+	30 DBK+UG1 60 T6 200
89.	C
90.	C FROM KOJKA COMPUTE KN USING RECURRENCE RELATION
91.	C
93+	DGJ+2+D0+(FL8AT(J)+1+D0)+DG1/DX+DG0
- 94+	1F(CDAbS(DGJ)=1+070) 33+33+32
95+	32 IER**
96 •	G0 TU 34
97.	33 666-061
99.	35 DG1+CGJ 34 D9X+CGJ
. 100.	- G0 T0 200
101+	36 D8+DX/2+D0
102.	IF (HEAL(08)) 70,71,70
103.	71 JF (A]HAG(D0)) 72,70,73
	72 IANG*+1P1/2+00
105.	G9 TU 75
106+	73 TANG+TP1/2+00
107+	75 TAUS+COAdS(DB)
108+ 109+	TAR+0+57721600+0L0G(TABS)
109•	0A+0CHPLX(TAR) TANG)
111+	70 DA+C+5772156600+CCLUG(DB)
	76 DC+UB+CB
113+	1F(N-1)37,43,37
114+	C
115+	C COMPUTE KO USING BERIES EXPANSION
117.	37 CG0++UA
. 118+	DX57=0C4bCx(1+00+0+00)
119.	TFACT+1+DO
120+ 121+	THJ+C+D0
	TRJ#1+100/FLUAT(J)

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126. 40 DG0+DG0+DX2J+TFACT+(THJ+DA) 1F(N)43,42,43 128 .. -42 Disk+Cuiu _ 129+ GP 10 200 130. č 131 . COMPUTE KI USING SERIES EXPANSION 132. ċ 133. 43 DX2J=DB 134 . - TFACT#1+DO ----135 -THJ=1.DC 136. CG1=1+DC/DX+DX2J+(+5DQ+CA+THJ) 137. C8 50 J#2,8 138+ CX2J=DX2J=DC 139+ TRJ#1+DC/FLEAT(J) TFACT+TFACT+TRJ+TRJ 140. 141+ THJ=THJ+TRJ 50 CG1+CG1+CX2J+TFACT+(+5D0+(DA+THJ)+FLBAT(J)) 142+ 18(1.-1)31,52,31 143. 144 . 52 DEX+L31 145. С 146+ -C---C&MPUTE-HANKEL-FUNCTION-USING-KO-AND-KI-147. Ĉ 148. 200 IF (N+EG+0+AND+KIND+EG+1) 68 TO 110 149. IF(N+EG+0+AND+KINC+EG+2) G8 TO 115 IF (N+EQ+1+ANC+KIND+ER+1) GO TO 120 150+ 151+ IF (N+EG+1+AND+KINC+EG+2) G8 TB 120 110_DBH= 2.30.0CHPL: 10.00-1.001+08K/TP1-152-15 Ge Te 130 154+ 115 DB4+2+D0+DCHPLX(0+D0+1+D0)+DBK/TP1 155+ 60 10 130 156+ 120 DBH+-2.DU+08K/TP1 130 CONTINUE 157. 158. XYL.OBH. 159. RETURN 160. END 29.00 SUBROUTINE QG10(XL, XU,F,Y) 1 х ч A= +5+(XU+XL) 23 B . XU . XL 4 C++486953318 5 Ye .0333567*(F(A+C)+F(A-C)) 67 C=+4325317+8 Y 1 Y++07472567# (F (A+C) +F (A+C)) C++3397048+8 8 5 Y+ Y+ + 1095432+ (F (A+C) +F (A-C)) 10 C++2166977+8 11 . Y+Y++1346334+(F(A+C)+F(A-C))

C+.074+3717+8 Y18=(Y+.1477623+(F(A+C)+F(A-C)))

RETURN

END

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FORTPAN IV & LEVEL	21	FK11	DATE = 75205	14/42/31
0031	SUBPOUTINE EKTI	(M1,MJ,X,TR,T1)		
2905	TIMPLICIT COMPLE	X=8 (C)+REAL #4(Y)		
0003 .	COMPEN TAKO, CHU	R TPY TA CK1 CAK	L.TH.T.TKOT.TKO, IPS	
0034	CKOT= (G 1 .) * TK		· · · · · ·	
0005 -	CY=1.+(0.,1.)*(X/TKOT}		
0.06	CY2=CY**2			
<u> </u>	CV=TAK0*CSQRT(1	(Y2)		
0.0101	TCALL TASI SHELOTC	V.C))		
0.00%	CJ2=CJ**?			
2010	[4=4**I-4			
3011	T[4=F CAT([4)			
0712	CF=CEXPIC×OT*TI	4)		
0313	CIP=CEXP(CFOT)			
0014	TIM=CFXPT-CFOT)			
0015]44=4##]-4			
0016	T14=FLOAT(144)			
001/	146=4**1-0			
0018	116=FLCAT(146)			
0019	T111=EXP(-X*T14)		
0020	1112=1X0(-X*116.)		
0021	CFX=CF*CJ2*(CIP	*T111-C1M#T112}/(CKOT+CY)	
0022	TR=PFAL(CFX)			
2023	T (= A IMAG(CFX)			•
0024	RETURN		······································	
0025	END			

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FUR	14	Lt	VEL	21	

FRITT

DATE # 75205 _____ 14/42/31

0001	SURKOUTINE EMILL(HE,MJ,X,TP,YL)
0002	LPPITCIT COMPLEX-SICILIEAL (SIC)
00-11	CCHANY TAKO, CHAR, TOY, TA, CK1, CANL, TH, T, TKOT, TKO, LPS
0004	CK01+(C,1,1)+TK0T
0005	CYx1.+{0.,1.}+(X/1K01}
0006	CY2*CY**2
0001	(v=TAKC+CSUk I{},=CY2}
0003	(A) (AS(SAL (0, CV, CJ)
0009	CJ2#CJ#+2
	ել ԱՀՈՑՆԱԳԳՇ՝ է են հետության հանձեն տեղություններին համարիներին է։ 14.84.94.91.94.0
	14#4=4]=4 T14#F1(AT(14)
0011	
0717	
0013	CIPACTXP((KOT)
0014	CINY(EXD(-CKOY)
0115	
0516	T14#FL()#T(144)
0017	[4/+4+M]-/
0019	U16+f1(Af(146)
0010	f1]]=+xP[=x+T[4]
0020	Y1(2+1 XP(-X+1(A)
1500	<pre>LFX#CF+CJ2*(C10+T111+C1H+T112)/(CKOT+CY)</pre>
0077	CFX+CFX+TA+1A/LV
60723	TR=PFA1(CFX)
0024	TINAIMAGICEXT
0025	PCTURN
0026	TND
	•

FORTRAN IV & LEVEL 21 FK 211 PATE = 75205 SUEPCUTINE FX2111H1,MJ,X,TR,11) TVH1CTT CCMPEFX+UTC),REAL+4(T) 0001 2025 0003 CCHMON TAKO, CHUP, TPY, TA, CK1, CAK1, TH, T, TKOT, TKO, IPS 0004 CK01=(0.,1.)=TKUT 00.05 CY=1.+(0..1.)*(X/TKOT) • • • • 0036 CY2=CY**2 CV=14KO+CSOFT(1.-CY2) (1).17 CALL ISERVETO, CV.CJ) 0034 0000 LJ2=(JA+2 0010 14=4*M1-4 0011 TI4=FLPAT(14) 0012 Cf=CfXP(Ck01+T14) CIP+CEXPLCKOT) 0013 0515 CINELIXPL-CRUT) 0215 144=4+1-4 0016 114=FLCAT(144) 0017 146=4*21-6 011 110-11/01/146. T111=+XP(-y+T14) 0019 1112=1 XP(-XnT16) 0020 CFX=UF=CJ2+(CIP+T111-CI==T112)/(CKOT+CY) 0321 CFX=CFX/(TA=CV) 0022 0023 TR=PEAL (CFX) 0024 TINATHAGECERS 9ETURN 0025 0325 TNO F4211 NATE # 75205 FURTRAN IV G LEVEL 21 0221 SUCCOUTINE THEISCHI, MJ. X. TO. ILE 1017 PHILTON RESPLEXIZIES AUSTRALIS CC INCH TAKO, CHUR, TPY, TA CKI, CAKE, TH, T. TKUT, TKO, IPS 5553 0004 rkot=(0,,1,)*tkot 0005 CY=1.+(v.,1.)+(X/TKOT) CY2+CY++2 00.05 0001 CV+TAKG-CSORTI1.-CY21 CALL DISISHELD, CV. CJ) 0071 CUZACUA42 0000 0313 14=474 -4 0011 TI4=FLGAT(14) CF+CFXP(C×01+114) 0012 0011 CINSCINP(CFOT) CIVERI XOC-CROTT 0114 144=4=41-4 0.0115 0110 114+8164863443 146. 4 + 41 - 4 0317 TICALL SALLIAGE 2014 116+ FLOAT(146) 0317 1027 YY117 FXD1-Y-Y141 1112+FXPL-X+1101 0121 3322 CFX+CF+CJ2+(C)P+1[11-C]H+Y[12)/[CK0Y+CY] CFX+-CFX+TA+TPY 90 ? 1 TRAFFAL (CFX) 0024 0025 11+ALMAGICEX1 ALLINAN. 0026 3027 FAC

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····· · · · · · ·			
FOR TRAN 1V G LEVEL	21	FKIIR	DATE = 75205-
0001	FUNCTION FRIIP(YE)	
000,	THE LOT TO COPPLEX S	C) , KIAL NA(T)	
0,003	COMMON TAKO, CMUR,	TPY TA CKI CAKI	+TH+T+TKUT+TKO+IPS
0004	Y[2= YF ++ 2		
0905	CU=TAKO*CSCRT((1.	-YE2)*(10.)}	
~ 30 05	CU1 = CU		
1022	CALL HSLSYL(0,CU,	CJI	
0.7.73	CALL RESHICUL, 0,1	CH, IFR)	
0.709	_CF=(0.+4.)*CJ*CH*	SIN(TKOT=YE)/YE	
0010	FKIIR= REAL(CF)		
0011	RFTURN		
0012	END		
EORTPAN IV G LEVEL	21	FKILL	DATE = 75205
0001	FUNCTION FRIIT(YE	1	
0002	TAPITCIT COMPLEXE	(C) RIAL 4(T)	
0003	COMMEN TAKO, CHUR,	PY.TA.CKI.CANI	TH, T, TKOT, TKO, IPS
0004	YF7=YF+#2		
03-35	CU=TAK0+CSORT(()	-YF2)=(1	
0006	CL1=CU		
0007	CALL ASLSHLID, CU,	· J)	
0005	CALL BESECCUI.0.1.		
0009	CF=(0.,4.)*CJ*CH+5	IN(TKOTAYE)/YE	
0010	FKILL=AINAGICF)	ter a contractor	
0011	RETURN	•	
0012	FND	•	
FURTHAN IN G LEVEL	21	FALLE	DATE = 75205
00.01	FUNCTION FRITIER	3	
0702	TMATCHICKNETCO	10, 11, 11, 14, 10, 10	
0001	COMPON YAKG, CHIR, I	PY. 14. CKL. CAKL	THEESTROTEEROLEPS
0004	ALG#AL#45		• • • • • • • • • • • • • • • • • • • •
0005	CI#14X0*CSC#1111	YE2) *(1))	
T U034	CUI*CU		•
0017	CALL ASISHI (1, CU,C	'J1	
0001	CALL AESHEGULIVIL	06,000	
0000	CF#10+14+1+TA+CJ+C	H*SINCTROT *YES	/(YF+(1,-YE2)+1K0)
0010	"FM1111=A1MAG(CF)	e i vi in ender	
0011	RETURN		
0012	FND		
		•	•
FORTAN IN G LEVEL	21	LWIIIK	DATE # 75205
0901	FUNCTION FRIITFIYE		
00.35	TADLIC LI CCHOLF X48		
0011	COMPON TAXO, CHUR, T	PY.TA.CKI.CAKI.	TH.T.T.OT.TKO.1PS
-0004	465×46++5		
0005	CUETAKO+CSORTILL	YE21+11.,0.11	
0000	CUI=CII		
0007	CALL OSISPLEL.CU.C		
0003	CALL BESHICULIOIT.		
0007	CF=(0.,4.)+TA=CJ+C	H+SIN(TKOT+YF)/	(YF+(1,-YE2)+TKO)
0010	FHILLR REAL(CF)		
0011	AFTURN		
0015	END		

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FIDTRAN IV G LEVEL 21 FK 211R DATE = 75205 0001 FUNCTION PRZIIP(YE) THPI IT IT CTHPLEXTR(C), STAL #4(T) 335 CCHMCA TAKO, CMUR, TPY, TA, CK1, CAK1, TH, T, TKOT, TKO, IPS 0004 0004 Y1 2= YF ## 2 CU=TAKD*CSQRT([1.-YE2]*(1..O.)) JU05 0006 CU1+CH 0107 CALL BSLSPILG, CU, CJ) CALL BESHICULTITIES 0333 0007 Cf={0.,++.}*****{1.+YT2}*CJ*CF*S1\{1x0T*Y-}/YE 0.010 FX2118+REAL(LF) 0011 RETURN 0912 FAI FORTRAN LY G LEVEL 21 FK2111 PATE # 75205 2221 FUNCTION FR2111(YE) 0002 THELICIT COMPLEXENTED PENTATION 1224 CCHMEN TAKO, CMUR, TPY, TA, CK1, CAK1, TH, T, TKOT, TKO, 1PS ¥12=¥1++2 -1114 CU=TAKO*CSCFT((1.-YE2)*(1.,0.)) 0005 03.)5 0.01=0.0 0007 CALL HSI.SHL(0+CU+CJ) CALL BSI.SH(CU1+L+L+LH+TF+) 103.33 01.00 CF= (0.,-4.)*IKO*(1.-YE2)*CJ*CH*SIN(TKOT*YE)/YE 0010 FK2111=A1 MAG(CF) oni RETURN 0012 FND FIRITIAN IN 5 LEVEL 21 132119 DATE = 75205 000 FUNCTION PRZEIRCYCE CONCA TAKO, CYDATTPY, TATICAL CART THIT TKOT, TKO, IPS דרייס 00.14 THPLICIT COMPLEX*B(C), PEAL+411) 0014 YF2 YFANZ 0005 CL = TAKOACSUP TE(1.-YF2)*(1..0.)) 0015 **ບ**ິເ≆ເບ CALL ASUSHLILICUICS 0007 CALL RESHICULILITYCHILEY" -----6000 0004 CF+(0.,4.)+TA+CJ+CH+SIN(TROT+YF)/YE 0010 F#211k=#FALICF1 0011 RETURN ----ENC TH2111 FORTRAN IV & LEVEL 21 GATE # 75205 00-11 FUNCTION CM211 LEVEL THEL ICTT TOURIER HEICH, AFALTATT 0112 0003 COMP. S. TARO, CPUR, TPY, TA, CK1, CAKL, TH, T, TKOT, TKO, 1PS 3371 YEZZYCONZ CU=TAK0+CSQRT((1.-YE2)+(1..0.)) 0005 .. . 6115 011=00 CALL HSLSHELL+CU.CJ) 0007 0034 ALT STSHICULITILICHITERT CF+ (0.,4.)+TASCJ+CH+SIN(TKOT+YF)/YE 00.)1 1011 FH7111=AIMAGIGET oni RETURN 0012 * END

