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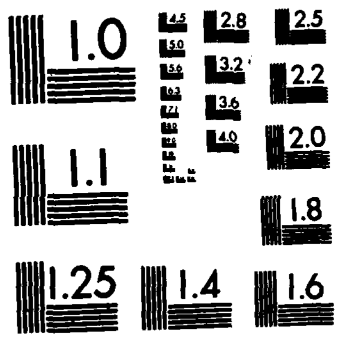

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Final Technical Report
December 1982

ANALYSIS AND COMPUTER STUDIES OF MAGNETOSTATIC WAVE TRANSDUCERS

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University of Lowell

I. Jacob Weinberg

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APPROVED: James C Sethares

JAMES C. SETHARES
Project Engineer

APPROVED: Allan C. Schell

ALLAN C. SCHELL, Chief
Electromagnetic Sciences Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

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This report contains the results obtained for magnetostatic wave transducers which were outlined in the Interim Technical Report.

The analysis is presented for obtaining magnetostatic Wave power, radiation resistance, radiation reactance and insertion loss for forward volume waves and backward volume waves. Included for consideration are ground planes, apodization of the fundamental mode, isolated independent conduc-

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) tors, multistrip meander line and parallel grating, for a uniform current distribution without variable coupling.

Also presented are the results for the dispersion relation and group delays for volume waves with ground planes for arbitrary orientation of the biasing field. We also include the results of attempting to obtain non-dispersive, electronically tunable time delay elements by combining two volume waves with the same specified biasing field orientation but with different magnitudes of the magnetic field intensity.

We also present the results of incorporating a non-uniform, hyperbolic current distribution in the basic magnetostatic surface wave program.

For each of the tasks described above there are presented the analysis, the computer program with detailed documentation enabling its use by others and computer produced graphical results for cases of interest.

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Introduction

The purpose of this report is to present the results obtained for magnetostatic wave transducers under contract number F19628-80-C-0029 from the Air Force ESD RADC/EEA Hanscom AFB, MA since obtaining the results presented in the Interim Technical Report [1].

In the earlier report the analysis, computer programs and graphical results were displayed for the flat field, basic theory magnetostatic surface wave program, the micro-strip model for surface waves and the dispersion relation for generalized surface waves. There was also presented the analysis for complex impedance for surface waves in free space.

We here present the analysis and computer program for obtaining the dispersion relation, group delay, magneto-static wave power, radiation resistance, radiation reactance and insertion loss for forward volume waves and backward volume waves. Included are the consideration of ground planes, apodization of the fundamental mode, multistrip meander line and parallel grating and isolated independent conductors for a uniform current distribution without variable coupling. The analysis, computer program and its use together with graphical results are presented.

The analysis for obtaining the dispersion relation and group delay for volume waves with arbitrary orientation of the biasing field is presented here. The computer program and graphical results for cases of interest for the generalized dispersion relation for volume waves including ground planes are presented. Also included in the report are the results of attempting to obtain nondispersive, electronically tunable time delay elements by combining the group delays for volume waves of two different biasing field magnitudes in the same specified orientation.

We also present the analysis of incorporating a non uniform, hyperbolic current distribution in the basic magnetostatic surface wave program. The computer program accomplishing this task is also presented.

Basic Theory - Forward and Backward Volume Waves

The basic theory leading to the dispersion relation, group delay, magnetostatic wave power, radiation resistance, radiation reactance and insertion loss for forward and backward volume waves for a transducer consisting of a YIG region sandwiched between two finite dielectrics (see Figure 1) is here outlined. We follow the previous work on surface waves [1],[4]. We start with Maxwells equations

$$\nabla x \overline{H} = \frac{\partial \overline{D}}{\partial t} \quad ; \quad \nabla \cdot \overline{B} = o \tag{1}$$

$$\nabla x \overline{E} = - \frac{\partial \overline{B}}{\partial t} \quad ; \quad \nabla \cdot \overline{D} = o$$

and the constitutive relations in each region

$$\overline{B} = \mu_o \ (\overline{H} + \overline{M}) \tag{2}$$

$$\overline{D} = \varepsilon \ \overline{E}$$

where $\overline{M}$ is non zero in the YIG region only. We utilize the gyromagnetic relation in the YIG region

$$\frac{\partial \overline{M}}{\partial t} = -\gamma \ \overline{M} x \overline{H} \tag{3}$$

and retain first order terms only.

We assume the time dependence of all physical quantities to be $e^{j\omega t}$, we also assume the magnetostatic approximation

$$H_z = E_x = E_y = o \tag{4}$$

$$\omega \varepsilon E_z = o$$

and no variation of any physical quantity in the z direction.

We have

$$\frac{\partial E_z}{\partial y} = -j\omega\, B_x \qquad (5)$$

$$\frac{\partial E_z}{\partial x} = j\omega\, B_y$$

Also

$$B_x = \mu_o\, H_x \qquad (6)$$

$$B_y = \mu_o\, H_y$$

in the non YIG regions, while

$$\begin{pmatrix} B_x \\ B_y \end{pmatrix} = \mu_o \begin{pmatrix} \mu_{11} & -j\mu_{12} \\ j\mu_{21} & \mu_{22} \end{pmatrix} \begin{pmatrix} H_x \\ H_y \end{pmatrix} \qquad (7)$$

in the YIG region; where, for forward and backward volume waves,

$$\mu_{12} = \mu_{21} = o \qquad (8)$$

and, for forward volume waves, (θ=o in Figure 1),

$$\mu_{11} = \left(1 + \frac{\gamma^2 H_o\; 4\Pi M_o}{\gamma^2 H_o^{\,2} - f^2}\right)$$

$$\mu_{22} = 1 \qquad (9)$$

and, for backward volume waves, (θ=90°, ϕ=o in Figure 1)

$$\mu_{11} = 1$$

$$\mu_{22} = \left(1 + \frac{\gamma^2 H_o\; 4\Pi M_o}{\gamma^2 H_o^{\,2} - f^2}\right) \qquad (10)$$

where

$$\gamma = 2.8 \text{ mhz/oe} \; ; \; 4\Pi M_o = 1750 \text{ oe} \; , \; f = \frac{\omega}{2\Pi} \qquad (11)$$

We define

$$\alpha^2 = -\frac{\mu_{11}}{\mu_{22}} \tag{12}$$

so that

$$\alpha^2 = \begin{cases} -\left(1 + \dfrac{\gamma^2 H_o\ 4\Pi M_o}{\gamma^2 H_o^2 - f^2}\right) & \text{forward volume waves} \\ -\left(1 + \dfrac{\gamma^2 H_o\ 4\Pi M_o}{\gamma^2 H_o^2 - f^2}\right)^{-1} & \text{backward volume waves} \end{cases} \tag{13}$$

and, in order to have volume waves,

$$\alpha^2 > o \tag{14}$$

Solutions are sought which satisfy boundary conditions $B_y = o$ at the ground planes and continuity conditions on H_x and B_y at the region junctions except, that at $y = o$ we require H_x to be discontinuous by the amount of the surface current density, J(x), supplied there.

Assuming a solution in the form of a potential function

$$\psi = R(y)e^{j(\omega t - kx)} \tag{15}$$

where

$$H_x = \frac{\partial \psi}{\partial x} \quad \text{and} \quad H_y = \frac{\partial \psi}{\partial y} \tag{16}$$

we find the form of R(y) in the non YIG regions as

$$R(y) = A_i\ e^{|k|y} + B_i\ e^{-|k|y} \qquad i=1,3 \tag{17}$$

and in the YIG region

$$R(y) = A_2 \cos \alpha|k|y + B_2 \sin \alpha|k|y \tag{18}$$

Attempting to resolve the boundary and continuity conditions results in a quantity F(k) appearing in the expressions for the constants in (17) and (18).

For forward volume waves

$$F(k) = \frac{\sin \alpha|k|d \ e^{-|k|d}}{\alpha} \Big\{ -\alpha \cot \alpha|k|d \ [(\coth |k|t_1+1)-e^{-2|k|\ell} (\coth |k|t_1-1)] + (\alpha^2 \coth |k|t_1-1)+e^{-2|k|\ell}(\alpha^2 \coth |k|t_1+1) \Big\} \quad (19)$$

and, for backward volume waves

$$F(k) = \frac{\sin \alpha|k|d \ e^{-|k|d}}{\alpha} \Big\{ -\alpha \cot \alpha|k|d \ [(\coth |k|t_1+1)-e^{-2|k|\ell} (\coth |k|t_1-1)] + (\alpha^2-\coth |k|t_1)-e^{-2|k|\ell}(\alpha^2+\coth |k|t_1) \Big\} \quad (20)$$

where ℓ, d, t_1, are the widths of the three regions (see Figure 1).

If we require that F(k) vanishes we obtain the dispersion relation

$$\frac{\tan \alpha|k|d}{\alpha \ [(\coth |k|t_1+1)-e^{-2|k|\ell}(\coth |k|t_1-1)]} = \left\{ \begin{array}{ll} [(\alpha^2\coth |k|t_1-1)+e^{-2|k|\ell}(\alpha^2\coth |k|t_1+1)]^{-1} & \underline{\text{forward}} \text{ waves} \\ [(\alpha^2-\coth |k|t_1)-e^{-2|k|\ell}(\alpha^2+\coth |k|t_1)]^{-1} & \underline{\text{backward}} \text{ waves} \end{array} \right\} \quad (21)$$

which is solved numerically, by iteration, to obtain k as a function of f.

There are an infinite number of solution modes of (21) corresponding to the multiplicity of the inverse tangent function. For each mode the solution for positive k ($s = |k|/k = 1$) is the same as for negative k ($s = |k|/k = -1$) since only the magnitude of k appears in the dispersion relation.

The bandwidth for which the solution is obtained is given by

$$\gamma H_o < f < \gamma\sqrt{H_o (H_o + 4\Pi M_o)} \quad (22)$$

We can now find the group delay from the dispersion relation curves, k vs f, by numerically applying

$$v_g = \frac{\partial \omega}{\partial k} \tag{23}$$

We can find all the constants in the solution and proceed to find the field equations as for surface waves [4]. The magnetostatic wave power is then obtained from [4]

$$P = \frac{1}{2} \int_{-(\ell+d)}^{t_1} E_z \overline{H_y}\, dy \tag{24}$$

utilizing (5).

We then find

$$P = \frac{\omega\ \mu o\ G^2}{4|k|^2}\ A \tag{25}$$

where k is obtained from the dispersion relation, and

$$G = \frac{e^{-|k|d}\ \tilde{J}(k)}{\left|\frac{\partial}{\partial k'} F(k')\right|_{k'=k}} \tag{26}$$

For independent conductors

$$|\tilde{J}(k)| = \left| \sum_{i=1}^{N} \operatorname{sinc} \frac{a_i k}{2\pi}\ \eta^i \sqrt{\ell_{1i}}\ e^{-jkp_i i} \right| \tag{27}$$

where ℓ_{1i}, a_i, p_i are the strip lengths, strip widths and center to center spacings for the N strips and η=1 for a parallel grating while η = -1 for a meander line and

$$\operatorname{sinc} x = \frac{\sin \pi x}{\pi x} \tag{28}$$

For uniform N strips we can write

$$|\tilde{J}(k)| = \sqrt{\ell_1} \left|\operatorname{sinc} \frac{ak}{2\pi}\right| \left| \frac{1-\eta^N\ e^{jkpN}}{1-\eta\ e^{jkp}} \right| \tag{29}$$

For the quantity A in (25) we have, for forward volume waves,

$$A = 2e^{-2|k|\ell}(\sinh 2|k|\ell - 2|k|\ell) + (\alpha^2+1)d|k| - \frac{\alpha^2-1}{2\alpha}\sin 2\alpha|k|d + \cos 2\alpha|k|d - 1$$

$$+\left(\frac{\sinh 2|k|t_1 - 2|k|t_1}{2\sinh^2|k|t_1}\right)\left[\frac{\alpha^2+1}{2} - \frac{(\alpha^2-1)}{2}\cos 2\alpha|k|d - \alpha\sin 2\alpha|k|d\right]$$

$$+ 2e^{-2|k|\ell}\left\{(\alpha^2-1)d|k| - \frac{(\alpha^2+1)}{2\alpha}\sin 2\alpha|k|d + \frac{(\sinh 2|k|t_1 - 2|k|t_1)}{2\sinh^2|k|t_1}\right.$$

$$\left.\left[\frac{\alpha^2-1}{2} - \frac{(\alpha^2+1)}{2}\cos 2\alpha|k|d\right]\right\} \qquad (30)$$

$$+ e^{-4|k|\ell}\left\{(\alpha^2+1)d|k| - \frac{\alpha^2-1}{2\alpha}\sin 2\alpha|k|d - (\cos 2\alpha|k|d - 1)\right.$$

$$\left.+\left(\frac{\sinh 2|k|t_1 - 2|k|t_1}{2\sinh^2|k|t_1}\right)\left[\frac{\alpha^2+1}{2} - \frac{(\alpha^2-1)}{2}\cos 2\alpha|k|d + 2\sin 2\alpha|k|d\right]\right\}$$

and, for backward volume waves,

$$A = 2e^{-2|k|\ell}(\sinh 2|k|\ell - 2|k|\ell) - (\alpha^2+1)|k|d - \frac{(\alpha^2-1)}{2\alpha}\sin 2\alpha|k|d + \cos 2\alpha|k|d$$

$$-1 + \left(\frac{\sinh 2|k|t_1 - 2|k|t_1}{2\sinh^2|k|t_1}\right)\left(\frac{\alpha^2+1}{2\alpha^2} + \frac{\alpha^2-1}{2\alpha^2}\cos 2\alpha|k|d + \frac{\sin 2\alpha|k|d}{\alpha}\right)$$

$$+ 2e^{-2|k|\ell}\left[(\alpha^2-1)d|k| + \frac{\alpha^2+1}{2\alpha}\sin 2\alpha|k|d - \left(\frac{\sinh 2|k|t_1 - 2|k|t_1}{2\sinh^2|k|t_1}\right)\right.$$

$$\left.\left(\frac{\alpha^2-1}{2\alpha^2} + \frac{\alpha^2+1}{2\alpha^2}\cos 2\alpha|k|d\right)\right] \qquad (31)$$

$$+ e^{-4|k|\ell}\left[1 - (\alpha^2+1)d|k| - \frac{(\alpha^2-1)}{2\alpha}\sin 2\alpha|k|d - \cos 2\alpha|k|d\right.$$

$$+ \left(\frac{\sinh 2|k|t_1 - 2|k|t_1}{2 \sinh^2 |k| t_1}\right) \left(\frac{\alpha^2+1}{2\alpha^2} + \frac{\alpha^2-1}{2\alpha^2} \cos 2\alpha|k| d - \frac{\sin 2\alpha|k|d}{\alpha}\right)\Bigg]$$

Proceeding as for surface waves[1], the radiation resistance is

$$R = \frac{4|P|}{(1-\eta) + (1+\eta)N^2} \tag{32}$$

for one wave.