0.301 SUPPOUTINE FORK(H1,HJ,X,TP,T1) 0.303 CPMECK TAKO (CUB, FTQ,TA,FA(T) 0.303 CYAL, +(0,+1,)*(X/TKOT) 0.304 CY2-(Y+2) 0.305 CY2-(Y+2) 0.306 CY2-(Y+2) 0.307 CALL +(0,+1,)*(X/TKOT) 0.308 CY2-(Y+2) 0.309 CY2-(Y+2) 0.301 CJ7-CALL +S(SYNLO,(Y,CJ) 0.302 CY2-(Y+2) 0.303 CJ7-CALL +S(SYNLO,(Y,CJ) 0.304 CJ7-CALL +S(SYNLO,(Y,CJ) 0.305 CJ7-CALL +S(SYNLO,(Y,CJ) 0.306 CJ7-CALL +S(SYNLO,(Y,CJ) 0.301 CTSCFCFC2/2001/1 0.301 CTSCFCFC2/2001/1 0.301 CTSCFCFC2/2001/1 0.301 SLANCUTINE FORMULAND 0.301 SLANCUTINE FORMULAND 0.301 SLANCUTINE FORMULAND 0.302 CMN 0.303 CCMPLN TAMO, CMUN, TAY, TW, TU, TANOT, TKOT, TKO, TKO, THO, TMO, CMUN, TAY, TW, TU, T, TKOT, TKO, TKO, THO, TY, TAYO, CMUN, TAY, TY, TAYO, CMUN, TAY, TY, TU, T, TKOT, TKO, TKO, THO, TY, TAYO, CMUN, TAY, TY, TU, T, TKOT, TKO, TKO, TY, TY, TY, TY, TY, TY, TY, TY, TY, TY	FOPTRAN IV G LEVEL	21	FCTK	DATE = 75205
7772 THA11CTY CLONELEX+LCTY AFALT*GTY1 0033 CPMECN TAK0.CHUR.TPY.TA.CKI.CAKL.TH.T.TK0T.TK0.1PS 0334 CY=1.+(0.,1.)*(X/TK0T) 0305 CY=1.+(0.,1.)*(X/TK0T) 0306 CY=1.4(0.,1.)*(X/TK0T) 0307 CAT 0308 CY=1.4(0.,1.)*(X/TK0T) 0307 CAT 0308 CY=1.4(0.,1.)*(X/TK0T) 0307 CAT 0308 CY=1.4(0.,1.)*(X/TK0T) 0309 1.2=24MI-2 0301 T12=11TATT12 0301 T12=11TAT12 0313 CT=CRPLX11*1100 0314 CAT 0315 CT=CRPLX17*110 0316 CT=CRPLX17*111 0317 CAT 0318 CT=CRPLX17*1 0319 CAT 0314 CAT 0315 CT=CRPLX17*1 0316 CAT 0317 TAT*AHATVE 0318 CT=CRPLX17*1 0319 CAT 0319 CAT 0319 CAT 0310 CAT	0.301	SUPPOUTINE FO	TK(H1,HJ,X,TP,T])	
3)33 CY=1.+(0.+1.)=(X/TK0T) 0)03 CY2=CY=02 0)36 CY=1AK0+CSCFT(1CY2) 1)77 CATI =S(SVL(0,(V, (J))) 0003 CJ2+CJ*+7 0003 CJ2+CJ*+7 0010 T12+AH1+2 0011 TV02=TK3(TT12) 0012 CK07=CA(TT12) 0013 CT=CEXT(CQ2) 0014 CATTANA(N1, W, W, W, W, TE, TT) 0015 C1=CMP(X (TF, T1)) 0016 CF=CEXT(CQ2) 0017 TR=FEAL(CTX) 0018 CATCTANA(TF, T1) 0019 UNIN 0101 TF=ATMA(FFX) 0011 TF=ATMA(FFX) 0011 TF=ATMA(FFX) 0011 TF=ATMA(FFX) 0020 ENO 0031 CLVFL 21 FCTH1 PATE 0031 CLVFL 21 FCTH1 PATE 0031 CLVFL 21 FCTH1 PATE 0032 CLVFL 21 FCTH1 PATE FCTH1 FCTH1 FCTY F	0.203	THAL TOTY CONF	PLEX+6(C), RFALTAT	
3)33 CY=1.+(0.+1.)=(X/TK0T) 0)03 CY2=CY=02 0)36 CY=1AK0+CSCFT(1CY2) 1)77 CATI =S(SVL(0,(V, (J))) 0003 CJ2+CJ*+7 0003 CJ2+CJ*+7 0010 T12+AH1+2 0011 TV02=TK3(TT12) 0012 CK07=CA(TT12) 0013 CT=CEXT(CQ2) 0014 CATTANA(N1, W, W, W, W, TE, TT) 0015 C1=CMP(X (TF, T1)) 0016 CF=CEXT(CQ2) 0017 TR=FEAL(CTX) 0018 CATCTANA(TF, T1) 0019 UNIN 0101 TF=ATMA(FFX) 0011 TF=ATMA(FFX) 0011 TF=ATMA(FFX) 0011 TF=ATMA(FFX) 0020 ENO 0031 CLVFL 21 FCTH1 PATE 0031 CLVFL 21 FCTH1 PATE 0031 CLVFL 21 FCTH1 PATE 0032 CLVFL 21 FCTH1 PATE FCTH1 FCTH1 FCTY F	0.0.93	COMMON TAKON	MUR . TPY . TA . CKI . CAL	<1.TH.T.YKJT.TKO.1P5
0.00.5 CY=TAK04CSCST(1,-CY2) 0.016 CY=TAK04CSCST(1,-CY2) 0.017 CAIT #K1(SVL(0,(V,CJ)) 0.001 CJ=2(J)*/2 0.010 CJ=2(J)*/2 0.011 TV0/TK1T12 0.012 CK07=(C,1,1,2)K07 0.013 CT=2(X)*/X,TR,TT) 0.014 CK07=(C,1,1,2)K07 0.015 CT=2(X)*/X,TR,TT) 0.014 CK07=(C,1)(CK01+CY) 0.017 TAFFALLCTX) 0.018 CT=2(CK07)(CK01+CY) 0.019 T+AINAC(CTX) 0.010 T+AINAC(CTX) 0.011 TV=AK10C(CTX) 0.011 T+AINAC(CTX) 0.011 T+AINAC(CTX) 0.011 T+AINAC(CTX) 0.011 T+AINAC(CTX) 0.012 CN0. 0.013 CLV+CY 0.014 CL+CK1/Y 0.017 T+AINAC(CTX) 0.018 CLV+CY 0.019 CHUPTCTTTCUNTX+QUAL(CLOKI, CAIL, 1++T, TKOT, TKO, 1PS 0.0104 CY+L+(0, 1, 1)=(X/TVOTI 0.011 CLY+CY+Z 0.012 CV=CCX+	1) 14			
0)3Å CV=TAKAGESEST(1,-CV2) 0)77 CALL =SISML(0,(V,CJ) 0003 [2=24MI+2] 0010 [1=4+17AT[12] 0011 IV07TK3TT[2] 0012 CK07=(0,1,1)2[K07 0013 CT=(TFT1CK07) 0014 CALT AUA(M1, WJ, WJ, W, TR, TT) 0015 CT=(CFT1CK07) 0014 CALT AUA(M1, WJ, WJ, W, TR, TT) 0015 CT=(CFT1CK07) 0016 CF=(CFT1CK07) 0017 TA=FEAL(CFX) 0018 CALC(TINE FCIMI(K1, MJ, X, TF, TT) 0014 TA=FEAL(CFX) 0014 TA=FEAL(CFX) 0014 TA=FEAL(CFX) 0017 FCTM1(K1, MJ, X, TF, TT) 0018 SLAWC(CTINE FCTM1(K1, MJ, X, TF, TT) 0019 LNA 0020 ENA 0031 CLWFV 00320 ENA 0033 CLWFV, TAWO, CMUQ, TOY, TA, CK1, CALL, TH, TI, TKO, TPS 0034 CY=VV, TAKO, CMUQ, TOY, TA, CK1, CALL, TH, T, TKO, TPS 0035 CLWFV, TAKO, CMUQ, TOY, TA, CK1, CALL, TH, T, TKO, TPS 0036 CY=VV, TAKO, CMUQ, TOY, TA, CK1, CALL,	0.00.5			
0037 CA1 CL_CL_CL_CL_CL_CL_CL_CL_CL_CL_CL_CL_CL_C			()(Y2)	
0014 CJ2+CJ2+2 0005 [2+2#MI+2] 0011 IV07=IK3T+T12 0012 CK07=(G,L,L)=1K07 0013 CT=CEXPICK07) 0014 CATTAUX(M1,MJ,X,TE,TT) 0015 C1=CMP(X(IR,TI)) 0016 CT=CEXPICK07+(K01+CY) 0017 TA=FEAL(CTX) 0018 C1=CMP(X(IR,TI)) 0019 C1=CMP(X(IR,TI)) 0010 ENC 0011 TA=FEAL(CTX) 0011 TA=FEAL(CTX) 0011 TA=FEAL(CTX) 0011 TA=FEAL(CTX) 0020 ENC 0030 CL*WFL 71 0031 SLOWCCTING FCIMI(KI, *J, X, TF, TT) 0030 CL*WFL 74 0031 SLOWCCTING FCIMI(KI, *J, X, TF, TT) 0032 CL*WFL 72 0333 CL*WFL 74X00(CT) PEAL=A(T) 0344 CY+CY+V 0355 CY+CY+V 0366 CY+CY+V 0376 CY+CY+V 0377 CV+CY+V 0376 CY+CY+V 0377 CV+CY+V				
0000 12 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2				
1010 (1) = 1 (Λ1 (1)) 0011 1 × 0/= 1 K (1 × 1) 0012 C K (2) = (C, 1, 1) = 1 K (2) 0013 C (= C (2) (C (2)) 0014 C (= C (2) (C (2)) 0015 C (= C (2) (C (2)) 0014 C (= C (2) (C (2)) 0015 C (= C (2) (C (2)) 0014 C (= C (2) (C (2)) 0017 T = PEAL(C (X) 0018 C (= C (2) (C (2)) 0019 T = PEAL(C (X) 0010 T = PEAL(C (X) 0011 T = PEAL(C (X) 0010 T = PEAL(C (X) 0011 T = PEAL(C (X) 0020 ENO 0021 ENO 0020 ENO 0021 ENO 0111 T = PEAL(C (X) 0112 C = PEAL(C (X) 0113 C = PEAL(C (X) 0114 C = PEAL(C (X) 0115 C = PEAL(C (X) 0116 C = PEAL(C (X) 0117 <td></td> <td></td> <td></td> <td></td>				
J011 IV07=IKJT*I12 J012 CK07=10.,1.)=1K07 J013 CT=CTFV1CK073 J014 CAIT J015 CL=CMP1K073 J016 CF=CTFV1CK073 J017 CAIT J018 CT=CTFV1CK073 J014 CAIT J015 CL=CMP1K1F,T13 J016 CF=CTFV1CK073 J017 TA=FEAL(CTX) J018 TF=ALMAC(FX1 J019 FCTM1 J011 T=FEAL(CTX) J012 FCTM1 J013 CL=VFL J014 T=FEAL(CTX) J015 CL=VFL J016 CL=VFL J017 CL=VFL J018 CV=TAXC=CCUL J019 CH=L J112 FC=FEAL(CFX) J014 </td <td></td> <td></td> <td></td> <td></td>				
0012 CK07={C,1,1,3}KA7 0013 CF=CFP(CK07) 0014 CAITAWA(N,N,Y,TR,YT) 0015 C1=CK07(X(N,TR) 0016 C1=CK07(X(N,TY) 0017 TR=FEALLCTX) 0018 T1=ANAC(FFX) 0019 T1=ANAC(FFX) 0010 T1=ANAC(FFX) 0011 T1=ANAC(FFX) 0012 ENO 0013 CCVFL 0014 T1=ANAC(FFX) 0015 CLVFL 0016 CLVFL FD3T*AALIV G LEVFL FCINIKI, NJ, X, TR, TI1 0020 ENO 0031 SLOUCUTING FCINIKI, NJ, X, TR, TI1 0037 CVTTY 0030 CCVFL Y ANO, CHUR, TY, TA, CAXI, TR, TI1 0317 CVFL Y ANO, CHUR, TY, TA, CAXI, TR, TKO, TFS 0336 CCVFL Y ANO, CHUR, TY, TA, CAXI, TROTI 0337 CVFL Y ANO, CHUR, TY, TY, TKO, TKO, TKO, TKO, TY, TKO, TKO, TKO, CHUR, TY, TKO, TFS 0337 CVFL Y ANO, CHUR, TY, TY, TY, TKO, TKO, TKO, TY, TY, TY, TY, TKO, TFS 0336 CVFL Y ANO, CHUR, TY, TY, TY, TKO, TY, TKO, TFS, TY, TY, TY, TKO, TY, TKO, TY, TKO, TY, TKO, TY, TKO, TY, TKO, TY, TY, TY, TY, TY, TY, TY, TY, TY, TY				
0.13 CT=CEXPICK07) 0014 CATTAUX(NT,NJ,X,TR,YT) 0015 C1=CMPLX(TR,T1) 0016 CT=CMPLX(TR,T1) 0017 TA=REAL(CTX) 0018 CT=CFC22C(V(CK01+CY)) 0017 TA=REAL(CTX) 0018 T1=ANAC(FFX) 0019 ENO 0020 ENO 0021 SLOWCUTINE FCTMI(KI,NJ,X,TK,TT,TI) 0220 ENO 0231 SLOWCUTINE FCTMI(KI,NJ,X,TK,TT,TI) 0320 CLWFL 0331 CLWFL 0441 SLOWCUTINE FCTMI(KI,NJ,X,TK,TT,TI) 0340 CY=CY=CY=Z 0351				
0014 Ca1* Aux (M1, WJ, X, TR, YY) 0015 C1=CMPLx(TR, T1) 0016 Crx=CF+CJ2+C1/(CkO1+CY) 0017 TR=REAL(Crx) 0018 T1+ATMAC(FX) 0019 ENA 0010 T1+ATMAC(FX) 0011 T1+ATMAC(FX) 00120 ENA 0013 CLVFL 0014 P+TUMN 0020 ENA 0015 SLAW(UTIN* FCIMI(K1, WJ, x, TP, T1) 0017 CUMUX TANO, CHUQ, TPY, TA, CT, CAX1, TH, T, TKO, TPS 0016 CUMUX TANO, CHUQ, TPY, TA, CT, CAX1, TH, T, TKO, TPS 0017 CUMUX TANO, CHUQ, TPY, TA, CT, CAX1, TH, T, TKO, TPS 0018 CUMUX TANO, CHUQ, TPY, TA, CT, CAX1, TH, T, TKO, TPS 0019 CUMUX TANO, CHUQ, TPY, TA, CT, CAX1, TH, T, TKO, TPS 0010 CUMUX TANO, CHUQ, TY, TA, CT, CAX1, TW, T, TKO, TPS 0017 CALL ASLSPI(C, CVG, CJO) 0017 CVTAXC, CSUT11, CY1, CJ1 0018 CVTAXC, CSUT11, CY1, CJ1 0019 CVGCV 0010 CVGCV 0011 CJ2+CAHL-2 0011 CJ2+CAHL-2 0				
0015 Cl=CMPLX(IP,TL) 0016 Cfx=CF*CJ2*Cl/(CK01+CY) 0017 TA=FEALCTX) 0018 Cfx=CF*CJ2*Cl/(CK01+CY) 0017 TA=FEALCTX) 0018 Cfx=CF*CJ2*Cl/(CK01+CY) 0017 TA=FEALCTX) 0018 Cfx=CF*CJ2*Cl/(CK01+CY) 0019 ENA 0020 ENA 0021 SLnuc(C11W* C1H(H, NJ, X, FF, T1) 0033 CCWFw, XANO, CHUR, F0Y, TA, CK1, CAX1, TH, T, FK0T, FK0, FPS 0034 CY+1, et A., 1, + 5(X/FY01) 0035 CY+2, et A., 1, + 5(X/FY01) 0036 CY+2, et A., 1, + 5(X/FY01) 0037 CY+1, et A., 1, + 5(X/FY01) 0037 CY+1, et A., 1, et A., (+, C, V), et A., 1,				
0016 CFX=CFACJ2+CL/(CK0T+CY) 0017 TA=PEAL(CFX) 0014 TI+AFAAC(FX) 0017 PFTURN 0017 PFTURN 0017 PFTURN 0017 PFTURN 0020 ENO 0021 SLAUCCTINE FCINICKLANCY, X, TH, TTI 0032 CLVFL 7 0033 CLVFL 7 0034 CLVFL 7 0035 CLVFL 7 0036 CV+TAXC, CLUP, TAXC, CLUP, TA, CL, TA, CL				
0017 TA = FEALL(CTX) 0018 T1 + AIMAC(FFX) 0017 FLURA 0020 ENA 0021 ENA 0020 ENA 0020 ENA 0020 ENA 0020 ENA 0021 CUPUTOTTOTTOTTOTTOTTOTTOTTOTTOTTOTTOTTOTTOT				
0010 T1+ATMAC(FFX) 0011 PFTURN 0020 ENO			(/ (CKOT+CTT	
001-1 9 FTURN 0020 ENA FD3 TYAM IV G LEVFL 21 FGTH1 DA15 + 75205 0001 SLAWFUTING FGTRITX+0(G) PEAT=GTT1 0033 CLMPUT TAKA, CHUA, TPY, TA, TH, TT1 0034 CY+1, +10, -11, 9 (X/TYOT1 0035 CY+1, +10, -11, 9 (X/TYOT1 0036 CY+1, +10, -11, 9 (X/TYOT1 0037 CY+1, +10, -11, 9 (X/TYOT1 0036 CY+2, 492 0037 CY+1, +10, -11, 9 (X/TYOT1 0037 CY+1, +10, -11, 9 (X/TYOT1 037 CY+1, +10, -11, 9 (X/TYOT1 0317 CALL ASLSPI (C, CV6, CJO) 0317 CALL ASLSPI (C, CV6, CJO) 0317 CALL ASLSPI (C, CV6, CJO) 0317 CALL ASLSPI (C, CV7, CJ) 0318 CJ+2, CHUA, TAT, P, TH, TH, TH, TH, TH, TH, TH, TH, TH, TH				
0020 ENA FD3T*AALIV G LEVFL 21 FGTH1 D3T7 FD4T*AALIV G LEVFL 21 001 SLAVCUTIVE FGTP1K1, 43, 2, TFFT11 003 CCMPLY TAXA, CHUR, 19Y, 1A, CK1, CAK1, 1H, 1, TK0T, TK0, 1PS 003 CCMPLY TAXA, CHUR, 19Y, 1A, CK1, CAK1, 1H, 1, TK0T, TK0, 1PS 0036 CY+1, +(0, 11, 3) = (X/TY0T1) 0037 CV+1, YXAC, CUR, 11, -CY2) 0036 CY+2, +(0, -11, 3) = (X/TY0T1) 0037 CV+1, XX 0037 CV+1, XX 0037 CV+1, XX 0037 CV+1, XX 0037 CV+1, CV 0037 CV+1, XX 0037 CALL, ASLSPH (C, CVG, C, DO) 00310 CALL, ASLSPH (C, CVG, C, DO) 00311 CJ>, CX, CJ, D+C, LI 0031 CY, CT, NC, X(11, X, Y, TF, T1) 0031 CHY, TX, TX, TX, TX, TY, TY, TY, TY, TY, TY, TY, TY, TY, TY				
FD2T*AH IV G LEVFL 21 FCTH1 DA15 + 75205 0001 SLAWCUTINE FCTH(H, Y, Y, Y, TH, TI) 033 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0033 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0034 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0035 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0036 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0037 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0036 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0037 CINE, Y TAYA, CHUR, TPY, TA, CL, CAXI, TH, T, TKO, TPS 0037 CINE, CINE, CHUR, TPY, TA, CL, TY, TH, TH, T, TKO, TEX, TKO, TPS 0037 CV TAXGECS, SUBTIL, CV2, TAXGECS, CL, TA, CL, CL, TAXGECS, CL, TL, CL, TAXGECS, CL, TL, CV2, TAXGECS, CL, TL, CV1, TJ, TL, TL, TT, TL, TL, TT, TL, TL, TT, TL, TL				میں اور
0001 \$L04(U114* FC181481,43,2,18,11) 017 UP1TC17 FC0077848(2):PE41*4(1) 0103 CC4845 0004 Y=1,+10,-11,9E41*4(1) 0005 CY2-2+(0,-11,9E4)*4(1) 0005 CY2-2+(0,-11,9E4)*4(1) 0007 CY4-1,+10,-11,9E4)*4(1) 0007 CY4-1,+10,-11,9E4)*4(1) 0007 CY4-1,+10,-11,9E(1,-11) 0007 CY1+CY 0017 CALL ASLSPI(C,CVC,CJO) 0010 CALL ASLSPI(C,CVC,CJO) 0011 CJ2+2+0+-2 0011 CJ2+2+0+2 0014 CJ+2+0+17 0015 CJ4+(CY07) 0014 CJ+2+0+2(1++11) 0015 CJ+2+0+2(1+CF2) 0017 CALLANAG(CF3) 0027 TA+0+AC(CF3) 0028 AEU\$	0020	F NU		
033 Up (T(T) (T(0)) T Y+4(T(1) DEAT*4(T)) 0033 C(Y+U, Y TAYO, CHUQ, TPY, TA, C4, C4X, L, TH, T, TYOT, TKO, TPS 0034 C(Y+U, Y TAYO, CHUQ, TPY, TA, C4, C4X, L, TH, T, TYOT, TKO, TPS 0035 C(Y+L, Y CA, C4X, L, TYOT) 0036 C(Y+L, Y CA, C4X, L, TYOT) 0037 CY+L, Y CA, C4X, L, TYOT) 0037 CY+LAY CCSULT(L, CY2) 0037 C4L ASLSPI(C, CVG, C30) 0037 C4L ASLSPI(L, CY1, C31) 0031 C1 V CVG CV 0310 CAL ASLSPI(L, CV1, C31) 0311 C3+C4, TA, C4, T1, TY, TY 0311 C3+C4, TA, C4, T1, TY, TY, TY, TY, TY, TY, TY, TY, TY, TY				
0003 CTMPLY TAKO, CHUR, TOY, TA, CK1, CAK1, TH, T, TKO, TPS 0036 CY+1,+10.11.)*(X/TYOT) 0037 CY+2(++2 0037 CV+2(+2 0037 CV+1(-Y 0047 CVC(TV 0057 CVC(TV 0050 CV+1(-Y 0051 CVC(TV 0051 CVC(TV 0051 CVC(TV 0010 CALL ASLSMI(C, CVG, CJO) 0011 CJ2+2(A)(-CJ1) 0011 CJ2+2(A)(-CJ1) 0011 TJ2+2(CAL1-2) 0011 CALL ASLSMI(C, L)(-CJ2) 0014 CJ2+2(A)(-2) 0015 CALL ASLSMI(TH, NJ, *TKQ2) 0014 C1+CAMLX(TH, TJ) 0015 C1+CAMLX(TH, TJ) 0017 CALL ASLSMI(CFX) 0027 TR+PFALTCFX) 0071 T1+A1+AG(CFX) 0072 AFUAN	FORTYON IN G LEVEL		FC 1H1	NA 15 • 75205
0094 (Y1,+(0,1,+)*(X/TYOT) 0995 (Y2>CY+2) 0037 (Y1=Y2) 0037 (Y1=Y2) 0037 (Y1=Y2) 0037 (Y1=Y2) 0037 (Y1=Y2) 0037 (Y1=Y2) 0040 (Y1=Y2) (Y1	0901	SLANCUTING FO		• • • • • • • • • • • • • • • • • • •
0005 CY25CY**2 0036 CY4TAKC*CSCRT[1]**CY2 0037 CY1*CY 0051 CYC*CY 0051 CYC*CY 0051 CYC*CY 0051 CYC*CY 0010 CALL ASLSP1(C,CYC,CJO) 0011 CJ2*CCJ0*CJ1 0011 CJ2*CCJ0*CJ1 0011 112*CCJ0*CJ1 0011 CJ2*CCJ0*CJ1 0011 CYC*CY*CY1 0014 CT*C(XP1CY07) 0015 CTxCT*CY2*CY1 0014 CT*C(XP1CY07) 0015 CTxC*C*CY2*CY1 0016 CT*CT*CY2*CY1 0017 CALLANCX(TA:TATATATATATATATATATATATATATATATATATA	0201	SLANCUTINE FO	THIIN	}
0.336 CV+1AXGeCSURT[1,-CY2] 0.337 CV+FC 0.347 CV+FC 0.357 CALL ANS SPL(CV) (CJ) 0.317 CALL ANS PATE 0.318 CT+FCXPLXFL(FV) 0.317 CALL ANS (AL(A, N, N, N, L), FT) 0.318 CT+FCXPLX(TH, TL) 0.317 CALL ANS (AL(A, N, N, N, L), FT) 0.318 CT+FCXPLX(TH, TL) 0.317 CALL ANS (TH, N, N, N, L), FT) 0.318 CT+FCAC(CPC) 0.317 CALL ANS (TH, N, N, N, L), FT) 0.318 CT+FCAC(CPC) 0.317 CALL ANS (TH, TL) 0.317 CALL ANS (TH, N, N, N, N, L), FT) 0.317 CALL ANS (TH, N, N, N, N, L), FT) 0.317 CALL ANS (TH, N, N, N, N, L), FT) 0.327 <t< td=""><td>0201 022 0003</td><td>SLANCUTINE FO TUPITOLE FOR COMPLY TAKA.0</td><td></td><td>}</td></t<>	0201 022 0003	SLANCUTINE FO TUPITOLE FOR COMPLY TAKA.0		}
0.007 CV1+CV 09C1 CVG+CV 001 CALL 001 CALL 011 CALL 012 CALL 014 CALL 015 CALL 016 CALL 017 CALL 018 CALL 019 CALL 010 CALL 011 CJ+CLD+CLL 011 L2+2+ML-2 001. CHU/+LG+L++KQ2 001. CHU/+LG+L++KQ2 001. CHU/+LG+L++KQ2 001. CALL 011 CALL 021 CALL 0317 CALL 0318 C1+CHPLX(1k+L1) 0319 C1+C+PPAL(CFX) 0320 TA+PPAL(CFX) 0321 T1+AINAG(CFX) 0071 T1+AINAG(CFX)	0201 022 0023 0023 0024	SLONCUTING FC TURTETY FCG COMPLY TANO.C CY41.+101.1		}
Open CVCrCV DJJ0 CALL USLSPILC.CVC.CJO) O010 CALL USLSPILC.CVC.CJO) O011 CJ2CCJ0CLI D112 L2-2241-2 O011 112+5LCALL2 O014 CSYSTWOTATT2 O015 CKU2+LALL2 O014 CSYSTWOTATT2 O015 CKU2+LALL4 O014 CT+CCXPLCV01 O015 CL1CAPLX(1K, L), *TKQ2 O014 CT+CCXPLX(1K, L) O015 CT+CCXPLX(1K, L) O019 CT+CAPLX(1K, L) O019 CT+CCXPLX(1K, L) O019 CT+CCXPLX(1K, L) O019 CT+CCXPLX(1K, L) O021 TI+ALMACLCFX O022 APTUAN	0201 033 0033 0094 0995	SLOACUTINE FO TUPITOTE FO COMPLY TAKO.C CY=1.+10.+1.1 CY2×CY++2	1721 12 24 24 27 27 27 27 27 2	}
JJJn CALL ISLSPICOVC,CJO) O010 CALL ISLSPICOVC,CJO) O011 CJ2CJN2CLI J12 L222AH-2 0011 L123FLCAT[12] J12 L23FLATCOVC 0011 CRU2+(R_1,L)+FKQ2 0014 CRU2+(R_1,L)+FKQ2 0015 CT+CEXPLCVC1 0017 CALL ANX(H,NJ,X,15,T]) 0018 CT+CEXPLC1ACTACTAC(LC.,L.)+TKOT*CV*CY1 0027 TR*PFALTCEX) 0071 T1+ATMAG(CFX) 0072 AFUAN	0201 0237 0003 0024 0205 0205	SLONC UT ENG FC TYPETCET FYG CONFLY TAXO.C CY=1:+10:+1:1 CY2-CY4+2 CV=TAXG+CSURT	1721 12 24 24 27 27 27 27 27 2	}
0010 CA(1) \s(\$v((1,CV),CJ)) 0011 CJ>C_JOC_J1 0011 CJ>C_JOC_J1 0011 112×6(CA(12)) 0011 112×6(CA(12)) 0011 CKU2×101.)*FK02 0014 CT×C(XP(CVQ2)) 0014 CT×C(XP(CVQ2)) 0015 CALLANCX(14XJ,X,16.T1) 0019 CT×C(XP(X))×C(14.T1) 0019 CT×C(SZ)×C(2)×C(14.T1) 0019 CT×C(SZ)×C(2)×C(14.T1) 0020 TX×FFAL(CFX) 0021 T1×AINAC(CFX) 0022 AUTUAN	0001 035 0003 0004 0005 0037	SLAUCUTINE FC TVATOLE FC CLARUN TAKO+C CY+1++10++1+1 CY2+CY++2 CV+TAKO+CSCRT CV1+CY	1721 12 24 24 27 27 27 27 27 2	}
0011 CJ2+CJ0+CJ1 011 1/2+CLAT(12) 011 1/2+CLAT(12) 011 YTK0T*TP 001+ CKU+(n.,1,+)+TKQ2 001+ CH+(C+Q2) 0017 CALL AUX(ML,NJ,X+16,T1) 0317 CALL AUX(TL,NJ,X+16,T1) 0317 TAPPALT(CFX) 0317 TI=AINAG(CFX) 0317 CALL AUX(TL,NJ,X+16,T1)	0001 0037 0003 0004 0005 0036 0036 0037 0037	SLAUCUTING FC TUPITICIT FCA CLANUN TAXA.C CY-1.+10.+1+1 CY2CY++2 CV-TAXCPCSUH CV10CY CV0CYCY	11111111111111111111111111111111111111	}
3112 12+2+A1-7 0011 11>+F1(A1(12) 0315 TKYTTKOT*TY 0014 CKU/+1G,+1,+*KQ2 0014 C1+CKP4(GV0/) 0317 CALL ANX(A1,AJ,X,1F,T1) 0318 C1+CKP4(GV0/) 0319 C1+CKP4(GV0/) 0317 CALL ANX(A1,AJ,X,1F,T1) 0318 C1+CKP4(CKA,1) 0319 C1+CKP4(CKA,1) 0320 TK*PFAL(CKR) 03021 T1+A1MAG(CFR) 03022 AFU9A	0101 013 003 003 003 003 003 003 003 003	SLAUCUTINE FC TWEITITT FOR CENEUS TAKO.C CY2LI.+10.11.1 CY2CY+2 CV-TAKO.CSUT CV1CY CVGCCY CALL ASLSPICO	11111111111111111111111111111111111111	
0011 11251(1A112) 3315 YKYTKQTATY 0011. Cre(txr(r07) 0014. Cre(txr(r07) 0317 CALL ANLX(1A, NJ, X, 16, T1) 0318 C1+CNPLX(1A, 1) 0319 C1+CNPLX(1A, 1) 0310 C1+CNPLX(1A, 1) 0317 CALL ANLX(1A, NJ, X, 16, T1) 0318 C1+CNPLX(1A, 1) 0320 TA+PFAL(CFX) 0031 T1+A1+AG(CFX) 0032 AFUAN	0301 037 003 0094 0995 0995 0937 0937 0937 0317 0319 0319	SLAUCUTINE FC TUPTTCTY TOTO CCMMUS TAKOS CY=12+10-31-3 CY2+CY+2 CV=TAKGeCSUN CV1+CV CVGTCV CALL ASLSMIC CALL ASLSMIC	11111111111111111111111111111111111111	}
3)15 Y # 3 Y * T # 0 Y & T # 001. C # (/ * + (f, *, 1, + * K / 2) 001. C # (/ * + (K / 2)) 001. C + (/ * + (K / 2)) 001. C + (/ * + (K / 2)) 001. C + (/ * + (K / 2)) 001.7 C + (/ * + (K / 2)) 001.7 C + (/ * + (K / 2)) 001.7 C + (/ * + (K / 2)) 001.7 C + (/ * + (K / 2)) 001.7 C + (/ * + (K / 2)) 002.7 T + (/ * (/ * (/ *))) 002.1 T + (/ * (/ * (/ *))) 002.2 A # U + (/ * (/ *))	0001 017 0003 00094 0005 00074 0005 0007 0007 0007 0010	SLOUCUTINE FC TUPITCT TOU CCMPLY TANOG CY=1+10.1.1 CY=CY=CY CV=FC CV=CY CV=CY CV=CY CV=CY CALL ASLSPIC CALL ASLSPIC CALL ASLSPIC CALL ASLSPIC	11111111111111111111111111111111111111	}
001: CKU(+(G,1,1)*KQ2 001: Cf+(f#)(<yq7)< td=""> 001: Cf+(f#)(<yq7)< td=""> 001: Cf+(f#)(×Q7) 001: Cf+(f#)(×Q7) 001: Cf+(f#)(×G7) 001: Cf+(f#)(×G7) 001: Cf+(f*) 002: TA*FFAL(Cf*) 007: T1+A1*AG(CF*) 007: AFU\$A</yq7)<></yq7)<>	0901 013 0003 0004 0405 0407 000 000	SLOUTUTINE FC TUPITCTI FC CENNUS TANDAG CENNUS TANDAG CV-TAKOC SQUT CV-TAKOC	1H(1, 1, 4, 1, 4, 1, 1, 1) 1 Y Y W(1) P Y I A (4 1, 6 4) 1 (1, - (Y 2) 5, CVG, CJO) 1, CV1, CJ1)	}
OolA Cf+CfXP(CYO/) Ool7 CALL AUX(MI, XJ, X, 1F, T1) Ool3 C1+CP(X, 1T, T1) Ool3 C1+CP(X, 1T, T1) Ool3 C1×CF+CJ2*C1+TA/(Cc, 1, 1)+TXOT+CV+CY) OO2 TX*PFAL(CFX) OO2 T1+A1YAC(CFX) OO2 AFUAN	0301 037 037 003 0495 0495 0495 0495 0495 0495 0495 0495 0495 0495 0495 0495 0495 041 041 041 041 041 041 041 041	SLOUCUTINE FC TVPTTCTT TCP CCPMUS TAXOG CY+1,+10,1+1 CY>CV+22 CV+42 CV+42 CVG7CV CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC	114 (4, 1, 4, 2, 14, 17, 17) 117 (4, 17) DEAL-2(17) 114 (7, 17) PY, 1 A, (41, 6A) (11, -(42) (11, -(42) (11, -(42) (11, -(4)) (11, -(4))	}
0317 CALL ANIX (MI, NJ, X, 16, T]) 0318 C1=CNP(X(1N, (1)) 0019 C1=C2D=C1=CAPTACTACTAC((C, 1),)=TKOT=CV=CY) 0027 TR=PPALTCCCY) 0021 T1=A1MAG(CFX) 0022 A=USAN	0001 0007 0007 0007 0007 0007 0007 0007	SLOUTUTING FC TUPITCTY FCG3 CCMMUN TAKOG CCMUN TAKOG CY41+40-11-1 CY242+40-11 CY242+40-12 CV174	110 (1 , 4), x, 10 , 11 11 11	}
0613 C1+rAPLX(1k,1) 0613 C1+rAPLX(1k,1) 0623 C1+rAPLX(CrX) 0623 TR+PFAL(CrX) 0623 TI+ALMAGLCFX) 0623 AFUAN	0301 017 003 0094 0995 0376 0376 0377 0377 0317 0317 0311 3112 0011 3112 0011	SLOW(UTING FC TUPITCT 700 CCMUS TAND,6 CY=1,+10,.1.1 CY>CY+2 CV=CY+2 CV=CY CVCCV CALL ASLSPIC CJ2CCDCCJ T22CCDCCJ T22CCDCCJ T22CCDCCJ T22CCRCCJ CXU2(CALL) CU2CCC CXU2(CALL) CU2CCC CXU2(CALL)	1H(1H), 4, 7, 7H, 7 1 Y Y Y (() , D EAT= 4 (Y) HU X (Y O T A, (X), CA) (((((((((((((((((((
001-> Cfx+Cf+CJ2+C1+TA+TA/({C+1}-)+TXOT+CV+CY) 1027 TR+PFA((CfX) 0071 T1+A14AC(CFX) 0072 AFYUAN	0001 017 003 0094 0095 0037 0101 0101 0101 011 011 011 0014	SLOWINTING FC TUPITCTY FCG1 CCMMUN TAKOG CCMUN TAKOG CV=1,+(0,-1,-1) CV>2,+(0,-1) CV>2,+(0,-1) CV=2,+(0,-1) CV=2,+(0,-1) CV=2,+(0,-1) CV=2,+(0,-1) CKU2+(0,-1,-1) CH-(2,+(0,-1))	110 (x , 4), x , TP , T 17 Y + 0 (C :) PEAI= C (Y 17 Y + 0 , (x , 0 EAI= C (Y 10 ((Y 2)) (((Y 2)) (. ((Y 2)) (. ((Y 2)) . (. (. ((Y 2))) . (. (. (. ((Y 2)))) . (. (. (. (. (. (. (. (. (. (
1027 TREPALICEX) 0071 TIEAINAG(CEX) 0022 AFUAN	0901 017 007 007 007 007 007 007 0	SLOUGUTING FC TUPITCTT FCG3 CENWUN TAKO,G CY41,440.11.3 CY242,440.11.3 CY242,40.11 CY242,4	1H(1, 1, 4, 1, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7,	
0071 TI=A (NAG(CFX) 0022 AFTUAN	0301 0301 037 0403 04094 0405 0407 0407 0407 0407 0407 0417 0417 0417 041 041 041 041 041 041 041 041	SINUTUTING TC TUPITCTT TANDAC CUMUN TANDAC CY=1+4(0.11) CY=2+(0.11) CY=2+(0.11) CY=2+(0.11) CY=2+(0.11) CY=2+(0.11) T2>+(10+(10)) CX(10) CX	114 (+ , + 4), x T + T 117 (+ 1, + 2), T + T 117 (+ 1, + 2), T + 2) 114 (+ 1, + 2) 114 (+ 1, + 1), + 1) 114 (+ 1, + 1), + 1) 115 (+ 1, + 1), + 1) 115 (+ 1, + 1), + 1) 116 (+ 1, + 1), + 1) 117 (+ 1, + 1), + 1) 118 (+ 1, + 1), + 1) 119 (+ 1, + 1), + 1)	(1, <u>1</u> H,T, <u>1</u> ¥0 <u>T</u> , <u>1</u> K0,1P5
OUSS SELECTION	001 011 013 003	SLOWIUTING FC TUPITCTY FCG CUPALY TAKO,G CUPALY TAKO,G CV41,410,11,1 CV2CY+2 CV1CCC CV1CCC CV1CCC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CALL ASLSPICC CI-CEXPICCOPT CALL ANIXINI,S CI-CEXPICCOPT CALL ANIXINI,S CI-CEXPICCOPT CALL ANIXINI,S CI-CEXPICCOPT	114 (+ , + 4), x T + T 117 (+ 1, + 2), T + T 117 (+ 1, + 2), T + 2) 114 (+ 1, + 2) 114 (+ 1, + 1), + 1) 114 (+ 1, + 1), + 1) 115 (+ 1, + 1), + 1) 115 (+ 1, + 1), + 1) 116 (+ 1, + 1), + 1) 117 (+ 1, + 1), + 1) 118 (+ 1, + 1), + 1) 119 (+ 1, + 1), + 1)	(1, <u>1</u> H,T, <u>1</u> ¥0 <u>T</u> , <u>1</u> K0,1P5
	0901 017 003 0094 0995 0317 0014 0995 0317 0014 0317 0317 0319 0311 0317 0317 0317 0317 0317 0317 0317 0317 0317	SLOW(UTINE FC TUPITCT 7(0) CCPW() TAXO,G (Y=1,+40,.1.) CY>CY+2; CV=CY+2; CV=CY+2; CV=CY CVCCV CALL ASLSPIC CL2;2FR) TX:7TR)TETTT TX:7TR)TETTT CL2;CR(C) CALL ASLSPIC CL2;CR(C) CALL ASLSPIC CL2;CR(C) CL2;	TH[(H], 4, 4, 7, 74, 74, 71 TY+V((), 9, 24 = 4(Y) HU4, 19Y, 17, (41, 64) (11, - (Y2) (11, -	(1, <u>1</u> H,T, <u>1</u> ¥0 <u>T</u> , <u>1</u> K0,1P5
۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲۶۵۵ (۲	0001 017 0003 00094 00094 00095 00074 0007 0017 0017 0011 0011 0011 0011 0014 0013 0017 0007 000	SLOWFUTING FC TUPITCTY FCG1 CUMUN TAKOG CUMUN TAKOG CUMUN TAKOG CUMUN TAKOG CUMUN CUMU	TH[(H], 4, 4, 7, 74, 74, 71 TY+V((), 9, 24 = 4(Y) HU4, 19Y, 17, (41, 64) (11, - (Y2) (11, -	(1, <u>1</u> H,T, <u>1</u> ¥0 <u>T</u> , <u>1</u> K0,1P5
	0001 017 0003 0004 0005 0007 0007 0007 0007 0017 0011 0011	SLOWIUTING FC TUPITCTT FCM CCMMUS TAKO,G CY41,440.11.1 CY2CY42 CV4TCY CVGTCY CVGTCY CVGTCY CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICT CKU2+CALL CL2CAMPALTCTST TROPAUTCTST TIANMAGICEXI AETUBN	TH[(H], 4, 4, 7, 74, 74, 71 TY+V((), 9, 24 = 4(Y) HU4, 19Y, 17, (41, 64) (11, - (Y2) (11, -	(1, <u>1</u> H,T, <u>1</u> ¥0 <u>T</u> , <u>1</u> K0,1P5
	0901 017 003 0094 0095 0037 0037 0037 0037 004 004 004 004 004 004 004 00	SLOWIUTING FC TUPITCTT FCM CCMMUS TAKO,G CY41,440.11.1 CY2CY42 CV4TCY CVGTCY CVGTCY CVGTCY CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICC CALL ASLSMICT CKU2+CALL CL2CAMPALTCTST TROPAUTCTST TIANMAGICEXI AETUBN	TH[(H], 4, 4, 7, 74, 74, 71 TY+V((), 9, 24 = 4(Y) HU4, 19Y, 17, (41, 64) (11, - (Y2) (11, -	(1, <u>1</u> H,T, <u>1</u> K0 <u>T</u> , <u>1K</u> 0,1PS

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	-100-	FROM COPY FU	RNISHED TO	DDC	
ORTRAN IV G. LEVEL	21	FCTK2		CATE -	75205
0001	SUSFOUTINE FOTK2()	MI,*J,X,TF,T	[]		
	ĨĨŴ₽ĽĨĊĨŦĨĊŨŴ₽ĽĔXĬ¥Ĩ				
0003	GORDEN TAKO+CHUR+	TPY, TA, CK1, C	AK1,TH,T	,TKOT,T	KO, IPS
0004	CY=1.+{0.,1.}*(X/)	TKOTI			
0005	CY2=CY#*2				
0.006	CV=TAKO CSCRT(1(CY2)			
0007	CV1=CV				
0004	CV0=CV				
0004	CALL BSESME (0, CVC	(JO)			
0010	CALL BSLSMELLI,CV1	,CJ1)			
0011	C15=C10*C11		_	_	
0012	12=2**1-2			-	
0013	TI2=FLCAT(12)				
0014	TK07=TK0T*T12				
0015	CK0Z=(0.,1.)*TK0Z				
0016	CF=CEXP(CKOZ)				
	CALL AUX(MI,MJ,X,	TR, T1)			
	C1=CMPLX(TR,TI)				
	CFX=-CF*CJ2*CV*C1	*4./(TA*TKOT	*CY)		
0050	TR=R[AL(CFX)				
	TI = AIMAG(CFX)			· · · · · · · · · · · · · · · · · · ·	· · · · · · ·
	RFTURN END				
······································	- 1990,000, vê			·····	
0002	21 SUPRCUTINE FCTP2(1 TPPLICIT CCMPLIX) CC1PCN TAKO,CMUR,	B(C) #BEAC#4(Y)		(XO.1PS
	CY=1.+(0.,1.)+(X/				
	CY2uCYn62				
	CV=1AKO*CSCKT(1	CY2)		• • ••	
0001	CALL BSLSHLIL, CV.				
	712=(11==)				
0009	12=2*91-2			. .	
0910	112=11LCAT(12)		-		
0011	TF07=TF01+112				
	CK07=(0.,1.)*TK07				
	CI = CEXP(CKOZ)				
	CALL AUX("), VJ.X,	18,17)			
0015	C1=CHO(X(TR,TI)				
0016	C_X==4*616*C75*C1	/(TKAI+CY)			
1001	TP=PiAl(C"X)				
0018	T[=ALMAG(CEX)				
0017	RETURN				
2222	EKU				