The total radiation resistance is

$$R_m = 2R \tag{33}$$

and the radiation reactance is obtained from

$$X_m(f) = \frac{1}{\Pi} \int_{-\infty}^{\infty} \frac{R_m(f')df'}{f'-f} \tag{34}$$

by numerical integration.

The insertion loss is then given by

$$IL = 20 \log_{10} \frac{4 R R_g}{(R_g+R_m+R_L)^2+(X_m+X_L)^2} - \frac{76.4\ 10^6}{\partial\omega/\partial k} \Delta H\ \Delta r \tag{35}$$

where R_g is source resistance, R_L is conduction loss and X_L is a series matching impedance. ΔH is linewidth representing material loss and Δr is the propagation distance.

We thus have relations for all the quantities of interest for both forward volume waves and backward volume waves.

In figures 8-17 are presented graphical displays of the dispersion relation, group delay, radiation resistance, radiation reactance and insertion loss for forward volume waves and backward volume waves.

Dispersion Relation - Generalized Volume Waves

In this section we obtain the dispersion relation for volume waves including ground planes when the biasing field can be in an arbitrary direction (see Figure 1). We have the permeability tensor components appearing in (7) as[1],[5]

$$\mu_{11} = 1 + \gamma^2 H_o\ (4\Pi M_o)\ \frac{(\sin^2\theta\ \sin^2\phi + \cos^2\theta)}{\gamma^2\ H_o^2 - f^2}$$

$$\mu_{22} = 1 + \frac{\gamma^2\ H_o\ (4\Pi M_o)\ \sin^2\theta}{\gamma^2\ H_o^2 - f^2}$$

$$-j\mu_{12} = j\gamma\ (4\Pi M_o)\ \frac{\sin\theta(f\ \sin\phi + j\gamma\ H_o\ \cos\phi\ \cos\theta)}{\gamma^2\ H_o^2 - f^2} \qquad (36)$$

$$j\mu_{21} = \frac{-j\gamma\ (4\Pi M_o)\ \sin\theta(f\ \sin\phi - j\gamma\ H_o\ \cos\phi\ \cos\theta)}{\gamma^2\ H_o^2 - f^2}$$

where

$$\gamma = 2.8\ \text{mhz/oe}\ ,\ 4\Pi M_o = 1750\ \text{oe}\ ,\ f = \frac{\omega}{2\Pi} \qquad (37)$$

The solution is in the form of a potential function such as

$$\psi = e^{j(\omega t - kx)}(Ae^{|k|y} + Be^{-|k|y}) \qquad (38)$$

in the non YIG regions while, in the YIG region, we have the form for the solution as

$$\psi = e^{j(\omega t - kx)}\ (A\ \cos\ c|k|y + B\ \sin\ c|k|y)e^{-jkby} \qquad (39)$$

where

$$c^2 = \frac{-(\mu_{21} - \mu_{12})^2 - 4\mu_{11}\ \mu_{22}}{4\mu_{22}{}^2} \qquad (40)$$

$$b = \frac{-j(\mu_{21} - \mu_{12})}{2\ \mu_{22}}$$

and, for volume waves,

$$c^2 > o. \tag{41}$$

Here we note the additional propagation term containing b in (39) which vanishes for standard forward volume waves (θ=o) and backward volume waves ($\theta=90^{o}$, ϕ=o).

By attempting to satisfy the continuity conditions and boundary conditions we obtain the dispersion relation

$$[(\coth |k|t_1+1)-e^{-2|k|\ell}(\coth |k|t_1-1)]c\mu_{22} \cot c|k|d =$$

$$\coth |k|t_1 [c^2 \mu_{22}^2 -(j\mu_{21} + b\mu_{22})^2]$$

$$-1 + j \frac{|k|}{k} (\coth |k|t_1-1) (j\mu_{21} + b\mu_{22}) \tag{42}$$

$$+e^{-2k\ell}\Big\{\coth |k|t_1 [c^2 \mu_{22}^2 - (j\mu_{21} + b\mu_{22})^2]$$

$$+1 - j \frac{|k|}{k} (\coth |k|t_1+1) (j\mu_{21} + b\mu_{22})$$

There are an infinite number of solution modes for this equation corresponding to the multiplicity of the inverse tangent function. For each mode there is one solution for positive $k(|k|/k = s = 1)$ and another solution for negative $k(\frac{|k|}{k} = s =-1)$.

This dispersion relation reduces to the ones obtained for forward volume waves and backward volumes by specializing the θ and ϕ values.

The bandwidth for the existence of volume waves is known to be[2]

$$\gamma \sqrt{H_o(H_o + 4\Pi M_o \sin^2 \theta \sin^2 \phi)} < f < \gamma \sqrt{H_o(H_o + 4\Pi M_o)} \tag{43}$$

Dispersion relation curves are presented in Figures 3-6.

For the group delay we evaluate numerically

$$v_g = \partial\omega/\partial k \tag{44}$$

Non-dispersive Time Delay

The dispersion relation curves obtained in the plane defined by $\phi=o$ consist of a backward volume wave curve with a forward volume wave curve as shown in Figures 5 and 6. The frequency at which the changeover from backward volume wave to forward volume wave occurs is given by[2]

$$f_c = \gamma\sqrt{H_o(H_o + 4\Pi M_o \sin^2 \theta)} \tag{45}$$

This critical frequency is at the midpoint of the frequency spectrum when θ is approximately 43^o as is shown in Figure 6.

It then appeared feasible that, if two volume waves with different biasing fields were joined at this angle θ, we may be able to obtain regions of constant time delay. Figure 7 shows the results of such attempts, one curve is the joining of volume waves with biasing fields of 2500 and 2125 (oe) and the other curve is the joining of volume waves with biasing fields of 2500 and 2200 (oe), all at the same position $\phi=o^o$, $\theta=43.19^o$.

The results obtained can be compared with those obtained from the joining of a surface wave with a backward volume wave[3].

Hyperbolic Current Distribution

To be considered here is an alternative to the flat field current distribution J(x) which will now lead to a replacement for the transform function $\tilde{J}(k)$ of equations (27) or (29).

With ℓ_1, a, p being the strip length, strip width and center to center spacing for the N transducer strips, the current distribution now under consideration is

$$J(x) = \frac{I_o}{a} \frac{\cosh \frac{x-(i-1)p}{\delta}}{\frac{\sinh a/2\delta}{a/2\delta}} \eta^{i-1} \qquad i=1,2,\ldots,N \qquad -\frac{a}{2}+(i-1)p<x<\frac{a}{2}+(i-1)p \tag{46}$$

(see Figure 2).

where

$$\delta = \frac{\delta_1}{1+j} \tag{47}$$

for some given δ_1 ; j being $\sqrt{-1}$.

With $I_o=1$, the Fourier transform gives

$$|\tilde{J}(k)| = \left| \frac{\sqrt{\ell_1}}{\frac{\sinh a/2\delta}{a/2\delta}} \left(\frac{1-\eta^N e^{jkpN}}{1-\eta e^{jkp}}\right) \frac{[A_1 e^{a/2\delta}+A_2 e^{-a/2\delta}-j(A_3 e^{a/2\delta}+A_4 e^{-a/2\delta})]}{a^2(k^2 + j\frac{2}{\delta^2})} \right| \tag{48}$$

where

$$A_1 = d_1 (\cos c_1 + \cos f_1) + f_1 \sin c_1 + c_1 \sin f_1$$
$$A_2 = -d_1 (\cos c_1 + \cos f_1) + f_1 \sin c_1 + c_1 \sin f_1 \tag{49}$$
$$A_3 = d_1 (\sin f_1 - \sin c_1) + f_1 \cos c_1 - c_1 \cos f_1$$
$$A_4 = d_1 (\sin f_1 - \sin c_1) - f_1 \cos c_1 + c_1 \cos f_1$$

and

$$d_1 = a/2\delta \ , \ c_1 = \frac{a}{2}\left(k + \frac{1}{\delta}\right) \ , \ f_1 = \frac{a}{2}\left(k - \frac{1}{\delta}\right) \tag{50}$$

When apodization is considered we obtain, instead of (48),

$$|\tilde{J}(k)| = \left| \sum_{i=1}^{N} \frac{\sqrt{\ell_{1i}}\ \eta^{i} e^{-jkp_i i}}{\frac{\sinh a_i/2\delta}{a_i/2\delta}} \frac{[A_{1i}e^{a_i/2\delta}+A_{2i}e^{-a_i/2\delta}+j(A_{3i}e^{a_i/2\delta}+A_{4i}e^{-a_i/2\delta})]}{a_i^{\,2}(k^2 + j\frac{2}{\delta^2})} \right| \tag{51}$$

There is no consideration for a truncated array of normal modes here. When equations (48) or (51) are employed in the basic theory program we have the basic theory for a hyperbolic current distribution.

COMPUTER PROGRAMS

A. Basic Theory - Forward and Backward Volume Waves

There is a computer program* operational on the CDC 6600 at Hanscom AFB, MA which incorporates the results of the basic theory for both forward volume waves and backward volume waves. The program produces plots on the Calcomp plotter at Hanscom AFB depicting the various physical quantities as functions of frequency. Plots as well as printouts are obtained for wave number, group delay, radiation resistance, radiation reactance and insertion loss.

Flexibility is designed into the program so that one can choose the solution mode for (21) and whether we have uniform conducting strips or apodization in strip length, strip width and/or center to center spacing. Additionally, the program provides the relevant frequency range from (22).

Now follows a detailed description of the input cards with details on the use of the above described features. Columns 1-72 may be used on the first 5 cards and columns 1-70 may be used on the last three cards.

Card 1-H_o, t_1, d, ℓ, mode number, option

These six quantities are here supplied separated by commas. Lengths are in meters. Mode number is o for the fundamental mode of the dispersion relation (21). Option is o for forward volume waves while option is 1 for backward volume waves.

*FORTRAN

Card 2 - ΔH, Δr, N, η, R_L

Here are entered these five quantities as defined earlier.

Card 3 - first ℓ_1, $\Delta\ell_1$, ℓ_1 option

Card 4 - first a, Δa, a option

Card 5 - first p, Δp, p option

In cards 3, 4 and 5 three items are entered for each of the quantities ℓ_1, a, p. For each card; if the option (third item) is o then the dimension is entered for the first strip (first item) and an increment is entered for the remaining strips (second item), but if the option (third item) is 1 then the dimension is entered for the first strip (first item) and the increment (second item) increments the next $\frac{N-1}{2}$ strips and is then a decrement for the last $\frac{N-1}{2}$ strips. The number of strips, N, must be odd if the option is 1. When there is no apodization the increment (second item) is o as is the option (third item).