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	-101	FROM COPY FURNISHE	
FORTRAN IV G LEVEL	21	DECOMP	DATE = 75195
0001		ECOMP(NN, A, UL)	
0002		LES(35), IPS(35)	<u> </u>
0003		35),UL(35,35),PIVOT	5 M
0004			164
0005	COMMON TAKO,1 N=NN	PT+ (KU1+1P5	
	N = N N		
C C	INITIALIZE IF	SUL AND SCALES	
0006	00 5 1=1.N		
0007	1PS(1)=1		
0008	ROWNRM=0.0		
0009	00 2 J=1		
	UL(1,J)=		
0011		S(UL(1,J)) 1,2,2	
0012 1	ROWNRM= CABS		
0013 2			
0013 2	IF (ROWNRM) 3	A 3	
	SCALES(I)=1.0	V KUMNKA	· ·
0016			
0017 4	CALL SING(1)		
0018	SCALES(I)=0.0)	
	CONTINUE		
c			
C		INATION WITH PARTIA	LPIVOTING
0020	NM1=N-1		
0021	00 17 K=1.N	IM 1	
0022	BIG=0.0		
0023	00 11 1=K+N	1	
0024	1P=1PS(1)	-	
0025	SIZE= CABSIUL	(IP,K))*SCALES(IP)	
0026	IF(SIZE-BIG)		
0027 10	BIG=STZF		
0028	INXPIVel		
0029 11	CONTINUE		
0030	1F(816) 13.12	•13	AND DAYS IN THE OWNER OF A DAY
0031 12		And a second sec	
0032	GO TO 17	The second	
0033 13		14,15,14	
0034 14	J=1PS(K)	- Paid Paral Address	
0035	1PS(K)=1PS(10	XPIVI	A CARACTERISTIC AND A CARACTERISTIC CO
0036	IPS(IDXPIV)».		A CONTRACT OF A DECEMBER OF THE SECOND CONTRACT OF
	KP = [PS(K)		
003A	PIVOT UL (KP+K		Notation - The second case was an ended to second a second second
		. 7	
0039	KP1=K+1	A1	
0040	00 16 1 = KP1	14	
0041	1P=1PS(1)		The contract commence of a second state
0042	EM=-UL(IP,K)/	141401	•
0043	UL(IP,K)=-EM	بست منت بتهاي	
0044	DO 16 J=KP)		
0045		P,J)+EM*UL(KP,J)	
	INNER LOOP.	,	
0046 16	CONTINUE		• • • • • • • • • • • • • • • • • • •
0047 17	CONTINUE	•	
0048	KP=1PS(N)	,	
0049		(NI))_19,18119	
0050 18			
0051 19	RETURN	,	
	END		

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		-	-102-	THROW COL	Y FURNISH	ED TO DDC
FORTRAN LV C	G LEVEL	21		SOL VĘ		DATE = 75195
_0001		_SUBROUTINE .S		.uL.9.)	0	
0002		DIMENSION IF				
0003		COMPLEX UL (1351.81	351.504	
0004		COMMON TAKO			3777301	· · - · · · ·
			1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 -	11-2		
0005		N=NN			-	
0006	с	NP1= N+1				
0007	_ <u>`</u>	1P=1PS(1)				
8000		X(1) = B(IP)				
0009		00 2 1=2,N		• •		
0010		IP = iPS(1)				
0011		IM1=1-1		-		· · ·
		_SUM=(00.)				
0013		00 1 J=1,1				
0014	1	SUM=SUM+UL(1		11		
0015	2	X(I) = B(IP) - S	NUM .			
	С					
0016		(P=IPS(N))				
0017		X(N) = X(N) / U	L (TP .N)			
0018		DO 4 TBACK				
0019		I=NP1-184CK		•		
0019	C I		,			
00.20	C I	GCES (N-1),				
0020		IP = IPS(I)				
0021		191=1+1				
_0025		S'JM=(0.,0.)				
0023		00 3 J=191	. 31			
0024	3	SUM=SUM+UL (•	(J)		
0024 0025		SUM=SUM+UL(X(I)=(X(I)-S	1P,J)*X(
		X(I) = (X(I) - S	1P,J)*X(
0025			1P,J)*X(
0025 00 26	4	X(1)=(X(1)-S RFTURN	1P,J)*X(DAYE = 75195
0025 0026 0027	4 LEVFL	X (I) = (X (I) - S R ← TURN END 21	Î₽,J)*X(JUM}/UL(I	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G	4 LEVFL	X(I)=(X(I)-S RFTURN END 21 FUNCTION ANG	Ì₽,J)*X(UM)/UL(] UE(X, <u>Y)</u>	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001	4 LEVFL	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295	1P,J)*X(UM)/UL(1 LE(X, <u>Y)</u> 77951	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003	4 LEVFL	X(I)=(X(I)-S RFTURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)		DAYE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004	4 LEVFL 500	X(I)=(X(I)-S RFTURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550.500 IF(Y) 350.30	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0005	4 LEVFL 500	X(I)=(X(I)-S RFTURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550.500 (F(Y) 350.30 ANGLE =0.0	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)		DAYE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0005 0006	4 LEVFL 500 300	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 IF(Y) 350,30 ANGLE =0.0 RETURN	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)	,	DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0005 0006 0006	4 LEVFL 500 300	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.265 IF(X)550.500 (F(Y) 350.30 ANGLE=0.0 RETURN ANGLE=270.C	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)		DAYE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004	4 500 300 340	X(I)=(X(I)-S RFTURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550.500 (F(Y) 350.30 ANGLF=0.0 RFTURN ANGLF=270.0 RFTURN	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0005 0004 0005 0006 0006	4 500 300 340	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT*57.295 IF(X)550.500 (F(Y) 350.30 ANGLE*0.0 RETURN ANGLE*270.0 RETURN ANGLE*270.0	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004	4 500 300 350 250	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT*57.295 IF(X)550.500 IF(Y) 350.30 ANGLE = 0.0 RETURN ANGLE = 270.0 RITURN ANGLE = 270.0 RITURN ANGLE = 0.0 RETURN	LE(X,Y) 77951 +450 0+250	(P+[)		DAYE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004	4 500 300 350 250	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT*57.295 IF(X)550.500 IF(Y) 350.30 ANGLE = 0.0 RETURN ANGLE = 270.0 RITURN ANGLE = 270.0 RITURN ANGLE = 0.0 RETURN	LE(X,Y) 77951 +450 0+250	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004	4 5 LEVFL 500 300 350 250 450	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT*57.295 IF(X)550.500 (F(Y) 350.30 ANGLE*0.0 RETURN ANGLE*270.0 RETURN ANGLE*270.0	LE(X,Y) 77951 +450 0+250	(P+[)		DATE = 75195
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004	4 5 LEVFL 500 300 350 250 450	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.265 IF(X)550.500 (F(Y) 350.30 ANGLE=0.0 RETURN ANGLE=270.0 RETURN ANGLE=270.0 RETURN IF(Y) 455.45	LE(X,Y) 77951 +450 0+250	(P+[)		· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0005 0004 0005 0004 0005 0004 0005 0004 0005 0001 0001 0001 0001 0001 0001 0002 0001 0002 0001 0002 0001 0002 0001 0002 0001 0002 0000 0000 0000 0000 0000 0000	4 5 LEVFL 500 300 350 250 250 450	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.C RETURN ANGLF=0.0 RETURN IF(Y) 455,45 ANGLF=0.0 FETURN	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450 0,250	(P+T) ANGLE		DATE = 75195
0025 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0001 0010 0010 0010 0010 0010 002 002	4 5 LEVFL 500 300 350 250 250 450	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 IF(Y) 350,30 ANGLE=0.0 RETURN ANGLE=270.C RETURN ANGLE=270.C RETURN IF(Y) 455,45 ANGLE=0.0 FETURN ANGLE=COEFTM	1P.J)*X(UM)/UL(1 LE(X,Y) 77951 ,450 0,250	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0001 0004 0001 0004 0001 0004 0005 0004 0004 0005 0004 0005 0001 0004 0005 0001 0005 0001 0005 0001 0015 0011 0015	4 500 300 350 250 450 454	$ \begin{array}{c} x (1) = (x(1) - s \\ R \in TURN \\ END \\ \hline \\ 21 \\ FUNCTION ANG \\ COEFT = 57.255 \\ IF (x) 550.500 \\ IF (x) 550.500 \\ IF (x) 550.30 \\ ANG I = 0.0 \\ RI TUPN \\ ANG I = 0.0 \\ RI TUPN \\ ANG I = 0.0 \\ RI TUPN \\ ANG I = 0.0 \\ RF TUPN \\ IF (y) 455.45 \\ ANG I = 0.0 \\ FT TIRN \\ ANG I = 0.0 \\ FT TIRN \\ RF TURN \\ \end{array} $	1 P.J) + X (UM) / UL (1 77951 ,450 0,250 4,453 4,453	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0005 0004 0005 0004 0005 0004 0005 0010 0011 0012 0015 0016	4 500 300 350 250 450 454	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.0 RETURN IF(Y) 455,45 ANGLF=0.0 FETURN ANGLF=COEFT RETURN	1 P.J) + X (UM) / UL (1 77951 ,450 0,250 4,453 4,453	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0011 0012 0015 0014 0015 0015 0015 0015 0015 0017 0017 0015 0017 0017 0017 0017 0015 0017 0017 0017 0017 0017 0015 0017 0017 0017 0017 0017 0015 0017 0016 0017 0017 0016 0017 0017 0016 0017 0017 0016 0017 0007 0007 0007 0007 0007 0007 0000	4 5 LEVFL 300 300 250 450 454 453 455	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT*57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.C RETURN IF(Y) 455,45 ANGLF=0.0 FETIRN ANGLF=COFFT ANGLF=COFFT ANGLF=COFFT HETURN	1 P.J) + X (UM) / UL (1 77951 ,450 0,250 4,453 4,453	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0027 FORTRAN IV G 0001 0002 0003 0004 0001 0012 0012 0014 0012 0014 0015 0014 0015 0014 0015 0014 0015 0014 0015 0014 0015 0014 0015 0014 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0015 0016 0017 0018 0015 0016 0017 0018 0015 0016 0017 0018 0016 0017 0018 0016 0017 0018 0016 0017 0018 0016 0017 0018 0016 0017 0018 0018 0017 0018 0018 0017 0018	4 5 LEVFL 300 300 250 450 454 453 455	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGIF=0.0 RETURN ANGIF=0.0 RETURN ANGIF=0.0 RETURN IF(Y) 455,45 ANGIF=0.0 PETURN ANGLE=0.0 FETURN ANGLE=COEFT RETURN ANGLE=COEFT RETURN ANGLE=COEFT RETURN ANGLE=COEFT RETURN	1P.J)*X(UM)/UL(1 77951 ,450 0,250 4,453 4,453 4,453 4,453	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004 0004 0004 0015 0016 0017 0019 0019	4 500 300 350 250 451 454 453 455 550	$ \begin{array}{c} x (1) = (x(1) - s \\ R \in TURN \\ END \\ \hline \\ 21 \\ FUNCTION ANG \\ COEFT = 57.255 \\ F(x) 550,500 \\ (F(Y) 350,30) \\ ANGLE = 0.0 \\ RETURN \\ ANGLE = 270.0 \\ RETURN \\ ANGLE = 270.0 \\ RETURN \\ ANGLE = 0.0 \\ PT TIRN \\ ANGLE = $	1P.J)*X(UM)/UL(1 77951 ,450 0,250 4,453 4,453 4,453 4,453	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0005 0004 0005 0004 0005 0004 0005 0010 0011 0012 0015 0016 0017 0018 0019 0020	4 500 300 350 250 451 454 453 455 550	X(1)=(X(1)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.0 RETURN ANGLF=0.0 PETURN IF(Y) 455,45 ANGLF=COEFT RETURN ANGLF=-COEFT RETURN ANGLF=-COEFT RETURN XN=-X IF(Y)554,553	1P.J)*X(UM)/UL(1 77951 ,450 0,250 4,453 4,453 4,453 4,453	(P+T) ANGLE		· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0015 0014 0015 0014 0015 0016 0019 0020 0020 0021	4 5 LEVFL 300 350 250 450 453 455 550 553	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.C RETURN ANGLF=0.0 RETURN ANGLF=0.0 PETURN ANGLF=COFFT ANGLF=COFFT ANGLF=COFFT HETURN XN=-X IF(Y)554,553 ANGLF=180.0 RETURN	1 P.J)*X(UM)/UL(1 77951 ,450 0.250 4,453 ΔΤΛΝ(Υ/X •ΛΤΔΝ(-Y ,552	(P+T) ANGLE) /X)+36	0.0	· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0005 0004 0005 0004 0005 0004 0005 0010 0011 0012 0015 0016 0017 0018 0019 0020	4 5 LEVFL 300 350 250 450 453 455 550 553	X(1)=(X(1)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.0 RETURN ANGLF=0.0 PETURN IF(Y) 455,45 ANGLF=COEFT RETURN ANGLF=-COEFT RETURN ANGLF=-COEFT RETURN XN=-X IF(Y)554,553	1 P.J)*X(UM)/UL(1 77951 ,450 0.250 4,453 ΔΤΛΝ(Υ/X •ΛΤΔΝ(-Y ,552	(P+T) ANGLE) /X)+36	0.0	· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0004 0004 0004 0004 0004 0004 0004 0004 0004 0015 0014 0015 0014 0015 0016 0019 0020 0020 0021	4 5 LEVFL 300 350 250 450 453 455 550 553	X(I)=(X(I)-S RETURN END 21 FUNCTION ANG COEFT=57.295 IF(X)550,500 (F(Y) 350,30 ANGLF=0.0 RETURN ANGLF=270.C RETURN ANGLF=0.0 RETURN ANGLF=0.0 PETURN ANGLF=COFFT ANGLF=COFFT ANGLF=COFFT HETURN XN=-X IF(Y)554,553 ANGLF=180.0 RETURN	1 P.J)*X(UM)/UL(1 77951 ,450 0.250 4,453 ΔΤΛΝ(Υ/X •ΛΤΔΝ(-Y ,552	(P+T) ANGLE) /X)+36	0.0	· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FORTRAN IV G 0001 0002 0003 0004 0011 0015 0016 0017 0018 0020 0020 0020 0012 0022 0020	4 5 LEVFL 500 300 350 250 455 455 550 553 552	$ \begin{array}{c} x (1) = (x(1) - s \\ R \in TURN \\ END \\ \hline \\ 21 \\ \hline \\ FUNCTION ANG \\ COEFT = 57, 295 \\ IF (x) 550, 500 \\ (F(Y) 350, 30 \\ ANG \\ IF (x) 550, 500 \\ (F(Y) 350, 30 \\ ANG \\ IF (x) 550, 500 \\ (F(Y) 350, 30 \\ ANG \\ IF (y) 455, 45 \\ ANG \\ IF (y) 554, 553 \\ ANG \\ IF = 180, 0 \\ RETURN \\ ANG \\ IF = 180, 0 \\ RETURN \\ \end{array} $	TP,J)+X(UM)/UL(T 77951 ,450 0,250 4,453 ΔΤΛΝ(Υ/X •ΛΤΔΝ(-Y ,552 COFFT• ΔΤ	ANGLE /X) +36 AN (Y/X)	0.0 	· · · · · · · · · · · · · · · · · · ·
0025 0026 0027 FOR TRAN IV G 0001 0002 0003 0004 0005 0004 0005 0004 0005 0010 0010 0011 0012 0013 0014 0015 0016 0015 0016 0015 0016 0017 0018 0019 0020 0021 0022 0023	4 5 LEVFL 300 350 250 450 453 455 550 553 552 554	$ \begin{array}{c} x (1) = (x(1) - s \\ R \in TURN \\ END \\ \hline \\ 21 \\ \hline \\ FUNCTION ANG \\ COEFT = 57.295 \\ F(x) 550,500 \\ COEFT = 57.295 \\ F(x) 550,500 \\ If(y) 350,300 \\ ANGIF = 0.0 \\ RF TURN \\ ANGIF = 0.0 \\ RF TURN \\ ANGIF = 0.0 \\ RF TURN \\ If(y) 455,45 \\ ANGIF = 0.0 \\ FT TIRN \\ ANGUF = COFFT \\ RF TURN \\ ANGUF = COFFT \\ RF TURN \\ XN = - X \\ If(y) 554,553 \\ ANGIF = 180.0 \\ RF TURN \\ ANGIF = 180.0 \\ H \\ H \\ SN = 180.0 \\$	TP,J)+X(UM)/UL(T 77951 ,450 0,250 4,453 ΔΤΛΝ(Υ/X •ΛΤΔΝ(-Y ,552 COFFT• ΔΤ	ANGLE /X) +36 AN (Y/X)	0.0 	