Card 6 - heading for plots

Card 7 - heading for plots

Card 8 - heading for plots

These three lines will appear as headings, in the same order, on several plot frames.

```
      PROGRAM VOLIN(INPUT,OUTPUT)
C " OPN = 0 "--FORWARD VOLUME WAVES:;" OPN = 1 "--BACKWARD VOLUME WAVES
      DIMENSION PROGID(3),F(1201),FP(1201),FM(1201),CAP(1201),
     XCAM(1201),VGP(1201),VGM(1201)
      DIMENSION HEAD(7),HEAD1(7),HEAD2(7)
      DIMENSION FP(1201),PM(1201),RP(1201),RM(1201),RT(1201),
     X  PX(1201),SERP(1201),SERM(1201)
      COMMON D,EL,T1,S,C,UYY,PI,ENM,FCA,OPN,ETA,EN,EL1(30),PE(30),AA(30)
      READ *,H,T1,D,FL,ENM,OPN
      READ *,DELH,DIST,EN,ETA,RL
      READ *,ELBEGN,ELDEL,ELOPT
      READ *,ABEGIN,ADEL,AOPT
      READ *,PBEGIN,PDEL,POPT
      READ 100,HEAD
      READ 100,HEAD1
      READ 100,HEAD2
      N=EN
      DO 41 I=1,N
      EL1(I)=ELBEGN+(I-1)*ELDEL
      AA(I)=ABEGIN+(I-1)*ADEL
41    PE(I)=PBEGIN+(I-1)*PDEL
      NEL=(N+1)/2
      IF (ELOPT .EQ. 0.) GO TO 42
      DO 43 I=NEL,N
43    EL1(I)=EL1(NEL)-(I-NEL)*ELDEL
42    IF ( AOPT .EQ. 0.) GO TO 44
      DO 45 I=NEL,N
45    AA(I)=AA(NEL)-(I-NEL)*ADEL
44    IF (POPT .EQ. 0.) GO TO 46
      DO 47 I=NEL,N
47    PE(I)=PE(NEL)-(I-NEL)*PDEL
46    CONTINUE
      PRINT 60
      PRINT61,H,T1,D,FL,ENM
      PRINT *," DELTA H = ",DELH," DISTANCE =",DIST," OPTION = ",OPN
      PRINT *, "  R  LOSS  IS  ", RL," N = ",EN," ETA = ",ETA
      PRINT 81,(I,EL1(I),I=1,N)
      PRINT 82,(I,AA(I),I=1,N)
      PRINT 83,(I,PE(I),I=1,N)
      PRINT 60
      DATA PROGID/8HWEINBERG,4H2134,6HVOLUME/
      CALL PLTID3(PROGID,200.,12.,1.)
      PI=3.14159265
      NO=OPN
      SGN=(-1.)**NO
      PHI=0.
      IF (OPN .EQ.0.) THET=0.
      IF (OPN .EQ. 1.) THET=90.
      THET=THET*PI/180.
      ELL=0.
      CC=0.
      UO=4.*PI*1.E-7
      TMP=EL
      S=T1
      T=TMP
      FM=1750.
      GAM=2.8
      FLO=2.8*SQRT(H*(H+1750.*(SIN(THET))**2*(SIN(PHI))**2))
      FHI=2.8*SQRT(H*(H+1750.))
      FDEL=2.
      FBEG=AINT(FLO)+25.
      NF=INT(FHI)-INT(FLO)-38
      NF=NF/2
      DO 40 I=1,NF
40    F(I)=FBEG+(I-1)*FDEL
      TL=GAM**2*H*FM
      K=1
      I=1
      J=1
50    FF=F(K)
      TC=(GAM*H)**2-FF**2
      UYY=TL/TC*(SIN(THET))**2+1.
      UXX=TL/TC*((SIN(THET)*SIN(PHI))**2+(COS(THET))**2)+1.
      TEM=      -4.*UXX*UYY
      IF (TEM .LE. 0.) PRINT *," NEGATIVE SQUARE ROOT"
      IF (TEM .LE. 0.) GO TO 35
      U=SQRT(TEM)*.5/UYY
```


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```
      L=1
 30   IF (L .EQ. 2) GO TO 2
  1   S=1.
      GO TO 3
  2   S=-1.
  3   CONTINUE
       IF (J .GT. 1) GO TO 53
      CAO=ATAN(2.*C*UYY/((C*UYY)**2             -1.))/C/D
      IF (CAO .LT. 0.) CAO=CAO+ABS(PI/C/D)
      CAO=CAO+ABS(2NM*PI/C/D)
 53   CONTINUE
      IF (I .EQ. 1) GO TO 51
        IF (J .EQ. 1) GO TO 51
      IF(L .EQ. 1) CAO=CAP(I-1)
      IF(L .EQ. 2) CAO=CAM(J-1)
 51   M=1
  5   CONTINUE
      CA1=FT(CAO)
C     PRINT *,CAO,CA1,FCA
      IF (ABS((CA1-CAO)/CAO) .LT. .0001) GO TO 10
      CAO=CA1
      M=M+1
      IF(M .GT.15) GO TO 35
      GO TO 5
 10   IF (L .EQ. 2) GO TO 20
      CA=CA1
      IF (ABS(FCA ) .GT. 1.) GO TO 35
      IF (CA .LT. 0.) GO TO 35
      FP(I)=EF
      CAP(I)=CA
      I=I+1
C     PRINT *,"CA= ",CA,"F= ",EF
       L=2
       GO TO 30
 20   CA=CA1
      IF (ABS(FCA ) .GT. 1.) GO TO 35
      IF (CA .LT. 0.) GC TO 35
      FM(J)=EF
      CAM(J)=CA
      J=J+1
C     PRINT *,"CA= ",CA,"F= ",EF
       IF (J .EQ. I) GO TO 15
      IF (J .GT. I) GO TO 31
      I=J-1
      K=K-1
 31   J=J-1
 15   K=K+1
      IF (K .LE. NF) GC TO 50
      PRINT 62
      I1=I-1
      J1=J-1
      GC TO 24
 35   PRINT *,"ITERATION DOES NOT CONVERGE.F= ",EF," S= ",S
      IF (L .EQ. 2) GO TO 15
      L=2
      GC TO 2
 24   CONTINUE
      PRINT 63,(FP(LL),CAP(LL),LL=1,I1,5)
      PRINT 64,(FM(LL),CAM(LL),LL=1,J1,5)
      PRINT 62
      DC 21 I=1,I1
      IF (I .EQ. 1) VGP(I)=5./PI*(CAP(2)-CAP(1))/FDEL
      IF (I .EQ. I1) VGP(I)=5./PI*(CAP(I1)-CAP(I1-1))/FDEL
      IF (I .NE. 1 .AND. I .NE. I1) VGP(I)=
     X5./PI*(CAP(I+1)-CAP(I-1))/FDEL*.5
 21   CONTINUE
C     PRINT 37,(FP(I),VGP(I),I=1,I1,5)
      DC 22 J=1,J1
      IF (J .EQ. 1) VGM(J)=5./PI*(CAM(2)-CAM(1))/FDEL
      IF (J .EQ. J1) VGM(J)=5./PI*(CAM(J1)-CAM(J1-1))/FDEL
      IF (J .NE. 1 .AND. J .NE. J1) VGM(J)=
     X 5./PI*(CAM(J+1)-CAM(J-1))/FDEL*.5
 22   CONTINUE
C     PRINT 35,(FM(J),VGM(J),J=1,J1,5)
      S=1.
      DC 23 I=1,I1
      EF=FP(I)
```

```
      CA=CAP(I)
      TO=(GAM*H)**2-EF**2
      UYY=TO/TO* (SIN(THET))**2+1.
      UXX=TO/TO* ((SIN(THET)*SIN(PHI))**2+(COS(THET))**2)+1.
      TEM=          -4.*UXX*UYY
      C=SQRT(TEM)*.5/UYY
      C=2.*PI*EF*1.E6
      IF  (CFN .EQ. 0.)  ON=1.
      IF  (OPN .EQ. 1.)  ON=1./C**2
      P1=SGN*
     X     (C**2+1.)*D*CA-(C**2-1.)/2./C*SIN(2.*C*CA*D)+COS(2.*C*CA*D)
      P2=(COTH(CA*EL)-CA*EL*(CSCH(CA*EL))**2)*(.5*(C**2+1.)-SGN*(
     X .5*(C**2-1.)*COS(2.*C*CA*D)+C*SIN(2.*C*CA*D)))*ON
      R=ABS(2.*CA*T1)
      IF  (R .GT. 337.)  GO TO 56
      P3=2.*
     X      EXP(-2.*CA*T1)*(-2.*CA*T1+(C**2-1.)*D*CA-SGN*(C**2+1.)/2./C*
     XSIN(2.*C*CA*D)+SGN*(COTH(CA*EL)-CA*EL*(CSCH(CA*EL))**2)*
     X (.5*(C**2-1.)-SGN*.5*(C**2+1.)*COS(2.*C*CA*D))*ON)
      P4=EXP(-4.*CA*T1)*(SGN*
     X                      (C**2+1.)*D*CA-.5*(C**2-1.)/C*SIN(2.*C*CA*D)-
     XCOS(2.*C*CA*D)+(COTH(CA*EL)-CA*EL*(CSCH(CA*EL))**2)*(.5*(C**2+1.)
     X -SGN*(         .5*(C**2-1.)*COS(2.*C*CA*D)-C*SIN(2.*C*CA*D)))*ON)
      GO TO 55
56    P3=0.
      P4=0.
55    CONTINUE
      GECA=GE(CA)
      FP(I)=    D*UO* GECA    **2*(P1+P2+P3+P4)/4./CA**2
      RP(I)=ABS(FP(I))/((1.-ETA)+(1.+ETA)*EN**2)*4.
25    CONTINUE
      S=-1.
      DO 26 J=1,J1
      EF=FM(J)
      CA=CAM(J)
      TO=(GAM*H)**2-EF**2
      UYY=TO/TO* (SIN(THET))**2+1.
      UXX=TO/TO* ((SIN(THET)*SIN(PHI))**2+(COS(THET))**2)+1.
      TEM=          -4.*UXX*UYY
      C=SQRT(TEM)*.5/UYY
      C=2.*PI*EF*1.E6
      IF  (CFN .EQ. 0.)  ON=1.
      IF  (CFN .EQ. 1.)  ON=1./C**2
      P1=SGN*
     X     (C**2+1.)*D*CA-(C**2-1.)/2./C*SIN(2.*C*CA*D)+COS(2.*C*CA*D)
      P2=(COTH(CA*EL)-CA*EL*(CSCH(CA*EL))**2)*(.5*(C**2+1.)-SGN*(
     X .5*(C**2-1.)*COS(2.*C*CA*D)+C*SIN(2.*C*CA*D)))*ON
      R=ABS(2.*CA*T1)
      IF  (R .GT. 337.)  GO TO 49
      P3=2.*
     X      EXP(-2.*CA*T1)*(-2.*CA*T1+(C**2-1.)*D*CA-SGN*(C**2+1.)/2./C*
     XSIN(2.*C*CA*D)+SGN*(COTH(CA*EL)-CA*EL*(CSCH(CA*EL))**2)*
     X (.5*(C**2-1.)-SGN*.5*(C**2+1.)*COS(2.*C*CA*D))*ON)
      P4=EXP(-4.*CA*T1)*(SGN*
     X                      (C**2+1.)*D*CA-.5*(C**2-1.)/C*SIN(2.*C*CA*D)-
     XCOS(2.*C*CA*D)+(COTH(CA*EL)-CA*EL*(CSCH(CA*EL))**2)*(.5*(C**2+1.)
     X -SGN*(         .5*(C**2-1.)*COS(2.*C*CA*D)-C*SIN(2.*C*CA*D)))*ON)
      GO TO 48
49    P3=0.
      P4=0.
48    CONTINUE
      GECA=GE(CA)
      FM(J)=    D*UO* GECA    **2*(P1+P2+P3+P4)/4./CA**2
      RM(J)=ABS(FM(J))/((1.-ETA)+(1.+ETA)*EN**2)*4.
26    CONTINUE
      PRINT 71,(FP(I),RP(I),I=1,I1,10)
      PRINT 72,(FM(J),RM(J),J=1,J1,10)
      IF  (I1 .NE. J1)  GO TO 90
      DO 84 I=1,I1
84    RT(I)=RP(I)+RM(I)
      PRINT 58
      PRINT 75,(FP(I),RT(I),I=1,I1,10)
      FP1=FP(1)
      FPL=FP(I1)
      CALL FTRAN(RT,PX,I1,FP1,FPL)
      PRINT 60
      M=I1-1
```

```
      PRINT 73,(FP(I),FX(I),I=1,M ,20)
      DO 54 I=1,M
       XL=2.*PI*FP(I)*ELL
      XL=XL*1.E5
      L=I
      IF (I .EQ. 1) L=2
      SERP(I)= 20.*ALOG10((4.*RP(I)/RG)/
     X  ((1.+(PT(I)+PL)/RG)**2
     X                      +((PX(I)+XL)/RG)**2))
      SERP(I)=SERP(I)-76.4*DELH*DIST/
     X(2.*PI*1.E6*(FP(I+1)-FP(L-1))/(CAP(I+1)-CAP(L-1)))
      SERM(I)= 20.*ALOG10((4.*RM(I)/RG)/
     X  ((1.+(PT(I)+PL)/RG)**2
     X                      +((PX(I)+XL)/RG)**2))
      SERM(I)=SERM(I)-76.4*DELH*DIST/
     X(2.*PI*1.E6*(FM(I+1)-FM(L-1))/(CAM(I+1)-CAM(L-1)))
 54   CONTINUE
      PRINT 81
      PRINT 77,(FP(I),SERP(I),I=1,M ,10)
      PRINT 80
      PRINT 78,(FP(I),SERM(I),I=1,M ,10)
      FBEGO=.01*FBEG
      XMIN=AINT(FBEGO)*100.
      XX=AINT(.01*FHI)-AINT(.01*FLO)+1.
      DX=200.
      YMIN=0.
      DY=1.E5
      DO 13 I=1,I1
      IF (CAP(I) .GT. 1.E6) CAP(I)=1.E6
      VGP(I)=ABS(VGP(I))
 13   IF (VGP(I) .GT. 1000.) VGP(I)=1000.
      DO 14 J=1,J1
      IF (CAM(J) .GT. 1.E6) CAM(J)=1.E6
      VGM(J)=ABS(VGM(J))
 14   IF (VGM(J) .GT. 1000.) VGM(J)=1000.
      Z=11.
      X=10.
      YY=10.
      XX=10.
      CALL PLOT(1.5,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,0.,26HWAVE NUMBER K(+) (1/METER),26,X,90.,YMIN,DY,YY)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z  ,0.,XMIN,DX,YY)
      CALL LINE (FM,CAM,
     X                  J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT (16.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,0.,26HWAVE NUMBER K(-) (1/METER),26,X,90.,YMIN,DY,YY)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z  ,0.,XMIN,DX,YY)
      CALL LINE(FP,CAP,
     X                  I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DY=100.
      CALL PLOT(15.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,0.,
     X               25HGROUP DELAY/CM (+) (NSEC),25,XX ,90.,YMIN,DY,YY)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z  ,0.,XMIN,DX,YY)
      CALL LINE(FM,VGM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(15.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,0.,
     X               25HGROUP DELAY/CM (-) (NSEC),25,XX ,90.,YMIN,DY,YY)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z  ,0.,XMIN,DX,YY)
      CALL LINE(FP,VGP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      YMIN=0.
      DY=30.
      DO 27 I=1,I1
      IF (RP(I) .GT. 300.) RP(I)=300.
      IF(RP(I) .GT. 2000.) RP(I)=2000.
```

```
27    CONTINUE
      CALL PLOT(10.,0.,-3)
      CALL AXIS (0.,0.,27HRAD. RES., MINUS WAVE (OHMS),27,10.,90.,
     X  YMIN,DY,10.)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FP,RP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DO 25 J=1,J1
      IF (RM(J) .GT.  300.) RM(J)=300.
      IF (RM(J) .GT.  2000.) RM(J)=2000.
      IF (RT(J) .GT.  300.) RT(J)=300.
      IF (RT(J) .GT.  2000.) RT(J)=2000.
25    CONTINUE
      CALL PLOT(17.,0.,-3)
      CALL AXIS (0.,0.,27HRAD. RES., PLUS WAVE (OHMS),27,10.,90.,
     X  YMIN,DY,10.)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FM,RM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(17.,0.,-3)
      CALL AXIS(0.,0.,22HRAD. RES. TOTAL (OHMS),22,10.,90.,YMIN,DY,10.)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FP,RT,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      I1=M
      J1=M
      YMIN=-10000.
      YMIN=-250.
      DY=2000.
      DY=50.
      DO 32 I=1,I1
      IF (PX(I) .LT.  -10000.) PX(I)=-10000.
      IF (PX(I) .LT.  -250.) PX(I)=-250.
      IF (PX(I) .GT.  10000.) PX(I)=10000.
      IF (PX(I) .GT.   250.) PX(I)=250.
32    CONTINUE
      CALL PLOT(17.,0.,-3)
      CALL AXIS(0.,0.,22HRAD. REAL TOTAL (OHMS),22,10.,90.,YMIN,DY,10.)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FP,PX,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DO 33 I=1,I1
       IF (SERP(I) .LT. -60. ) SERP(I)=-60.
       IF (SERM(I) .LT. -80. ) SERM(I)=-80.
33    CONTINUE
      YMIN=-60.
       DY=10.
      CALL PLOT(14.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,0.,26H-INS. LOSS,MINUS WAVE (DB),26, 8.,90.,YMIN,
     X  DY,10.)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FP,SERP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(14.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,0.,26H-INS. LOSS, PLUS WAVE (DB),26, 8.,90.,YMIN,
     Y  DY,10.)
      CALL AXIS(0.,0.,15HFREQUENCY (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FM,SERM,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL ENDPLT
      STOP
91    PRINT 76
      STOP
60    FORMAT(1H1)
61    FORMAT(5X," H= ",E15.7/5X," T1= ",E15.7/5X," L= ",E15.7/
     X                  5X," L= ",E15.7/                         5X,"MODE= ",F8.0)
62    FORMAT(//1X(5E15.5/))
63    FORMAT(///50X,"S=1"//(10X,"F= ",E15.7,10X,"K  (-) =  ",E15.7/))
64    FORMAT(///50X,"S=-1"//(10X,"F= ",E15.7,10X,"K  (+) = ",E15.7/))
71    FORMAT(///(10X,"F= ",E15.7,10X,"RAD. RES. (-)  = ",E15.7/))
72    FORMAT(///(10X,"F= ",E15.7,10X,"RAD. RES. (+)   = ",E15.7/))
73    FORMAT( //(10X,"F= ",E15.7,10X,"RAD. REAL. TOTAL= ",E15.7/))
75    FORMAT(///(10X,"F= ",E15.7,10X,"RAD. RES. TOTAL = ",E15.7/))
76    FORMAT ("1  A K ROOT EXISTS FOR ONE WAVE ONLY")
77    FORMAT(//(10X,"F= ",E15.7,10X,"INS. LOSS  (-) = ",E15.7/))
78    FORMAT(//(10X,"F= ",E15.7,10X,"INS. LOSS (+)  = ",E15.7/))
87    FORMAT("    F=  ",E15.7,"    GROUP DELAY (-) =  ",E15.7)
```

```
81    FORMAT(//(10X,"L1(",I4,")= ",E15.7/))
82    FORMAT(//(10X," A(",I4,")= ",E15.7/))
83    FORMAT(//(10X," P(",I4,")= ",E15.7/))
85    FORMAT(/(10X," F= ",E15.7,10X,"GROUP DELAY (*) = ",E15.7/))
100   FORMAT(7A10)
      END

      FUNCTION COTH(CA)
      COTH    =1./TANH(CA)
      RETURN
      END

      FUNCTION COT(CA)
      COT      =1./TAN(CA)
      RETURN
      END

      FUNCTION FI(CA)
      COMMON D,EL,T1,S,C,UYY,PI,ENM,FCA
      A=2.*CA*T1
      A=ABS(A)
      IF(A .GT. 675.) GO TO 5
      A1=       COTH(CA*EL)+1.-EXP(-2.*CA*T1)*  (COTH(CA*EL)-1.)
      GO TO 6
5     A1=       COTH(CA*EL)+1.
6     CONTINUE
      B1=-1. +COTH(CA*EL)*  (C*UYY)**2
      IF  (A  .GT.  675.) GO TO 2
      C1=EXP(-2.*CA*T1)*(-1.
     X  -COTH(CA*EL)*  (C*UYY)**2)
      GO TO 3
2     C1=0.
3     CONTINUE
      FI= ATAN(C*UYY*A1/(B1-C1))          /C/D
      IF  (FI   .LT.  0.)  FI =FI  +ABS(PI/C/D)
       FI=FI  +ABS(ENM*PI/C/L)
      FCA=A1*C*UYY*COT(C*CA*D)-B1+C1
      RETURN
      END

      FUNCTION CSCH(CA)
      CSCH=0.
      IF  (CA  .LE.  740.)  CSCH=1./SINH(CA)
      RETURN
      END

      FUNCTION SINC(CA)
      PI=3.14159265
      SINC=(SIN(PI*CA))/(PI*CA)
      RETURN
      END
```

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```
      FUNCTION FT1(CA)
      COMMON D,EL,T1,S,C,UYY,PI,ENM,FCA,OPN
      IF (OPN .EQ. 0.)
     XFT2=(((C**2+1.)*D-C**2*EL*((CSCH(CA*EL))**2)*SIN(C*CA*D)+
     X(C*(C**2+1.)*COTH(CA*EL)+EL*(CSCH(CA*EL))**2)*C*COS(C*CA*D))
     X*S*EXP(-CA*D)
      IF (OPN .EQ. 1.)
     XFT2=(((C**2+1.)*C*COTH(CA*EL)+EL*(CSCH(CA*EL))**2)*SIN(C*CA*D)+
     X((C**2+1.)+EL*(CSCH(CA*EL))**2)*C*COS(C*CA*D))
     X*S*EXP(-CA*D)
      B=ABS (CA*(D+2.*T1))
      IF (B .GT. 87.) GO TO 3
      IF (OPN .EQ. 0.)
     XFT3=D*(C**2*COTH(CA*EL)+1.)-EL*(CSCH(CA*EL))**2-(2.*T1+D)*
     X  (COTH(CA*EL)-1.)
      IF (OPN .EQ. 1.)
     XFT3=-(D+2.*T1)*(COTH(CA*EL)-1.)-EL*(CSCH(CA*EL))**2-
     X  D*(C**2+COTH(CA*EL))
      IF (OPN .EQ. 0.)
     XFT4=(D+2.*T1)*(C**2*COTH(CA*EL)+1.)+C**2*EL*(CSCH(CA*EL))**2+
     X  C**2*D*(COTH(CA*EL)-1.)
      IF (OPN .EQ. 1.)
     XFT4=-(D+2.*T1)*(C**2+COTH(CA*EL))-EL*(CSCH(CA*EL))**2+
     X  C**2*D*(COTH(CA*EL)-1.)
      FT1=S*EXP(-CA*(D+2.*T1))*(C*COS(C*CA*D)*FT3-SIN(C*CA*D)*FT4)/C
     X  +FT2/C
      GO TO 2
    3 FT1=FT2/C
    2 CONTINUE
      RETURN
      END

      FUNCTION GAY(CA)
      COMPLEX E,CS
      COMMON D,EL,T1,S,C,UYY,PI,ENM,FCA,OPN,ETA,EN,EL1(30),PE(30),AA(30)
      N=EN
      E=CMPLX(0.,0.)
      DO 1 I=1,N
      CS=CMPLX(COS(CA*I*PE(I)),-SIN(CA*I*PE(I)))
      E=E+SINC(.5*AA(I)*CA/PI)*ETA**I*SQRT(EL1(I))*CS
    1 CONTINUE
      GAY=CABS(E)
      RETURN
      END



      FUNCTION GE(CA)
      COMMON D,EL,T1,S,C,UYY,PI,ENM,FCA
      GE    =ABS(GAY(CA) *EXP(-  CA*D)/FT1(CA))
      RETURN
      END
```

```
      SUBROUTINE HTRAN(R,X,N,FBEG,FEND)
      DIMENSION R(3),X(3)
      PI=3.14159265359
      FDEL=(FEND-FBEG)/(N-1)
      F=FBEG+.5*FDEL
      INC=MOD(N,2)
      NI=N+INC-1
       NM1=N-1
      NIM2=NI-2
      DO 33 I=1,NM1
      X(I)=0.
      IF (I .EQ. 1) RX=(3.*R(1)+6.*R(2)-R(3))/8.
      IF (I .EQ. NM1) RX=(-R(N-2)+6.*R(NM1)+3.*R (N))/8.
      IF (I .EQ. 1 .OR. I .EQ. NM1) GO TO 20
      RX=(-R(I-1)+9.*R(I)+9.*R(I+1)-R(I+2))/16.
20    CONTINUE
      FI=FBEG
      DO 20 IP=1,NIM2,2
      X(I)=X(I)+4.*(R(IP+1)-RX)/((FI+FDEL)**2-F**2)
     X            +2.*(R(IP  )-RX)/(  FI         **2-F**2)
      FI=FI+2.*FDEL
20    CONTINUE
      FEN=FEND
      IF(INC .EQ. 0 ) FEN=FEND-FDEL
      X(I)=X(I)+ (R(NI)-RX)/(FEN**2-F**2)
     X            - (R(1  )-RX)/(FBEG**2-F**2)
      X(I)=FDEL/3.*X(I)
      IF(INC .EQ.1) GO TO 30
      X(I)=X(I)+.5*FDEL* ((R(NI)-RX)/(FEN**2-F**2)
     X            + (R(N)-RX)/(FEND**2-F**2))
30    X(I)=2./PI*F*X(I)+RX/PI*ALOG
     X ((1.-F/FEND)/(1.+F/FEND)*(F+FBEG)/(F-FBEG))
      F=F+FDEL
33    CONTINUE
      NM2=N-2
      X1=(15.*X(1)-10.*X(2)+3.*X(3))/8.
       X2=(3.*X(1)+6.*X(2)-X (3))/8.
      DO 31 I=3,NM2
      XT=(-X(I-2)+9.*X(I-1)+9.*X(I)-X(I+1))/16.
      X(I-2)=X1
      X1=X2
      X2=XT
31    CONTINUE
      X(N)=(15.*X(NM1)-10.*X(NM2)+3.*X(N-3))/8.
      X(N-1)=(3.*X(NM1)+6.*X(NM2)-X(N-3))/8.
      X(N-2)=X2
      X(N-3)=X1
      RETURN
      END
```

B. Dispersion Relation - Generalized Volume Waves

A computer program has been implemented on the CDC 6600 at Hanscom AFB, MA which obtains the dispersion relation and group delay for volume waves of arbitrary orientation of the biasing field. Plots on the Calcomp plotter at Hanscom AFB as well as computer printouts are produced for the wave number and group delay as functions of frequency. One can choose the solution mode for the dispersion relation (42). The frequency range is determined by the program from (43).

The use of the input cards to this program now follows

Card 1- H_o, t_1, d, θ, ℓ, ϕ, mode number

Seven quantities, separated by commas, are supplied here. All lengths are measured in meters. Angles are measured in degrees. Their orientations can be determined from figure 1. For the fundamental mode the mode number is o. Columns 1-72 may be used