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FOR TRAN	1 <u>v</u> _ G	LEVEL	21		IMPRUV		DATE =	75195	
_0001				PRUV (NN	A.UL B.X.C	IGITS			
0002			CUMMON TAKO,T						
0003			COMPLEX A(35,).X(35).R(35)	DX(35).	ĩ
0004			COMPLEX*16 S					· · · · · · · · · · · · · · · · · · ·	
		c us			G10()				
0005		•	N=NN						
0005		r	14 m (4)4						
0006		<u> </u>	EPS=1.0E-8						
0000			ITMAX=16						
		с · .	#EPS AND ITMAX		CHINE DEDEN	OCAIT			
		-	*CF2 AND TIMEY	. АКС МА	CHINE DEPEN	UENI +			
~ ~ ~ ~ ~	-	C .							
0008			XNORM=0.0						
0009			DO 1 I=1.N				·····	·····	
0010		1	XNORM-AMAX1 (X		BS(X(I))				
0011			IF(XNORM) 3,		•••••• ••••				
0012		2	DIGITS = -ALC	GIOLEPS)			-	
0013			GO TO 10						
		с							
0014		•	DO 9 ITER=1,	TTMAX					
0015		<u> </u>	DO 5 1=1+N						
0016			SUM=0.0						
0017	• • •		00 4 J=1.N					•• •	
			UU 4 J≡I•N AIJ=A(I•J)						
_0018 .				· · · -				-	
0019			XJ=X(J)						
0020	• · · · · · ·	4	SUH=SUH+AIJ *X	J					
0021			SUM=B(I)-SUM						
0022			R(1)=SUM	-					
	-	C **	IT IS ESSENTIA	L THAT	$A(I_{J}) * X(J)$	YIELD	A DOUBL	E PRECI	SION
		Ç	RESULT AND THA	T THE A	BOVE + AND	- 8E 0	OUBLE_PF	RECISION	.**
			CALL SOLVEIN	I.UL.R.D	X)				
0023					•				
			DXNORM=0.0						
0023 _0024 _0025	<u>.</u>		DXNORM=0.0						
0024	<u> </u>	147 <u></u>	D() 6 1=1+N						
0024 0025 0026			D() 6 [=1+N T=X(1)			·····			
0024 0025 0026 0027			D() 6 [=1+N T=X(1) X(1)=X(1) +P	((1)	****				
0024 0025 0026 0027 0028		······································	D() 6 [=1,N T=X(]) X(])=X(]) +C> DXNORM=AMAX1(((1)	CA,85 (X (, [).:			······	
0024 0025 0026 0027 0028 0028 0029		6	D() 6 [=1,N T=X(I) X(I)=X(I) +() DXNORM=AMAXI(CONTINUE	((1) DXNORN,	CA85(X(().	 		1.220,1120,120,120,200,1	
0024 0025 0026 0027 0028 0028 0029 0030			D() 6 [=1,N T=X(I) X(I)=X(I) +C) DXNORM=AMAXI(CONTINUE LE(ITER=1) 81	((1) (DXNORN,					
0024 0025 0026 0027 0028 0029 0030 0031		7	D() 6 [=1,N T=X(1) X(1)=X(1) +(?) DXNORM=AMAX1(CONTINUE LF(1TER=1)_E1 DIGITS=-ALOG	((1) (DXNORM, 7,8 ()(444X	L (DXNORM/X)	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032			D() 6 [=1,N T=X(]) X(])=X(]) + (?) DXNORM=AMAX1(CONTINUE (TTER=1) & 1 D [G]TS=-ALOC IF (DXNORM=E PS	((1) (DXNORM, 7,8 ()(444X	L (DXNORM/X)	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031		7 8 9	D() 6 [=1,N T=X(I) X(I)=X(I) + () DXNORM=AMAXI(CONTINUE LE(ITER=1) 41 DIGITS=-ALOC IF(DXNORM=EPS CONTINUE	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032		7 8 9	D() 6 [=1,N T=X(]) X(])=X(]) + (?) DXNORM=AMAX1(CONTINUE (TTER=1) & 1 D [G]TS=-ALOC IF (DXNORM=E PS	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032		7 8 9	D() 6 [=1,N T=X(I) X(I)=X(I) + () DXNORM=AMAXI(CONTINUE LE(ITER=1) 41 DIGITS=-ALOC IF(DXNORM=EPS CONTINUE	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0030 0030 0031 0032 0033		7 8 9 C 1	D() 6 [=1,N T=X(I) X(I)=X(I) + () DXNORM=AMAX1(CONTINUE IF(ITER-1) 4 DIGITS=-ALOC IF(DXNORM-EPS CONTINUE TERATION OID 5 CALL SING(3)	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0030 0030 0031 0032 0033		7 8 9 C 1	D() 6 [=1,N T=X(I) X(I)=X(I) + (P) DXNORM=AMAX1(CONTINUE IF(ITER-1) 4 DIGITS=-ALOC IF(DXNORM-EPS CONTINUE TERATION OID 5 CALL SING(3)	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		*****
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		*****
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035	-	7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		*****
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		*****
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		
0024 0025 0026 0027 0028 0029 0030 0031 0032 0033 0034 0035		7 8 9 C 1	D() 6 [=1,N T=X(1) X(1)=X(1) + () DXNORM=AMAX1(CONTINUE LF(ITER-1) 8, DIGITS=-ALOC IF(DXNORM-FES CONTINUE TERATION OID 5 CALL SING(3) RETURN	((1) (DXNORM , (DXNORM , (DXNORM) (DXNORM)	10,10,9	IORM, EP	511		