Card 2- heading for plots

Card 3- heading for plots

Here, there are two lines supplied, in order, which are used as headings on several plot frames. Columns 1-70 may be used on each card.

```
C     THETA=90 DEG    ------------    BACKWARDS VOLUME WAVES
C      PHI=90 DEG   -----------------    FORWARD VOLUME WAVES
      PROGRAM VOLM(INPUT,OUTPUT)
      DIMENSION PROGID(3)
      DIMENSION F(1201),FP(1201),FM(1201),CAP(1201),CAM(1201),
     X  VGP(1201),VGM(1201),ELAP(1201),ELAM(1201)
      DIMENSION HEAD1(7),HEAD2(7)
      COMMON D,EL,TL,S,C,UYY,UYXYYI,PI,ENM,FCA
      READ *,H,T1,D,THET,EL,PHI,ENM
      READ 10 ,HEAD1
      READ 100,HEAD2
      PRINT 60
      PRINT 61,H,T1,D,THET,EL,PHI,ENM
      PRINT 62
      DATA PROGID/8HSCIHARES,4H110,1 HJ.WEINERFG/
      CALL PLTID3(PROGID,10.,12.,1 )
      PI=3.1415926
      THET=THET*PI/180.
      PHI=PHI*PI/180.
      TMP=EL
      EL=1
      T1=TMP
      EM=1750.
      GAM=2.8
      FLO=2.8*SQRT(H*(H+1750.*(SIN(THET))**2*(SIN(PHI))**2))
      FHI=2.8*SQRT(H*(H+1750.))
      FDEL=2.
      FREG=AINT(FLO)+25.
      NF=INT(FHI)-INT(FLO)-35
      NF=NF/2
      DO 40 I=1,NF
   40 F(I)=FREG+(I-1)*FDEL
      IF (F(1) .LT. FLO) PRINT *,"FREQUENCIES TOO LOW"
      IF (F(NF) .GT. FHI) PRINT *,"FREQUENCIES TOO HIGH"
      TL=GAM**2*H*EM
      K=1
       I=1
       J=1
   50 EF=F(K)
      TD=(GAM*H)**2-EF**2
      T2=GAM*EM*EF
      UYY=TU/TD*(SIN(THET))**2+1.
      UXX=TU/TD*((SIN(THET)*SIN(PHI))**2+(COS(THET))**2)+1.
      UXYYX=-2.*TU/TD*COS(THET)*COS(PHI)*SIN(THET)
      UYXYYI=T2/TD*SIN(THET)*SIN(PHI)
      TEM=UXYYX**2-4.*UXX*UYY
      L=2
      IF (TEM .LE. 0.) PRINT *,"  NEGATIVE SQUARE ROOT"
      IF (TEM .LE. 0.) GO TO 35
      C=SQRT(TEM)/2./UYY
      L=1
   30 IF (L .EQ. 2) GO TO 2
    1 S=1.
      GO TO 3
    2 S=-1.
    3 CONTINUE
       IF (J .GT. 1) GO TO 53
      CAO=ATAN(2. C UYY/((C*UYY)**2+UYXYYI*(-1.)))/C/D
      IF (CAO .LT. 0.) CAO=CAO+ABS(PI/C/D)
      CAO=CAO+ABS(ENM*PI/C/D)
   53 CONTINUE
      IF (I .EQ. 1) GO TO 51
        IF (J .EQ. 1) GO TO 51
      IF(L .EQ. 1) CAO=CAP(I-1)
      IF(L .EQ. 2) CAO=CAM(J-1)
   51 M=1
    5 CONTINUE
      CA1=FT(CAO)
C     PRINT *,CAO,CA1,FCA
      IF (ABS((CA1-CAO)/CAO) .LT. .001) GO TO 10
      CAO=CA1
      M=M+1
      IF(M .GT.15) GO TO 35
      GO TO 5
   10 IF (L .EQ. 2) GO TO 20
      CA=CA1
      IF (ABS(FCA ) .GT. 1.) GO TO 35
```

```
      IF (CA .LT. 0.) GO TO 35
      FP(I)=EF
      CAP(I)=CA
      I=I+1
C     PRINT *,"CA= ",CA,"F= ",EF
       L=2
       GO TO 50
   20 CA=CA1
      IF (ABS(FCA ) .GT. 1.) GC TO 35
      IF (CA .LT. 0.) GO TO 35
      FM(J)=EF
      CAM(J)=CA
      J=J+1
C     PRINT *,"CA= ",CA,"F= ",EF
       IF (J .EQ. I) GC TO 15
      IF (J .GT. I) GO TC 31
      I=J-1
      K=K-1
   31 J=J-1
   15 K=K+1
      IF (K .LE. NF) GC TO 50
      PRINT 60
      I1=I-1
      J1=J-1
      GC TO 24
   35 PRINT *,"ITERATICN DOES NOT CONVERGE.F= ",EF," S= ",S
      IF (L .EQ. 2) GO TC 15
      L=2
      GC TO 2
   24 CONTINUE
      PRINT 63,(FP(LL),CAP(LL),LL=1,I1,5)
      PRINT 64,(FM(LL),CAM(LL),LL=1,J1,5)
      PRINT 65
      DC 11 I=1,I1
   11 ELAP(I)=2.*PI/CAP(I)*1.E6
      DC 12 J=1,J1
   12 ELAM(J)=2.*PI/CAM(J)*1.E6
C     PRINT 65,(FP(LL),ELAP(LL),LL=1,I1,5)
C     PRINT 66,(FM(LL),ELAM(LL),LL=1,J1,5)
      DC 21 I=1,I1
      IF (I .EQ. 1) VGP(I)=5./PI*(CAP(2)-CAP(1))/FDEL
      IF (I .EQ. I1) VGP(I)=5./PI*(CAP(I1)-CAP(I1-1))/FDEL
      IF (I .NE. 1 .AND. I .NE. I1) VGP(I)=
     X5./PI*(CAP(I+1)-CAP(I-1))/FDEL*.5
   21 CONTINUE
C     PRINT 67,(FP(I),VGP(I),I=1,I1,5)
      DC 22 J=1,J1
      IF (J .EQ. 1) VGM(J)=5./PI*(CAM(2)-CAM(1))/FDEL
      IF (J .EQ. J1) VGM(J)=5./PI*(CAM(J1)-CAM(J1-1))/FDEL
      IF (J .NE. 1 .AND. J .NE. J1) VGM(J)=
     X 5./PI*(CAM(J+1)-CAM(J-1))/FDEL*.5
   22 CONTINUE
C     PRINT 65,(FM(J),VGM(J),J=1,J1,5)
       XMIN=2500.
      XMIN=4200.
      XMIN=7000.
      DX=100.
      DY=200.
      YMIN=0.
      DY=1000.
      DY=1.25
      DC 13 I=1,I1
      IF (CAP(I) .GT. 1.E6) CAP(I)=1.E6
      IF (ELAP(I) .GT. 1000.  ) ELAP(I)=1000
      VGP(I)=ABS(VGP(I))
   13 IF (VGP(I) .GT. 1000.) VGP(I)=1000.
      DC 14 J=1,J1
      IF (CAM(J) .GT. 1.E6) CAM(J)=1.E6
      IF (ELAM(J) .GT. 1000.  ) ELAM(J)=1000.
      VGM(J)=ABS(VGM(J))
   14 IF (VGM(J) .GT. 1000.) VGM(J)=1000.
      Z=11.
      X=1.
      YY=10.
      XX=10.
      CALL PLOT(1.5,0.,-3)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,7 )
```

```
      CALL SYMBOL(.,9.4,.1,HEAD2,0,7 )
      CALL AXIS(0.,  .,26HWAVE NUMBER K(+)  (1/METER),26,X,90.,YMIN,DY,YY)
      CALL AXIS(0., ., ,15HFREQUENCY  (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE (FM,GAM,
     X              J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT (10.,0.,-3)
      CALL SYMBOL(.,9.6,.1,HEAD1,0,7.)
      CALL SYMBOL(. ,9.4,.1,HEAD2,0,7 )
      CALL AXIS(0.,  .,26HWAVE NUMBER K(-)  (1/METER),26,X,90.,YMIN,DY,YY)
      CALL AXIS(0.,  .,15HFREQUENCY  (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FP,GAP,
     X              I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DY=10..
      CALL PLOT  (13 ,0.,-3)
      CALL SYMBOL(.,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,  ,24HWAVELENGTH  (+)  (MICRONS),24,XX,90.,YMIN,DY,YY)
      CALL AXIS(0.,  .,15HFREQUENCY  (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE  (FM,ELAM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT  (13 ,0.,-3)
      CALL AXIS(0.,  ,24HWAVELENGTH  (-)  (MICRONS),24,XX,90.,YMIN,DY,YY)
      CALL AXIS(0.,  .,15HFREQUENCY  (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE  (FP,ELAP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(10.,0.,-3)
      CALL SYMBOL(.,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.,9.4,.1,HEAD2,0,7.)
      CALL AXIS(0.,  .,
     X             25HGROUP  DELAY/CM  (+)  (NSEC),25,XX  ,90.,YMIN,DY,YY)
      CALL AXIS(0.,  .,15HFREQUENCY  (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FM,VGM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(10.,0.,-3)
      CALL SYMBOL(.,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.,9.4,.1,HEAD2,0,70)
      CALL AXIS(0.,  .,
     X             25HGROUP  DELAY/CM  (-)  (NSEC),25,XX  ,90.,YMIN,DY,YY)
      CALL AXIS(0. ,  .,15HFREQUENCY  (MHZ),-15,Z   ,0.,XMIN,DX,YY)
      CALL LINE(FP,VGP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL ENDPLT
      STOP
 60   FORMAT(1H1)
 61   FORMAT(5X," H= ",E15.7/5X," T = ",E15.7/5X," D= ",E15.7/
     X" THETA=",E15.7/5X," L= ",E15.7/5X,"PHI= ",E15.7/5X,"MODE= ",F8.0)
 62   FORMAT(//10(5E15.5/))
 63   FORMAT(///50X,"S=1"//(10X,"F= ",E15.7,10X,"K  (-)=  ",E15.7/))
 64   FORMAT(///5 X,"S=-1"//(10X,"F= ",E15.7,10X,"K  (+) = ",E15.7/))
 65   FORMAT(///5 X,"S=1"//(10X,"F= ",E15.7,10X,"LAM(-)=  ",E15.7/))
 66   FORMAT(///5 X,"S=-1"//(10X,"F= ",E15.7,10X,"LAM(+) = ",E15.7/))
 87   FORMAT("   F=  ",E15.7,"     GROUP DELAY (-) =  ",E15.7)
 85   FORMAT(/(10X," F= ",E15.7,10X,"GROUP DELAY (+) = ",E15.7/))
 100  FORMAT(7A10)
      END
```

```
      FUNCTION COTH(CA)
      COMMON D,EL,T1,S,C,UYY,UYXYYI
      IF (CA .GT. 17.3) GO TO 3
      IF (CA .LT. -17.3) GO TO 4
      COTH     =1./TANH(CA)
      GO TO 2
3       COTH=1.
      GO TO 2
4     COTH=-1.
2      CONTINUE
      RETURN
      END
```

```
      FUNCTION COT( A)
      COMMON D,EL,T1,S,C,UYY,UYXYYI
      COT      =1./TAN(CA)
      RETURN
      END
```

```
      FUNCTION FT(CA)
      COMMON D,EL,T1,S,C,UYY,UYXYYI,PI,ENM,FCA
      A=2.*CA*T1
      A=ABS(A)
      IF(A .GT. 675.) GO TO 5
      A1=        COTH((A*EL)+1.-EXP(-2.*CA*T1)   (COTH(CA*EL)-1.)
      GO TO 6
5     A1=        COTH(CA*EL)+1.
6     CONTINUE
      B1=          (COTH(CA*EL)-1.)*S*UYXYYI-1
      F1=F1   +COTH(CA*EL)*((C*UYY)**2+UYXYYI**2)
      IF (A .GT.   675.) GO TO 2
      C1=EXP(-2.*CA*T1)*((COTH(CA*EL)+1.)*S*UYXYYI-1.
     X  -COTH(CA*EL)*((C*UYY)**2+UYXYYI**2))
      GO TO 3
2     C1= .
 3    CONTINUE
      FT= ATAN(C*UYY*A1/(B1-C1))              /C/D
      IF (FT   .LT.   .) FT =FT +ABS(PI/C/D)
       FT=FT  +ABS(ENM*PI/C/L)
      FCA=A1+C*UYY*COT(C*CA*D)-B1+C.
      RETURN
      END
```

C. Hyperbolic Current Distribution - Surface Waves

There is a surface wave program operational on the CDC 6600 at Hanscom AFB which employs the hyperbolic current distribution described earlier. The program produces plots and printout for quantities of interest for surface waves. The option for a truncated array of normal modes is eliminated from this program. Otherwise, the program is similar to the basic theory surface wave program described in the Interim Technical Report. The number of input cards is the same as in the earlier program and the use of most of them is the same. We here describe only those cards whose functions differ from the earlier version.

Card 5 - ΔH, Δr, δ_1, option, R_L

Here, there are five items to be input, with the first two, ΔH and Δr, already described. The third item is δ_1 which enters (47). The fourth item is an option. If the option is set 1 then (48) is used for the transform of the current distribution. If the option is o then (51) is used for the transform of the current distribution. The fifth item is conduction loss which is now to be input at this point.

Card 6- heading for plots

This is the first line for the heading for several plot frames. Columns 1-70 may be used. There is no indication now for an array of normal modes.

```
      PROGRAM POCT (INPUT,OUTPUT)
      DIMENSION PROGID(3)
      DIMENSION F(1200),FM(1200),FP(1200),CAP(1200),CAM(1200),VGM(1200),
     XPP(1200),PM(1200),RP(1200),RM(1200),R1(1200),FX(1200),SERP(1200),
     XSERM(1200),VNM(1200),VGP(1200)
      DIMENSION HEAD(7),HEAD1(7),HEAD2(7),HEAD3(7)
      DIMENSION FN(50),VM(50)
      COMMON EL,AL1,AL2,E,D,T1,G,S,ETA,EN,P,AY,A,EL1(40),PE(40),AA(40)
     X,LMODE,DEL1,JOPT
      READ *,H,T1,D,G,EL,EN,ETA
      READ *,ELBEGN,ELDEL,ELOPT
      READ *,ABEGIN,ADEL,AOPT
      READ *,PBEGIN,PDEL,POPT
      READ *,DELH,DIST,DEL1, JOPT,RL
      READ 100,HEAD
      READ 100,HEAD1
      READ 100,HEAD2
      READ 100,HEAD3
      LMODE=1
      IF (HEAD(1) .EQ. "NORM MODE ") LMODE=2
      N=EN
      DO 41 I=1,N
      EL1(I)=ELBEGN+(I-1)*ELDEL
      AA(I)=ABEGIN+(I-1)*ADEL
41    PE(I)=PBEGIN+(I-1)*PDEL
      NEL=(N+1)/2
      IF (ELOPT .EQ. 0.) GO TO 42
      DO 43 I=NEL,N
43    EL1(I)=EL1(NEL)-(I-NEL)*ELDEL
42    IF ( AOPT .EQ. 0.) GO TO 44
      DO 45 I=NEL,N
45    AA(I)=AA(NEL)-(I-NEL)*ADEL
44    IF (POPT .EQ. 0.) GO TO 46
      DO 47 I=NEL,N
47    PE(I)=PE(NEL)-(I-NEL)*PDEL
46    CONTINUE
      FLO=2.8*SQRT(H*(H+1750.))
      FHI=2.8*(H+875.)
      FDEL=1.
      FBEG=AINT(FLO)+1.
      NF=INT(FHI)-INT(FLO)-1
      DO 40 I=1,NF
40    F(I)=FBEG+(I-1)*FDEL
      IF (F(1) .LT. FLO) PRINT *,"FREQUENCIES TOO LOW"
      IF (F(NF) .GT. FHI) PRINT *,"FREQUENCIES TOO HIGH"
      PRINT 60
      FACT=1.
      IF (ETA .GT. -2.) GO TO 4
      ETA=-1.
      FACT=(2./EN)**2
      PRINT *,"   PI GRATING CASE"
4     CONTINUE
      PRINT 61,H,T1,D,G,EL    ,EN,ETA,NF
      PRINT *,"  DELTA H = ",DELH,"  DISTANCE =",DIST
      PRINT *, "  R  LOSS  IS   " , RL
      PRINT *,"  DELTA =  ",DEL1
      PRINT 81,(I,EL1(I),I=1,N)
      PRINT 82,(I,AA(I),I=1,N)
      PRINT 83,(I,PE(I),I=1,N)
      PRINT 60
      IF (ETA .EQ. -1.) ELL =.87*.4E-6*EN
       IF (ETA .EQ. 1.) ELL=.23*.4E-6/EN
      ELL=0.
      DATA PROGID/8HSETHARES,4H3724,10HJ.WEINBERG/
      CALL PLTID3(PROGID,200.,12.,1.)
      P=0.
      A=0.
      AY=0.
      PI=3.14159265 4
      RO=50.
      AYT=.5*AY*((1.-ETA)+EN*(1.+ETA))
      UO=4.*PI*1.E-7
      K=1
      I=1
      J=1
      CMH=H/1750.
50    DF=F(K)
```

```
      CM=EF/(2.6*1750.)
      U11=1.-OMH/(CM**2-CMH**2)
      U22=U11
      U12=CM/(OM**2-OMH**2)
      B=SQRT(U11/U22)
      L=1
30    IF (L .EQ. 2) GO TO 2
1     S=1.
      GO TO 3
2     S=-1.
3     CONTINUE
      AL1=U22*B+S*U12
      AL2=U22*B-S*U12
       IF (J .GT. 1) GO TO 53
      CAO=.5*SQRT(U22/U11)*ALOG(1.+4.*SQRT(U11*U22)/
     X(U12**2-(SQRT(U11*U22)+1.)**2))
      CAO=CAO/D
53    CONTINUE
      IF (I .EQ. 1) GO TO 51
        IF (J .EQ. 1) GO TO 51
      IF(L .EQ. 1) CAO=CAP(J-1)
      IF(L .EQ. 2) CAO=CAM(J-1)
51    M=1
5     DEL=.02*CAO
      CAOP=CAO+DEL
      CAOM=CAO-DEL
      CAOD=CAO*D
      CAOD=ABS(CAOD)
      CAOG=ABS(CAO*G)
      IF(CAOD .GT. 650.) GO TO 35
      IF(CAOG .GT. 650.) GO TO 35
      FTOO=FT(CAO)
      FTOP=FT(CAOP)
      FTOM=FT(CAOM)
      CA1=CAO-2.*DEL*FTOO/(FTOP-FTOM)
      IF(ABS(CA1) .GT. 1.E7) GO TO 35
      CA1D=CA1*D
      CA1D=ABS(CA1D)
      CA1G=ABS(CA1*G)
      IF(CA1D .GT. 650.) GO TO 35
      IF(CA1G .GT. 650.) GO TO 35
      FTO1=FT(CA1)
      IF (ABS((CA1-CAO)/CAO) .LT.  .001) GO TO 10
      CAO=CA1
      M=M+1
      IF(M .GT.10) GO TO 35
      GO TO 5
10    IF (L .EQ. 2) GO TO 20
      CA=CA1
      IF (ABS(FTO1) .GT. 1.) GO TO 35
      IF (CA .LT. 0.) GO TO 35
      FP(I)=EF
      CAP(I)=CA
      I=I+1
      L=2
      GO TO 30
20    CA=CA1
      IF (ABS(FTO1) .GT. 1.) GO TO 35
      IF (CA .LT. 0.) GO TO 35
      FM(J)=EF
      CAM(J)=CA
      J=J+1
       IF (J .EQ. I) GO TO 15
      IF (J .GT. I) GO TO 31
      I=J-1
      K=K-1
31    J=J-1
15    K=K+1
      IF (K .LE. NF) GO TO 50
      PRINT 60
      I1=I-1
      J1=J-1
      GO TO 24
35    PRINT *,"ITERATION DOES NOT CONVERGE.F= ",EF," S= ",S
      IF (L .EQ. 2) GO TO 15
      L=2
      GO TO 2
```

```
24    CONTINUE
      PRINT 63,(FP(I),CAP(I),I=1,I1,10)
      PRINT 64,(FM(J),CAM(J),J=1,J1,10)
      PRINT 60
      DO 22 J=1,J1
      IF (J .EQ. 1) VGM(J)=5./PI*(CAM(2)-CAM(1))/FDEL
      IF (J .EQ. J1) VGM(J)=5./PI*(CAM(J1)-CAM(J1-1))/FDEL
      IF (J .NE. 1 .AND. J .NE. J1) VGM(J)=
     X 5./PI*(CAM(J+1)-CAM(J-1))/FDEL*.5
22    CONTINUE
      PRINT 85,(FM(J),VGM(J),J=1,J1,10)
       PRINT 60
      DO 21 I=1,I1
      IF (I .EQ. 1) VGP(I)=5./PI*(CAP(2)-CAP(1))/FDEL
      IF (I .EQ. I1) VGP(I)=5./PI*(CAP(I1)-CAP(I1-1))/FDEL
      IF (I .NE. 1 .AND. I .NE. I1) VGP(I)=
     X5./PI*(CAP(I+1)-CAP(I-1))/FDEL*.5
21    CONTINUE
      PRINT 87,(FP(I),VGP(I),I=1,I1,10)
      J0=J1/2
      CAM0=CAM(J0)
      DO 23 J=1,J1
      CAMN=CAM0-CAM(J)
      CAMN=DIST*CAMN/PI
      CAMN=AMOD(CAMN,2.)
      IF (CAMN .GT. 1.) CAMN=CAMN-2.
      IF (CAMN .LT. -1.) CAMN=CAMN+2.
      VNM(J)=180.*CAMN
 23   CONTINUE
      PRINT 60
      PRINT 86,(FM(J),VNM(J),J=1,J1,10)
      S=1.
      DO 25 I=1,I1
      EF=FP(I)
      CA=CAP(I)
      O=2.*PI*EF*1.E6
      CM=EF/(2.8*1750.)
      U11=1.-OMH/(OM**2-OMH**2)
      U22=U11
      U12=CM/(OM**2-OMH**2)
      B=SQRT(U11/U22)
      AL1=U22*B+S*U12
      AL2=U22*B-S*U12
      P1=(T(CA)+1.)**2*(TANH(CA*EL)-CA*EL*(SECH(CA*EL))**2)
      P2=(R1(CA)*EXP(CA*G)-R2(CA)*EXP(-CA*G))**2/4.
     X*(COTH(CA*T1)-CA*T1*(CSCH(CA*T1))**2)
      P3=.25*(R1(CA)**2)*(EXP(2.*CA*G)-1.)-.25*(R2(CA)**2)
     X*(EXP(-2.*CA*G)-1.)-R1(CA)*R2(CA)*CA*G
      P4=AL1*(T(CA)**2)*(EXP(2.*B*CA*D)-1.)-AL2*(EXP(-2.*B*CA*D)-1.)
     X-4.*B**2*U22*CA*D*T(CA)
      GECA=GE(CA)
      PP(I)=    O*UO*  GECA    **2*(P1+P2+P3+P4)/8./CA**2*.5
      PP(I)=4.*PP(I)
      RP(I)=ABS(PP(I))/((1.-ETA)+(1.+ETA)*EN**2)*4.
      RP(I)=FACT*RP(I)
25    CONTINUE
      S=-1.
      DO 26 J=1,J1
      EF=FM(J)
      O=2.*PI*EF*1.E6
      CA=CAM(J)
      CM=EF/(2.8*1750.)
      U11=1.-OMH/(OM**2-OMH**2)
      U22=U11
      U12=CM/(OM**2-OMH**2)
      B=SQRT(U11/U22)
      AL1=U22*B+S*U12
      AL2=U22*B-S*U12
      P1=(T(CA)+1.)**2*(TANH(CA*EL)-CA*EL*(SECH(CA*EL))**2)
      P2=(R1(CA)*EXP(CA*G)-R2(CA)*EXP(-CA*G))**2/4.
     X*(COTH(CA*T1)-CA*T1*(CSCH(CA*T1))**2)
      P3=.25*(R1(CA)**2)*(EXP(2.*CA*G)-1.)-.25*(R2(CA)**2)
     X*(EXP(-2.*CA*G)-1.)-R1(CA)*R2(CA)*CA*G
      P4=AL1*(T(CA)**2)*(EXP(2.*B*CA*D)-1.)-AL2*(EXP(-2.*B*CA*D)-1.)
     X-4.*B**2*U22*CA*D*T(CA)
      GECA=GE(CA)
      PM(J)=    O*UO*  GECA    **2*(P1+P2+P3+P4)/8./CA**2 *.5
```

```
      PM(J)=4.*PM(J)
      RM(J)=ABS(FM(J))/((1.-ETA)+(1.+ETA)*EM**2)*4.
      RM(J)=FACT*RM(J)
   26 CONTINUE
      PRINT 60
      PRINT 71,(FP(I),RP(I),I=1,I1,10)
C     PRINT 72,(FM(J),RM(J),J=1,J1,5)
      IF (I1 .NE. J1) GO TO 90
       DO 84 I=1,I1
   84 RT(I)=RP(I)+RM(I)
      PRINT 60
      PRINT 75,(FP(I),RT(I),I=1,I1,10)
      FP1=FP(1)
      FPL=FP(I1)
      CALL FTRAN(RT,PX,I1,FP1,FPL)
      PRINT 60
      M=NM
       M=I1-1
      PRINT 73,(FP(I),PX(I),I=1,M  ,20)
      DO 94 I=1,M
       XL=2.*PI*FP(I)*ELL
      XL=XL*1.E6
      L=I
      IF (I .EQ. 1) L=2
      SERP(I)= 20.*ALOG10((4.*RP(I)/RG)/
     X  ((1.+(RT(I)+RL)/RG)**2
     X                          +((PX(I)+XL)/RG)**2))
      SERP(I)=SERP(I)-76.4*DELH*DIST/
     X(2.*PI*1.E6*(FP(I+1)-FP(L-1))/(CAP(I+1)-CAP(L-1)))
      SERM(I)= 20.*ALOG10((4.*RM(I)/RG)/
     X  ((1.+(RT(I)+RL)/RG)**2
     X                          +((PX(I)+XL)/RG)**2))
      SERM(I)=SERM(I)-76.4*DELH*DIST/
     X(2.*PI*1.E6*(FM(I+1)-FM(L-1))/(CAM(I+1)-CAM(L-1)))
   94 CONTINUE
      PRINT 60
      PRINT 77,(FP(I),SERP(I),I=1,M  ,10)
      PRINT 60
      PRINT 78,(FP(I),SERM(I),I=1,M  ,10)
      XMIN=2500.
      DX=50.
      XMIN=2500.
      XMIN=2400.
      FREQO=.01*FREQ
      XMIN=AINT(FREQO)*100.
      XX=AINT(.01*FHI)-AINT(.01*FLO)+1.
      DX=100.
      YMIN=0.
      DY=200.
       DY=10000.
      DO 96 J=1,J1
      IF (CAM(J) .GT. 100000.) CAM(J)=100000.
      IF (VGM(J) .GT. 1000.) VGM(J)=1000.
   96 CONTINUE
      DO 97 I=1,I1
      IF(CAP(I) .GT. 100000.) CAP(I)=100000.
      IF (VGP(I) .GT. 1000.) VGP(I)=1000.
   97 CONTINUE
      CALL PLOT(1.5,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL SYMBOL(.5,9.2,.1,HEAD3,0,70)