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		FROM COPY FULLYSSIE
1		SUBROUTINE SERIES (MINHLOR)
5		IMPLICIT COMPLEXAS(C), PEAL #4(T)
3		
4		COMMON TAKO, CMUR, TPY, TA, CKS, CAKS, TH, T, TKOT, TKO, IPS
5		
67		TJ1=FLOAT (MJ) +21.
8		TJ3=FLOAT(MJ)N23. K=2
จั		CSUM(K-1)=(0,,0,)
10		CCON=-4./(TPY=CMUR)
11		TN=0.
12	5	TP+ (TN++5) *(TPY/TH)
:3		CS=1((TP/CK1)**2)
14		CZ=CAK1+CSQRT(CS)
15		CZ1=CZ
16		C20=C2
17 18		CALL BSLSML (DICZO, CJO)
19		CALL BSL SML (1, CZ1, CJ1)
20		
		COEF T= (C JOYCZ/CJ1) - TAP-0.5 TC1=COS(2.XTP+1XT11)
55 52		TC2=C65(2.+TKOT+T 11)
23		TS1=STN(TPT+TJL)
24		TS2=SIN(TPT+TJ3)
52		TDR= (TN+0.5) + (TAKO*+2-TAP*+2)
26		1F=((TC1-TC2)*(TS1-TS2))/TOR
-		CSUM(K) + CSUM(K-1) + COEFT + TF
26		TI=CABS((SUM(K))
29		T2+CA35 (CSUM(K-1))
30		ERR*ABS ((T1-T2) / T1)
21 32		1F (ERR.LE.1.E-03) GO TO 20
33		K=K+1
36		TN_2TN_{11} TE (X.(E.26) CD TD (C
35		TF (K.(E.26) GO TO 15
36	16	HATTE (SIL6) FORMAT (SX, 'ERROR CRITERION UNSATISFIED IN 25 TERMS', //) CB-(0-,0-)
37		CB: (D: O.)
38		RETURN
30	15	60 ° O 5
40	20	CB=CCON+CSUM(L)
41		KE TORN
42		end
1.		SUBROUTING AUX(NEIMJIXITRITI)
2		INVLICIT COMPLEX. B(C), REAL eA(T)
23		
4		COMMEN TAKO, CMW2, TPY, TA, CK1, CAK1, TH, T, TKOT, TKO, IPS
5		11:2:1MJ-1
		J1=2 +MJ=1 TJ5 +FLOAT (J1)
6		J3+24MJ-1 TJ3+FLQAT(J1) J3+72MJ-3
6 7		J1:2:4MJ-1 TJ3:FEQAT(J1) J3:2IMJ-3 TJ3:FEQAT(J3)
67 2		J1:2440-1 TJ3:FLOAT(J1) J3:2410-3 TJ3:FLOAT(J3) CK072(0:11):A1K0T
6 7 8 5		J1 = 2 + MJ - 1 T3 + FLOAT (J1) J3 = 2 + MJ - 3 TJ3 = FLOAT (J3) CKOT = {O - , 1 + } = 1 KOT ML J8 + C + MJ + 2 AMJ - 6
67 8 5 10		J1 + 2 + MJ - 1 TJ3 + FLOAT (J1) J3 + 2 + MJ + 3 TJ3 = FLGAT (J3) CKOT = (D - 1 + 1 + A + KOT MI J3 + 2 + MI + 2 A + J - 6 TK3 + FLOAT (MI J4)
6 7 8 9 10 11		J1 E 2 4 M J - 1 T J3 + FLOAT (J1) J3 + 2 H J - 3 T J3 = FLOAT (J3) C KOT 2 (D, J1,) + T KOT MI J3 + C + MI + 2 A M J - 6 T E 1 + FLOAT (MI J4) J + MI - H J
67 8 5 10		J1 + 2 + MJ - 1 TJ3 + FLOAT (J1) J3 + 2 + MJ + 3 TJ3 = FLGAT (J3) CKOT = (D - 1 + 1 + A + KOT MI J3 + 2 + MI + 2 A + J - 6 TK3 + FLOAT (MI J4)
6 7 8 9 10 11 12		J1 = 2 = 4 M J = 1 T J = F = F (A T (J J) J3 = 2 = M J = 3 T J = J = F (A T (J J) C K O T = (0, T , 1, -) = T K O T M J =
6 7 8 10 11 12 13 14 15		J1:2440-1 TJ3:F(GAT(JJ) J3:240-3 CHOT2(D,1:)+TKOT MLJ4:C+M1;2240J-6 TL3:F(GAT(AJ)24) JJ-HT-HJ TL2:CAT(J)24 TL2:CAT(J)24 TL2:CAT(J)26 TL2:CAT(J)26 CT2:CAT(J)26 TL2:CAT(J)26 CT2:CAT(J)26
6 7 8 10 11 12 13 14 15 16		J1 E 2 4 M J - 1 T J3 + FLOAT (J1) J3 + 2 + M J - 3 T J3 = FLOAT (J3) C M O 7 2 (D - 1.1) + T K O T M L J3 + 2 + M J + 2 A M J - 6 T E 1 + FLOAT (J - 4) T J - FLOAT (M J - 4) T J - FLOAT (M J - 4) T 2 - A M J - 6 T E 3 - FLOAT (M J - 6) T E 3 - FLOAT (M J - 6 T E 3 - FLOAT (M J -
67 39 10 11 12 13 15 15 15 17		J1 = 2 + M J - 1 T J = FLOAT (J J) J3 + 2 + M J - 3 T J 3 = FLOAT (J J) CKOT 7 (D - 1 +) A TKOT ML J = + - M T J - FLOAT (ML J = -) T J - FLOAT (ML J =
67890112345678		J1 = 2 + M J - 1 T J3 + FLOAT (J1) J3 + 2 + M J - 3 T J3 = FLOAT (J3) C HOT 2 (D, 1.1,) + T HOT ML J3 + 2 + M J + 2 A M J - 6 T E J + FLOAT (J4) J J + H - M J T J - FLOAT (ML J4) T J - FLOAT (ML J4) T J - FLOAT (ML J4) T 2 - 4 M (- 2 + N J - 6 T 6 3 + FL 2 + 2 - 2 T 3 + 6 + 7 (- 2 + 16 2) T - 2 + M (- 2 + 16 2)
67850 11123456789 11111156789		$J_{1} \in 2 + M_{2} - i$ $T_{3} + F_{LOAT} (J_{1})$ $J_{3} \in 2^{1+M_{3}-3}$ $T_{3} = F_{LOAT} (J_{3})$ $C = K_{0} = C_{1} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + M_{1} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $M_{1} = J_{0} + C_{1} + C_{1} + C_{1}$ $T_{0} = K_{1} + C_{1} + C_{1} + C_{1}$ $T_{0} = K_{1} + C_{1} + C_{1} + C_{1}$
67350 10112345677A 1112145677A 1120		$J_{1} \in 2 + w_{1} - i$ $T_{1} + F_{1} \in A_{1} (J_{1})$ $J_{3} \in 2 + w_{1} \cdot 3$ $T_{3} = F_{1} \in A_{1} (J_{3})$ $C_{1} = 0 + (J_{1}) + 1 + k_{0} T$ $M_{1} = J_{2} + w_{1} - A_{2} + M_{1} - A_{2} + M_{1} + M_{2} + M_{2} + M_{1} + M_{2} + M_{2} + M_{1} + M_{2} + M_{2} + M_{2} + M_{1} + M_{2} + $
67850 11123145167789221		$J_{1} \in 2 + w_{1} - i$ $T_{13} + F_{1} \in A_{1} (J_{1})$ $J_{3} \in 2 + w_{1} \cdot 3$ $T_{3} : F_{1} \in A_{1} (J_{3})$ $C + M_{1} = 2 + w_{1} - k$ $T_{1} = 1 + w_{1} + w_{1} + w_{1} + k$ $T_{1} = 1 + w_{1} + w_{1} + k$ $T_{1} = 1 + w_{1} + w_{1} + k$ $T_{1} = 1 + w_{1} + w_{1} + k$ $T_{1} = 1 + w_{1} + k$ $M_{1} = 2 + w_{1} + k$ $T_{1} = 2 + w_{$
678510 111231456110 111231456110 1112212222		$J_{1} \in 2 + w_{1} - i$ $T_{1} + f_{0} \wedge r_{1} (J_{1})$ $J_{3} + 2 + w_{1} - 3$ $T_{3} + r_{0} \wedge r_{1} (J_{3})$ $T_{3} + r_{0} \wedge r_{1} + 2 + w_{1} - 4$ $T_{1} + r_{1} \wedge v_{1} + 2 + w_{1} - 4$ $T_{1} - r_{1} \wedge v_{1} + 2 + w_{1} - 4$ $T_{1} - r_{1} \wedge v_{1} + 2 + w_{1} - 4$ $T_{2} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{1} + 2 + v_{1} - 4$ $T_{3} - r_{1} \wedge v_{1} + v_{1$
678510 1112314 115677 1190122 23		$J_{1} \in 2 + w_{1} - i$ $T_{13} + F_{1} \in A_{1} (J_{1})$ $J_{3} + 2 + w_{1} - 3$ $T_{13} + F_{1} \in A_{1} (J_{3})$ $T_{13} + F_{1} \in A_{1} (J_{3})$ $T_{13} + F_{1} \in A_{1} (J_{3})$ $T_{13} + F_{1} = F_{1} + F_{1} +$
678510 111231456110 111231456110 1112212222		$J_{1} \in 2 + w_{1} - i$ $T_{1} + f_{0} \wedge r_{1} (J_{1})$ $J_{3} + 2 + w_{1} - 3$ $T_{3} + r_{0} \wedge r_{1} (J_{3})$ $T_{3} + r_{0} \wedge r_{1} + 2 + w_{1} - 4$ $T_{1} + r_{1} \wedge v_{1} + 2 + w_{1} - 4$ $T_{1} - r_{1} \wedge v_{1} + 2 + w_{1} - 4$ $T_{1} - r_{1} \wedge v_{1} + 2 + w_{1} - 4$ $T_{2} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{2} + v_{1} + 2 + w_{1} - 4$ $T_{3} - r_{1} \wedge v_{1} + 2 + v_{1} - 4$ $T_{3} - r_{1} \wedge v_{1} + v_{1$
67850 101123456789012284		$J_{1} \in 2 + w_{1} - i$ $T_{13} + F_{LOAT}(J_{1})$ $J_{3} \in 2 + w_{1} - 3$ $T_{3} = F_{LOAT}(J_{3})$ $T_{13} = F_{LOAT}(J_{3})$ $T_{13} = F_{LOAT}(J_{3})$ $T_{13} = F_{LOAT}(M_{1} + w_{1})$ $T_{2} = w_{1}(-x_{1} + t_{2})$ $T_{4} = F_{2} - 2$ $T_{4} = F_{4} - 2$ $T_$
6785011234567690122245627		J1:2440-1 TJ:-F(DAT(JJ) J3:240-3 TJ:-F(DAT(JJ) J3:240-3 TJ:-F(DAT(JJ) TJ:-F
67850 101234567890222222		$J_{1} \in 2 + w_{1} - i$ $T_{13} + F_{LOAT}(J_{1})$ $J_{3} \in 2 + w_{1} - 3$ $T_{3} = F_{LOAT}(J_{3})$ $T_{13} = F_{LOAT}(J_{3})$ $T_{13} = F_{LOAT}(J_{3})$ $T_{13} = F_{LOAT}(M_{1} + w_{1})$ $T_{2} = w_{1}(-x_{1} + t_{2})$ $T_{4} = F_{2} - 2$ $T_{4} = F_{4} - 2$ $T_$

1		5966971H; QGL10(I) J,FCT, TYR, TYI)
2		IMPLICIT COMPLEX+8(C),REAL+4(T)
3	C	
4	ç	10 POINT GAUSS-LAGUERRE QUADRATURE FORMULA OF S.S.P. (18M)
5		Tx + 29 - 92070
é		CALL FCT(I, J,TX, TGR, TGI)
7		TYR -9911827E-12* TGR
8		TY1= .9911827E-12 xTGI
9.		Tx 21-99659
10		CALL FCT(T, J,TX, TGR, TGI)
11		TYR - TYR + 18-395654 - 8 * 768
:5		1Y1+FY1+.18495C5E-8 *TGI
13		·x·16·2796c
14		$CALL \rightarrow CT(1)J, TX, TGR, TGI)$
:5		TYR=TYR++4249314E-6 * TGR
16		TY1=TY1++249314E-6 +TG1
17		TX=11-84379
16		CALL FCT (I, J, TX, TGR, TGI)
19	•	TYR= TYR+ .2825923E-4 * TGR .
50		TY1=TY1+.2825923E-4 # TG1
2:		Tx=8.330153
22		CALL FCT (I) J, TX, TGR, TGI)
25		TYR-TYR+.7530084E-3 * TGR
24		TY1-TY1+-7530064E-3 * TG1
25		Τλ=5-552496
26		CALL FCT (1) J, TX, TGR, TGI)
27		TYR=TYR++009501517 + 76R
28		TYI-TYI1 - 003501517 #761
زع		TX=3,401434
30		CALL FCT(1, J, TX, TGR, TGI)
		TyR+TyR+106208746 & TGR
3:		Fire a line and the set
32		
33		TX=1.608343
24		CALL FCT(1,J,TX,TGR,TGI) TYR=TYR+-2180683 & TGR
35		
36		TY1=TY1+-2180683 + TG1
37		Tx + . 7294545
38		CALL FCT (1, J, TX, TGR, TGL)
39		TYR . TYR + . 4011199 . TGR
40		TY1=TY1+-4011199 # TG1
41		Tx++1377935
42		CALL FCT (1, J, TX, TGR, TGL)
43		TYR+17R+.3084411 # TGR
44		TY1=TY1+-3084411 # 761
45		RC LONN
46		LND
-		

1		SUBCOUTINE SING(INNY)
2	11	FORMAT (SAHOMATRIX WITH O POW IN DECOMPOSE
3	12	FORMAT (SANOSINGULAS MATRIX IN DECOMPOSE. ZERO DIVIDE IN SILVE
4	13	OPMAT ISAHONG CONVERGENCE IN THPRUV. MATRIX IS NEARLY STAGULAP.
5		00 10 (1,2,3), 1844
6	1	WRITE (6.11)
7		60 10 10
8	2	WRITE (3.12)
9		60 TO 1C
10	3	WRITE (6.13)
11	10	PETURN
12		END

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APPENDIX D

BASIS FOR MORE ACCURATE COMPARISON OF THEORETICAL AND EXPERIMENTAL RESULTS

With reference to Fig. 8, the voltage V(z) induced in the receiving loop is proportional to the tangential electric field, viz.,

$$V(z) = \int \dot{B}_z dS = -2\pi a E_\phi(a,z)$$

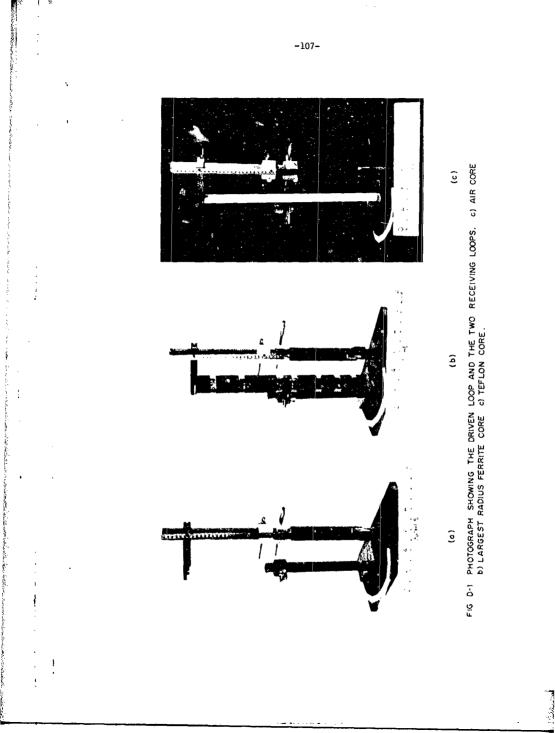
This relation, however, assumes that there is azimuthal symmetry and that the current in the receiving loop is negligible. These assumptions are investigated in detail.