      CALL AXIS(0.,0.,21HWAVE NUMBER (+) (1/M),21,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FM,CAM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DY=100.
      CALL PLOT(16.,0.,-3)
      CALL AXIS(0.,0.,
     X              25HGROUP DELAY/CM (+) (NSEC),25,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FM,VGM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DY=10000.
      CALL PLOT(16.,0.,-3)
      CALL AXIS(0.,0.,21HWAVE NUMBER (-) (1/M),21,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX,0.,XMIN,DX,10.)
      CALL LINE(FP,CAP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
```

```
      DY=100.
      CALL PLOT(15.,0.,-3)
      CALL AXIS(0.,0.,
     X          25HGROUP DELAY/CM (-) (NSEC),25,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FP,VGP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      YMIN=-180.
      DY=36.
      CALL PLOT(15.,0.,-3)
      CALL AXIS(0.,0.,22HNORMAL DISPERSION (+) ,22,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      JJ=0
58    CONTINUE
      DO 59 J=1,J1
      IF ((JJ+J) .GT. J1) GO TO 57
      FN(J)=FM(JJ+J)
      VM(J)=VNM(JJ+J)
      IF (J .EQ. 1) GO TO 59
      IF (VM(J) .LE. VM(J-1)) GO TO 59
      GO TO 57
59    CONTINUE
57    J2=J-1
      CALL LINE (FN,VM,J2,1,0,1,XMIN,DX,YMIN,DY,.08)
      JJ=JJ+J2
      IF ( (JJ+1) .LE. J1) GO TO 58
      YMIN=0.
      DY=30.
      DO 27 I=1,I1
      IF (RP(I) .GT. 300.) RP(I)=300.
      IF(RP(I) .GT. 2000.) RP(I)=2000.
27    CONTINUE
      CALL PLOT(15.,0.,-3)
      CALL AXIS (0.,0.,27HRAD. RES.,MINUS WAVE (OHMS),27,10.,90.,
     X  YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FP,RP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DO 28 J=1,J1
      IF (RM(J) .GT. 300.) RM(J)=300.
      IF (RM(J) .GT. 2000.) RM(J)=2000.
      IF (RT(J) .GT. 300.) RT(J)=300.
      IF (RT(J) .GT. 2000.) RT(J)=2000.
28    CONTINUE
      CALL PLOT(17.,0.,-3)
      CALL AXIS (0.,0.,27HRAD. RES., PLUS WAVE (OHMS),27,10.,90.,
     X  YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FM,RM,J1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(17.,0.,-3)
      CALL AXIS(0.,0.,22HRAD. RES. TOTAL (OHMS),22,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FP,RT,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      I1=M
      J1=M
      YMIN=-10000.
      YMIN=-250.
      DY=2000.
      DY=50.
      DO 92 I=1,I1
      IF (PX(I) .LT. -10000.) PX(I)=-10000.
      IF (PX(I) .LT. -250.) PX(I)=-250.
      IF (PX(I) .GT. 10000.) PX(I)=10000.
      IF (PX(I) .GT. 250.) PX(I)=250.
92    CONTINUE
      CALL PLOT(17.,0.,-3)
      CALL AXIS(0.,0.,22HRAD. REAC TOTAL (OHMS),22,10.,90.,YMIN,DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FP,PX,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      DO 93 I=1,I1
       IF (SERP(I) .LT. -80. ) SERP(I)=-80.
       IF (SERM(I) .LT. -80. ) SERM(I)=-80.
93    CONTINUE
      YMIN=-80.
        DY=10.
      CALL PLOT(16.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
```

```
      CALL SYMBOL(.5,9.2,.1,HEAD3,0,70)
      CALL AXIS(0.,0.,26H-INS. LOSS,MINUS WAVE (DB),26, 8.,90.,YMIN,
     X   DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FP,SERP,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL PLOT(15.,0.,-3)
      CALL SYMBOL(.5,9.8,.1,HEAD,0,70)
      CALL SYMBOL(.5,9.6,.1,HEAD1,0,70)
      CALL SYMBOL(.5,9.4,.1,HEAD2,0,70)
      CALL SYMBOL(.5,9.2,.1,HEAD3,0,70)
      CALL AXIS(0.,0.,26H-INS. LOSS, PLUS WAVE (DB),26, 8.,90.,YMIN,
     X   DY,10.)
      CALL AXIS (0.,0.,15HFREQUENCY (MHZ),-15,XX ,0.,XMIN,DX,10.)
      CALL LINE(FM,SERM,I1,1,0,1,XMIN,DX,YMIN,DY,.08)
      CALL ENDPLT
      STOP
   90 PRINT 76
      STOP
   60 FORMAT(1H1)
   61 FORMAT(5X," H= ",E15.7/5X," T1= ",E15.7/5X," D= ",E15.7/
     X5X," G= ",E15.7/5X," L= ",E15.7/
     X5X," N= ",E15.7/5X,"ETA=",E15.7////9X,"NO. OF F'S ARE ",I5)
   62 FORMAT(//10(5E15.5/))
   63 FORMAT(///50X,"S=1"//(10X,"F= ",E15.7,10X,"K (-) =  ",E15.7/))
   64 FORMAT(///50X,"S=-1"//(10X,"F= ",E15.7,10X,"K (+)  = ",E15.7/))
   66 FORMAT(///(10X,"F= ",E15.7,10X,"P (-)  = ",E15.7/))
   67 FORMAT(///(10X,"F= ",E15.7,10X,"P (+)  = ",E15.7/))
   68 FORMAT(///5X,"L1= ",E15.7/5X,"A= ",E15.7/5X,"F= ",E15.7/
     X5X,"IC= ",E15.7/5X,"N= ",E15.7/5X,"ETA= ",E15.7)
   71 FORMAT(///(10X,"F= ",E15.7,10X,"RAD. RES. (-)  = ",E15.7/))
   72 FORMAT(///(10X,"F= ",E15.7,10X,"RAD. RES. (+)   = ",E15.7/))
   73 FORMAT( //(10X,"F= ",E15.7,10X,"RAD. REAC. TOTAL= ",E15.7/))
   75 FORMAT(///(10X,"F= ",E15.7,10X,"RAD. RES. TOTAL = ",E15.7/))
   76 FORMAT ("1  A K ROOT EXISTS FOR ONE WAVE ONLY")
   77 FORMAT(//(10X,"F= ",E15.7,10X,"INS. LOSS  (-) = ",E15.7/))
   78 FORMAT(//(10X,"F= ",E15.7,10X,"INS. LOSS (+)  = ",E15.7/))
   81 FORMAT(//(10X,"L1(",I4,")= ",E15.7/))
   82 FORMAT(//(10X," A(",I4,")= ",E15.7/))
   83 FORMAT(//(10X," F(",I4,")= ",E15.7/))
   85 FORMAT(/(10X," F= ",E15.7,10X,"GROUP DELAY (+) = ",E15.7/))
   86 FORMAT("    F= ",E15.7,"  NORM DISPERSION (+) = ",E15.7)
   87 FORMAT("    F=  ",E15.7,"     GROUP DELAY (-) =  ",E15.7)
  100 FORMAT(7A10)
      END


      FUNCTION COTH(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      COTH  =1./TANH(CA)
      RETURN
      END



      FUNCTION SECH(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      SECH=0.
      IF (CA .LE. 740.) SECH=1./COSH(CA)
      RETURN
      END


      FUNCTION CSCH(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      CSCH=0.
      IF (CA .LE. 740.) CSCH=1./SINH(CA)
      RETURN
      END
```

```
      FUNCTION FT1(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      FTT     =EXP(-B*CA*D)*(R1(CA)*EXP(CA*G)-R2(CA)*EXP(-CA*G))
     X*S*T1*(CSCH(CA*T1))**2
      FTT2=
     X-S*B*EXP(-B*CA*D)*((COTH(CA*T1)+1.)*R1(CA)*EXP(CA*G)
     X+(COTH(CA*T1)-1.)*R2(CA)*EXP(-CA*G))
      FTT3=
     X+2.*B*S*D*EXP(-2.*B*CA*D)*((COTH(CA*T1)+1.)*(1.-AL2)
     X*EXP(CA*G)-(COTH(CA*T1)-1.)*(1.+AL2)*EXP(-CA*G))
      FTT5=
     X+S*EL*(AL1+AL2)*(SECH(CA*EL)**2)/(AL1-TANH(CA*EL))**2
      FTT6=
     X ((COTH(CA*T1)-1.)*(1.-AL1)*EXP(-CA*G)-(COTH(CA*T1)+1.)
     X*(1.+AL1)*EXP(CA*G))
      FTT4=FTT5*FTT6
      FT1=.5*(FTT+FTT2+FTT3+FTT4)
      RETURN
      END


      FUNCTION T(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      T      =(AL2+TANH(CA*EL))/(AL1-TANH(CA*EL))
      RETURN
      END


      FUNCTION FT(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      FT     =.5*((COTH(CA*T1)-1.)*R2(CA)*EXP(-CA*G)*EXP(-B*CA*D)
     X-(COTH(CA*T1)+1.)*R1(CA)*EXP(CA*G)*EXP(-B*CA*D))
      RETURN
      END


      FUNCTION GE(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A,EL1(40),FE(40),AA(40)
      GE     =ABS(GAY(CA)*EXP(-B*CA*D)/FT1(CA))
      RETURN
      END


      FUNCTION SINC(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A,EL1(40),FE(40),AA(40)
      PI=3.14159265
      SINC=(SIN(PI*CA))/(PI*CA)
      RETURN
      END
```

```
      FUNCTION GAY(CA)
      COMPLEX DC,D1,C1,F1,A1,A2,A3,A4,C,CS
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A,EL1(40),FE(40),AA(40)
     X,LMODE,DEL1,JOPT
      PI=3.14159265
      N=EN
      M=N
      IF (JOPT .EQ. 1) M=1
      C=CMPLX(0.,0.)
      DC=.5*DEL1*CMPLX(1.,-1.)
      DO 1 I=1,M
      W=AA(I)
      E1=EL1(I)
      F1=FE(I)
      D1=.5*W/DC
      D1R=REAL(D1)
      D1I=AIMAG(D1)
      C1=.5*W*(CA+1./DC)
      F1=.5*W*(CA-1./DC)
       A1= C1*(CCOS(C1)+CCOS(F1))+F1*CSIN(C1)+CSIN(F1)*C1
       A2=-C1*(CCOS(C1)+CCOS(F1))+F1*CSIN(C1)+CSIN(F1)*C1
      A3= C1*(CSIN(F1)-CSIN(C1))+F1*CCOS(C1)-C1*CCOS(F1)
      A4= C1*(CSIN(F1)-CSIN(C1))-F1*CCOS(C1)+C1*CCOS(F1)
      CS=CMPLX(COS(CA*P1*I),-SIN(CA*P1*I))*ETA**I
      IF(JOPT .EQ. 1) CS=(1.-ETA**N*CMPLX(COS(CA*P1*EN),SIN(CA*P1*EN)))/
     X  (1.-ETA*CMPLX(COS(CA*P1),SIN(CA*P1)))
      C=C+SQRT(E1)*CS*
     X(A1*CEXP(D1)+A2*CEXP(-D1)+CMPLX(0.,-1.)*(A3*CEXP(D1)+A4*CEXP(-D1
     X)))/
     X (W**2*(CA**2+CMPLX(0.,1.)*2./DC**2)*
     X(CMPLX( COS(D1I)*SINH(D1R),SIN(D1I)*COSH(D1R))/D1))
1     CONTINUE
      GAY=CABS(C)
      RETURN
      END


      FUNCTION R1(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      R1     =(1.-AL2)*EXP(-B*CA*D)+(1.+AL1)*T(CA)*EXP(B*CA*D)
      RETURN
      END


      FUNCTION R2(CA)
      COMMON EL,AL1,AL2,B,D,T1,G,S,ETA,EN,F,AY,A
      R2     =(1.+AL2)*EXP(-B*CA*D)+(1.-AL1)*T(CA)*EXP(B*CA*D)
      RETURN
      END
```