Azimuthal Symmetry. The value of ak_0 for the eleven cases studied in the experiment ranges from .00133 to .01662, whereas $|ak_1|$ has values between .02 to about .41. It is well known that a loop in free space has nearly constant current if $ak_0 \leq .1$. If this criterion is applied, all of the eleven cases are rotationally symmetric. However, if $|ak_1| \leq .1$ is the criterion, rotational symmetry is clearly absent in some of the cases. Because of the unique location of the driving loop on the surface p = a, a simple analytical criterion on the radius is not possible to ensure rotational symmetry. For this reason, rotational symmetry was ensured experimentally.

As shown in Fig. D-1, a shielded loop of 3/16 in. diameter was fabricated and used to measure the voltage induced by the radial magnetic field as a function of azimuthal coordinate for eight of the eleven croses. The largest deviation from a constant alue was found to be less than 5%. The three antennas not tested had lower values of $|ak_1|$ than those tested. The experimental measurements established rotational symmetry conclusively for all of the cases considered in the experimental study.

Measurements were then made of the total axial magnetic current on a

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dielectric rod made of Teflon, as shown in Fig. D-1(c). The experimental parameters are summarized below:

Diameter of the driven loop = 1.0⁺ inch Diameter of the Teflon rod = 1.0 inch Diameter of loop for ax!al measurements = 1.0 inch Diameter of loop for radial measurements = 3/16 inch Frequency = 20 MHz

The axial magnetic current distribution was measured with and without the Teflon rod present. The results are tabulated in Table D-1 and plotted in Fig. D-2. As one might expect, the dielectric rod ($c_r \simeq 2.2$) has very little effect, and the measurements taken with it present do not differ significantly from those taken with it absent. In both cases, rotational symmetry was confirmed experimentally. The characteristics of the Teflon rod antenna are similar to those of the air-core antenna because the loop used in the experiment was small enough to act as a magnetic dipole.

<u>Correction to Experimental Data</u>. An answer was then sought to the important question, what is the voltage V(z) induced at the terminals of the receiving loop? The receiving loop is loaded by the vector voltmeter which has a nominal impedance of 100 K-ohms shunted by a 2.5 pf capacitor. The frequency in this experiment varies from 5 to 150 MHz so that the vector voltmeter impedance has a range of values. An analysis based on circuit theory can be carried out to determine accurately the voltage $V_R(z)$ measured by the vector voltmeter. A diagram of the two coupled circuits is in Fig. D-3. The various quantities shown in the figure are:

Ve^{-iwt} = Oscillator voltage

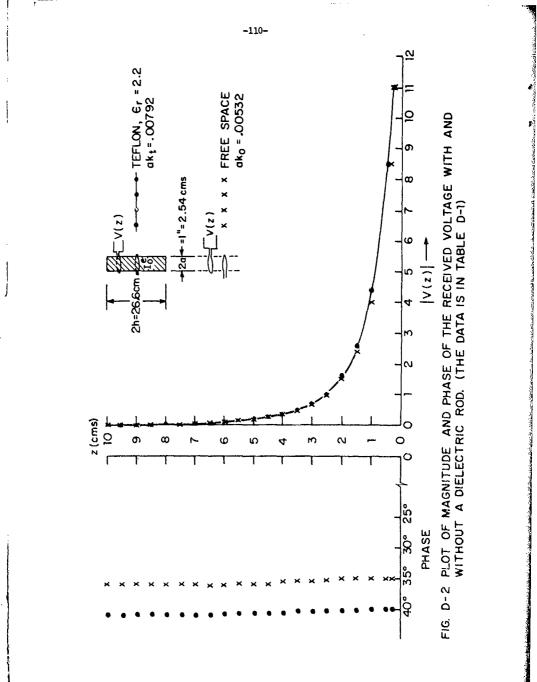
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TABLE D-1: Unnormalized experimentai data of total axial magnetic current with an air core and also a teflon rod. (This data is plotted in Figure D-2).

Z	Air Core a	k _o =.00532	Teflon, $\epsilon_r = 2.2$, $ak_o = .00792$		
cms	Mag	Phase	Mag	Phase	
$0.3 \\ 0.5 \\ 1.0 \\ 1.5 \\ 2.0$	11.0 8.4 4.5 2.4 1.5	35 35 35 35 35 35	11.0 8.5 4.35 2.58 1.60	40 40 40 40.1 40.2	
2.5	.98	35.4	1.02	40.3	
3.0	.65	35.5	.695	40.4	
3.5	.45	35.6	.500	40.6	
4.0	.33	35.6	.365	40.7	
4.5	.245	36	.265	40.7	
5.0	.18	36	.205	40.7	
5.5	.15	36	.155	40.7	
6.0	.135	36.2	.130	40.8	
6.5	.105	36.2	.10	41	
7.0	.085	36	.083	41	
7.5	.07	36	.067	41	
8.0	.06	36	.056	41	
8.5	.05	36	.048	41	
9.0	.04	36	.041	41	
10.0	.03	36	.03	41	

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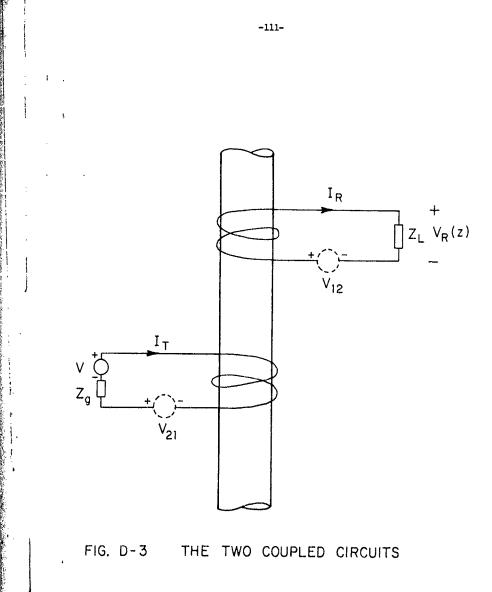


FIG. D-3 THE TWO COUPLED CIRCUITS

 Z_{σ} = Generator impedance

 $I_{\rm m}$ = Current in the transmitting loop

 $V_{21} = V_{12}$ = Fictitious generator due to coupling

 $I_R = Current$ in the receiving loop

 Z_{r} = Vector voltmeter impedance

The two mesh equations can be written as

$$V = I_{T}(Z_{g} + Z_{g}) - I_{R}Z_{M}$$
(D-1)
$$0 = I_{T}(-Z_{M}) + I_{p}(Z_{g} + Z_{1})$$
(D-2)

where Z_{M} is the mutual impedance, Z_{g} the self-impedance of the two loops. From (D-1),

$$I_{T} = (V + I_{R}Z_{M})/(Z_{s} + Z_{g})$$

Substituting this into (D-2) gives

$$0 = \frac{(v + I_R^2 Z_M) (-Z_M)}{(Z_s + Z_g)} + I_R (Z_s + Z_L)$$

or

$$\left[R = \frac{VZ_{M}}{(Z_{g} + Z_{g})} + \frac{1}{[(Z_{g} + Z_{L}) - Z_{M}^{2}/(Z_{g} + Z_{g})]}\right]$$

The measured voltage $V_R(z) = I_R^{7}L$ in Fig. D-3 is, therefore,

$$V_{R}(z) = \frac{VZ_{M}^{2}L}{(Z_{g} + Z_{g})} \frac{1}{[(Z_{g} + Z_{L}) - Z_{M}^{2}/(Z_{g} + Z_{g})]}$$
$$= \frac{VZ_{M}}{Z_{g}} \left(\frac{1}{1 + Z_{g}/Z_{g}}\right) \left(\frac{1}{1 + Z_{g}/Z_{L}}\right) \left[\frac{1}{1 - Z_{M}^{2}/(Z_{g} + Z_{g})(Z_{g} + Z_{L})}\right]$$
(D-3)

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The theoretical computations from the integral equation account only for the mutual coupling and ignore the generator impedance Z_g , the loading of the receiver by the vector voltmeter impedance Z_L , and the change in the current in the transmitting loop due to the nearness of the receiving loop. The correction terms can be identified in (D-3) as follows:

$$V_{R}(z) \Big|_{measured} = V_{R}(z) \Big|_{calculated} \times C_{1} \times C_{2} \times C_{3}(z)$$
 (D-4)

where

 $C_1 = Correction$ due to generator impedance.

 C_2 = Correction due to the loading of the vector voltmeter.

 $C_{3}(z)$ = Correction due to secondary coupling (Lenz's Law).

It is observed that the correction terms C_1 and C_2 are independent of the separation between the two loops. Since the measured $V_R(z)$ is only relative in the present study, $C_3(z)$ is the only correction factor which is significant. It is [from the right-hand term in (D-3)]:

$$C_{3}(z) = \left[\frac{1}{1 - Z_{M}^{2}(z)/(Z_{B} + Z_{g})(Z_{B} + Z_{L})}\right]$$
 (D-5)

As a first approximation the generator impedance Z_{g} is set equal to zero. Z_{L} is the impedance of the vector voltmeter transferred to the gap in the receiving loop. The impedance of the vector voltmeter is composed of a 100 k-ohm resistor shunted by a 2.5 pf capacitance, viz.,

 $Z_{VVM} = R/(1 + j\omega CR)$

with R = 10^5 ohms and C = 2.5 × 10^{-12} farads. Z_L can be calculated using

$$Z_{L} = R_{c} \left(\frac{Z_{VVM} + jR_{c} \tan \beta d}{R_{c} + jZ_{VVM} \tan \beta d} \right)$$
(D-6)

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where

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- $R_{c} = 50$ ohms = Characteristic impedance of the line
- $\beta = \beta_0 \varepsilon_{rt}^{1/2}$
- ert * Dielectric constant of Teflon FEP
 - d = Distance from the vector voltmeter output terminals to the gap in the receiving loop

An approximate value for $C_3(z)$ can now be computed using (D-5) with Z_g set equal to zero. However, Z_M - the mutual impedance between two loops that are in the near zone of one another - is still unknown. An excellent analysis of the mutual impedance of two loops in air is available [8]. In the present case, however, the mutual impedance is required when the ferrite is present. If the permeability μ_0 in King's analysis [8] is replaced by the permeability μ_1 of the ferrite, an approximate value for the mutual impedance is obtained, viz.,

$$z_{\rm M}(z) = (j_{\rm W} u_1 a^2/2) \{ [4/(z^2 + 4a^2)^{1/2}] [(2/\Lambda^2 - 1)K(\pi/2, \alpha) - (2/\Lambda^2)F(\pi/2, \alpha)] - j\pi a^2 k_1^3/3 \}$$
(D-7)

where

 $w = \text{Angular frequency; } \mathbf{k}_1 = \text{Propagation Constant in the ferrite} = w/v_1 \varepsilon_1$ $\mu_1 = \text{Permeability of the ferrite; } \varepsilon_1 = \text{Permittivity of the ferrite}$ a = Radius of the two loops

z = Distance separating the two loops

 $A^2 = \sin^2 \alpha = 4a^2/(z^2 + 4a^2)$

$$K(\pi/2,a) = \int_{0}^{\pi/2} \frac{d\psi}{(1 - \sin^2 a \sin^2 \psi)^{1/2}} = \text{Elliptic integral of the first kind}$$

and

All a strategy and a strategy

$$F(\pi/2,\alpha) = \int_{0}^{\pi/2} (1 - \sin^2 \alpha \sin^2 \psi)^{1/2} d\psi = \text{Elliptic integral of the}$$
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Fortran IV computer programs for computing the elliptic functions were available in the Scientific Subroutine Packs of IBM 360. Thus, the correction factor $C_{2}(z)$ was computed as a function of the separation distance z using equations (D-5), (D-6) and (D-7). This factor was then used to correct the experimental data for a comparison with the theoretical results. A typical comparison of the theory with corrected and uncorrected experimental data is shown in Fig. D-4 for the specific case of antenna #6. The uncorrected experimental data depart from the theoretical curve near the driving point. $0 \le z/h \le .25$. The vector voltmeter impedance 7, at the gap for the antenna configuration under consideration (antenna #6) is $Z_1 = 2.88 - \frac{1}{534.7}$ ohms. The corrected experimental data obtained when this value of $Z_{\rm T}$ is used to compute the correction factor are plotted in Fig. D-4 and are seen to deviate less from the theory than the uncorrected values. The correction factor does not account for the entire discrepancy, however. This is in part because of the approximations made in computing the correction factor and in part because of the lack of an accurate value for Z_1 . For this reason, the correction factor was also computed for a range of real and imaginary parts of Z. Two representative cases are shown in Fig. D-4. They illustrate that a precise knowledge of $2_{\rm L}$ could improve the accuracy of the correction factor applied to the experimental data and, thus, minimize the discrepancy with theory near the driving point. Away from the driving point (2/h > .25) the agreement is seen to be very good.

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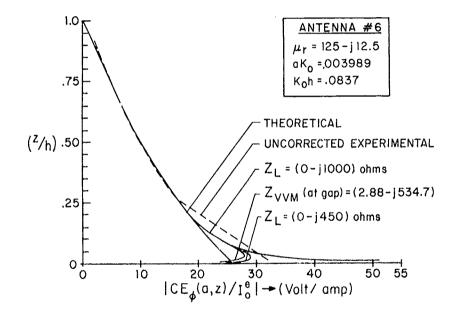


FIG. D-4 MAGNITUDE OF THE VOLTAGE RECEIVED BY THE MEASURING LOOP

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