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```
      SUBROUTINE HTRAN(R,X,N,FBEG,FEND)
      DIMENSION R(3),X(3)
      PI=3.141592653S9
      FDEL=(FEND-FBEG)/(N-1)
      F=FBEG+.5*FDEL
      INC=MOD(N,2)
      NI=N+INC-1
       NM1=N-1
      NIM2=NI-2
      DO 33 I=1,NM1
      X(I)=0.
      IF (I .EQ. 1) RX=(3.*R(1)+6.*R(2)-R(3))/8.
      IF (I .EQ. NM1) RX=(-R(N-2)+6.*R(NM1)+3.*R  (N))/8.
      IF (I .EQ. 1 .OR. I .EQ. NM1) GO TO 20
      RX=(-R(I-1)+9.*R(I)+9.*R(I+1)-R(I+2))/16.
20    CONTINUE
      FI=FBEG
      DO 28 IP=1,NIM2,2
      X(I)=X(I)+4.*(R(IP+1)-RX)/(( FI+FDEL)**2-F**2)
     X          +2.*(R(IP  )-RX)/(  FI      **2-F**2)
      FI=FI+2.*FDEL
28    CONTINUE
      FEN=FEND
      IF(INC .EQ. 0 ) FEN=FEND-FDEL
      X(I)=X(I)+ (R(NI)-RX)/(FEN**2-F**2)
     X          -(R(1  )-RX)/(FBEG**2-F**2)
      X(I)=FDEL/3.*X(I)
      IF(INC .EQ.1) GO TO 30
      X(I)=X(I)+.5*FDEL*((R(NI)-RX)/(FEN**2-F**2)
     X          +(R(N)-RX)/(FEND**2-F**2))
30    X(I)=2./PI*F*X(I)+RX/PI*ALOG
     X ((1.-F/FEND)/(1.+F/FEND)*(F+FBEG)/(F-FBEG))
      F=F+FDEL
33    CONTINUE
      NM2=N-2
      X1=(15.*X(1)-10.*X(2)+3.*X(3))/8.
       X2=(3.*X(1)+6.*X(2)-X(3))/8.
      DO  31 I=3,NM2
      XT=(-X(I-2)+9.*X(I-1)+9.*X(I)-X(I+1))/16.
      X(I-2)=X1
      X1=X2
      X2=XT
31    CONTINUE
      X(N)=(15.*X(NM1)-10.*X(NM2)+3.*X(N-3))/8.
      X(N-1)=(3.*X(NM1)+6.*X(NM2)-X(N-3))/8.
      X(N-2)=X2
      X(N-3)=X1
      RETURN
      END
```

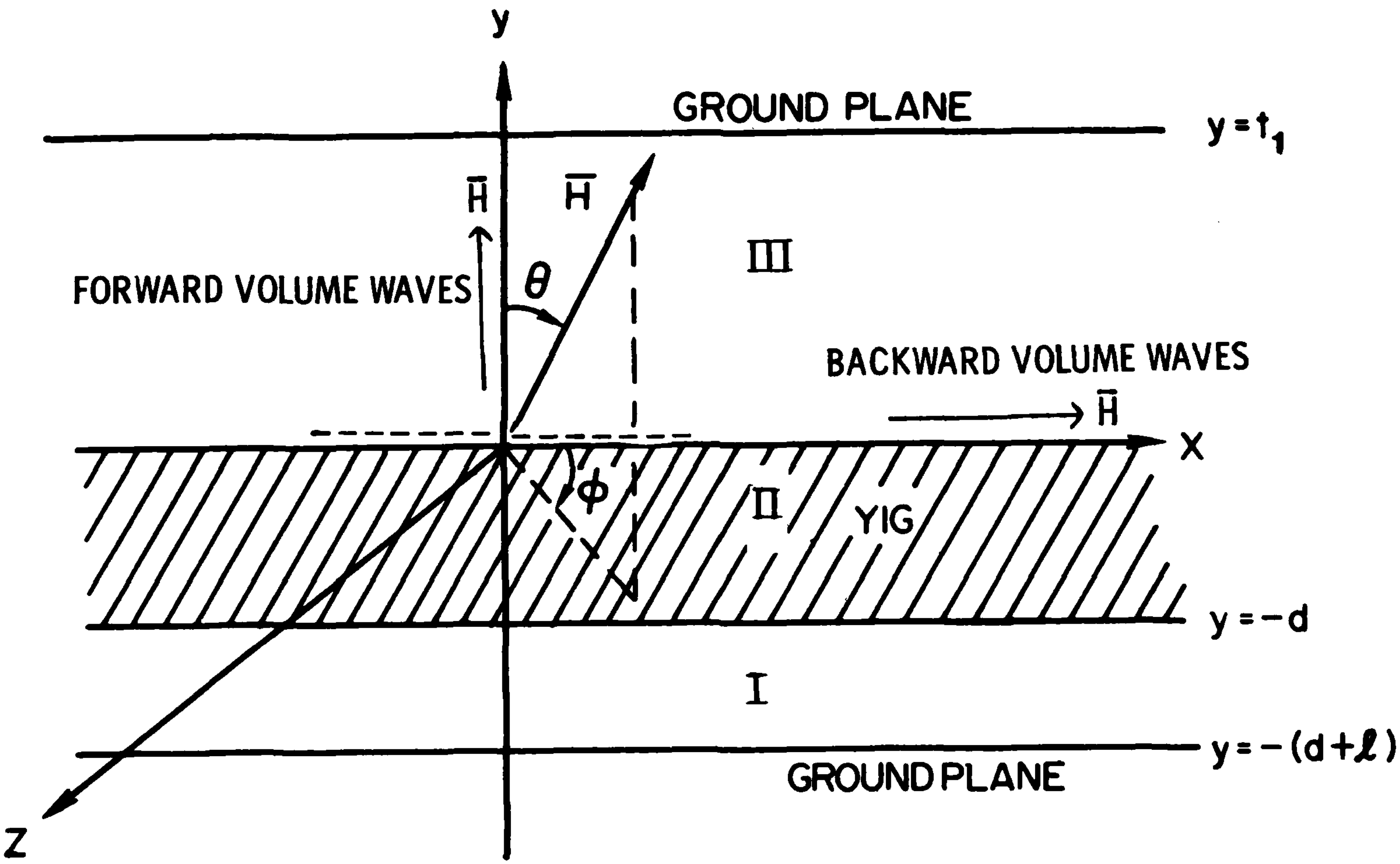

Figure 1 - Geometry of the System

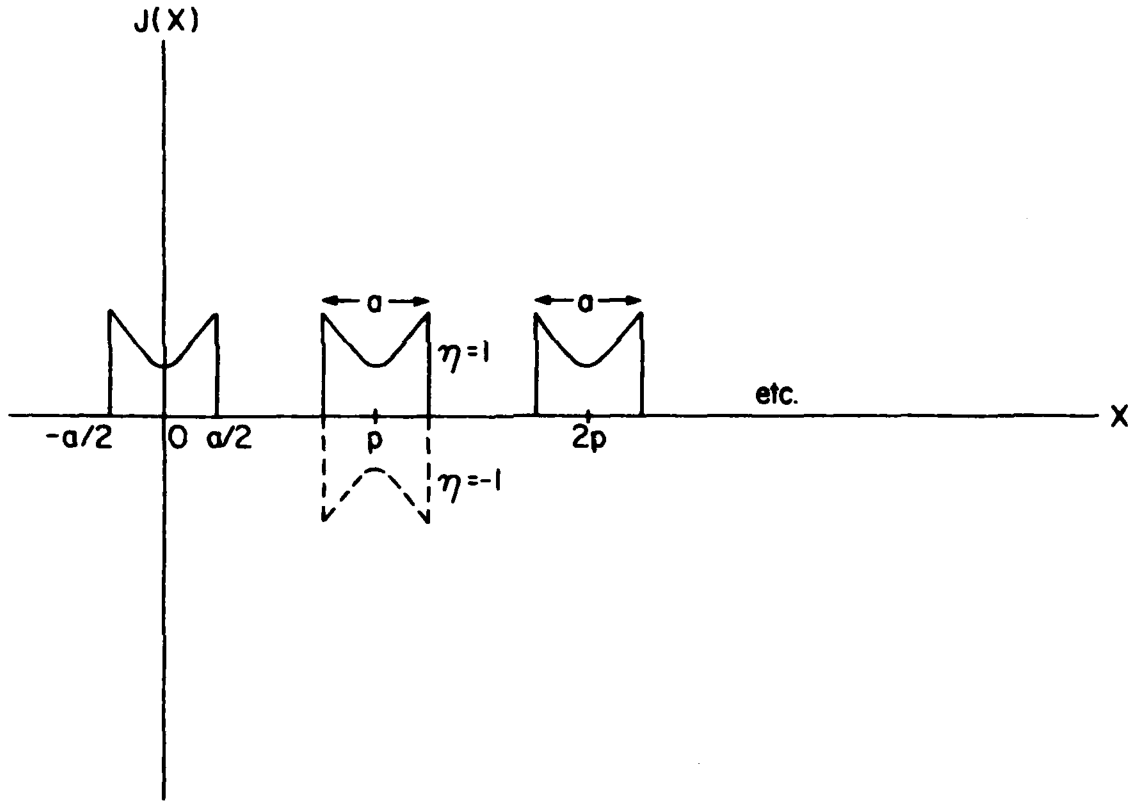

Figure 2 - Hyperbolic Current Distribution

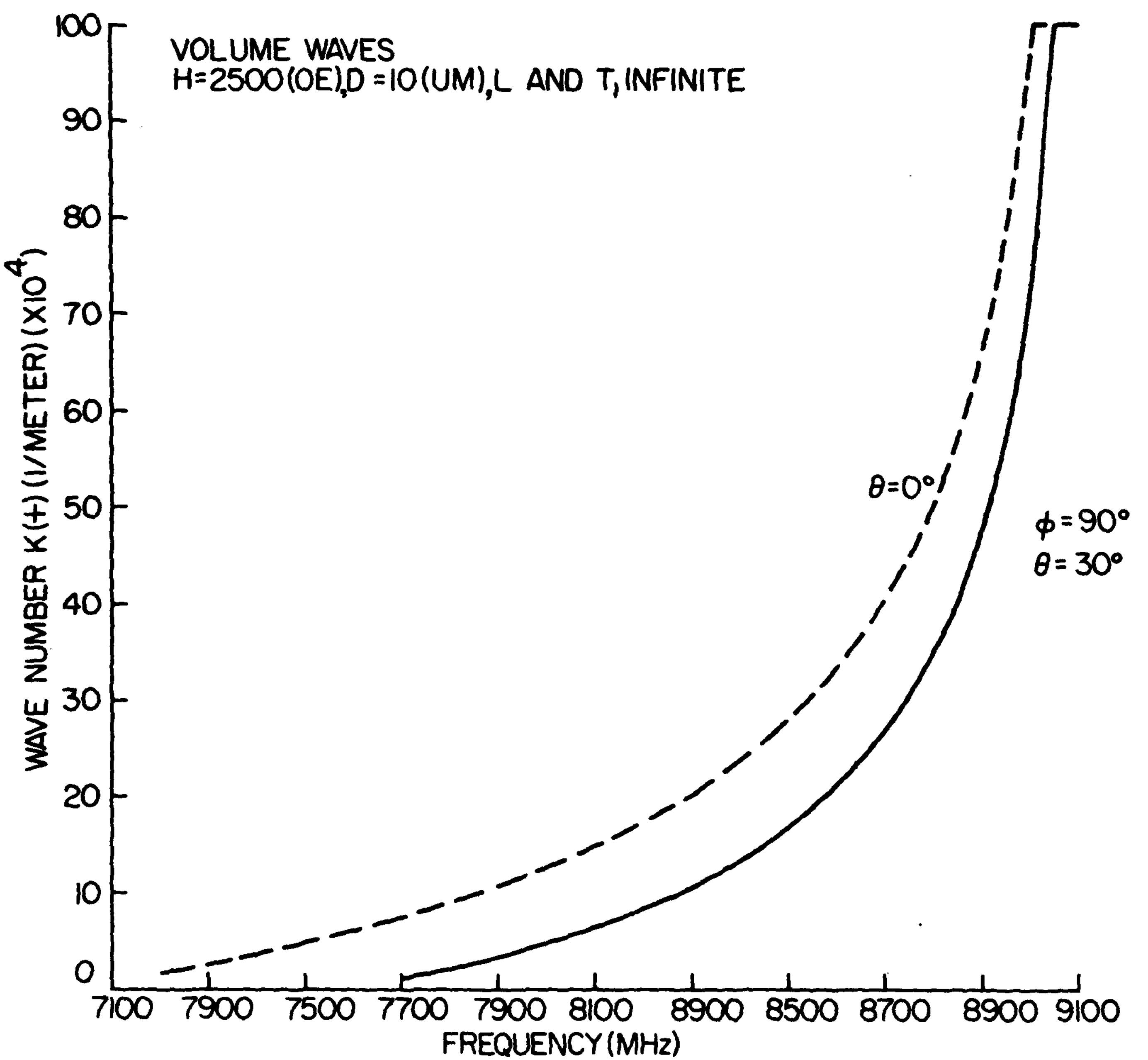

Figure 3 - Dispersion Relations - Generalized Forward Volume Waves

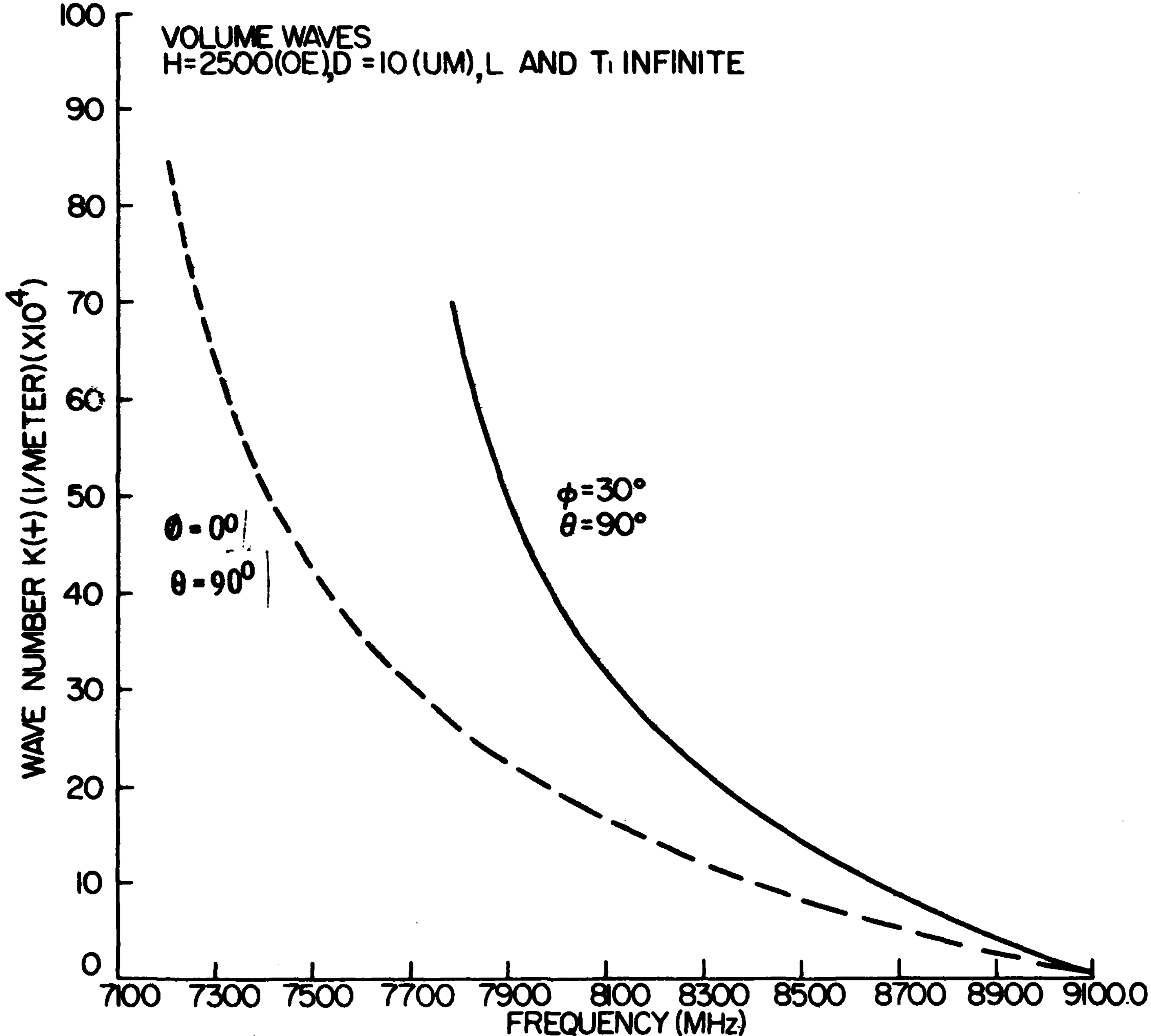

Figure 4 - Dispersion Relations - Generalized Backward Volume Waves

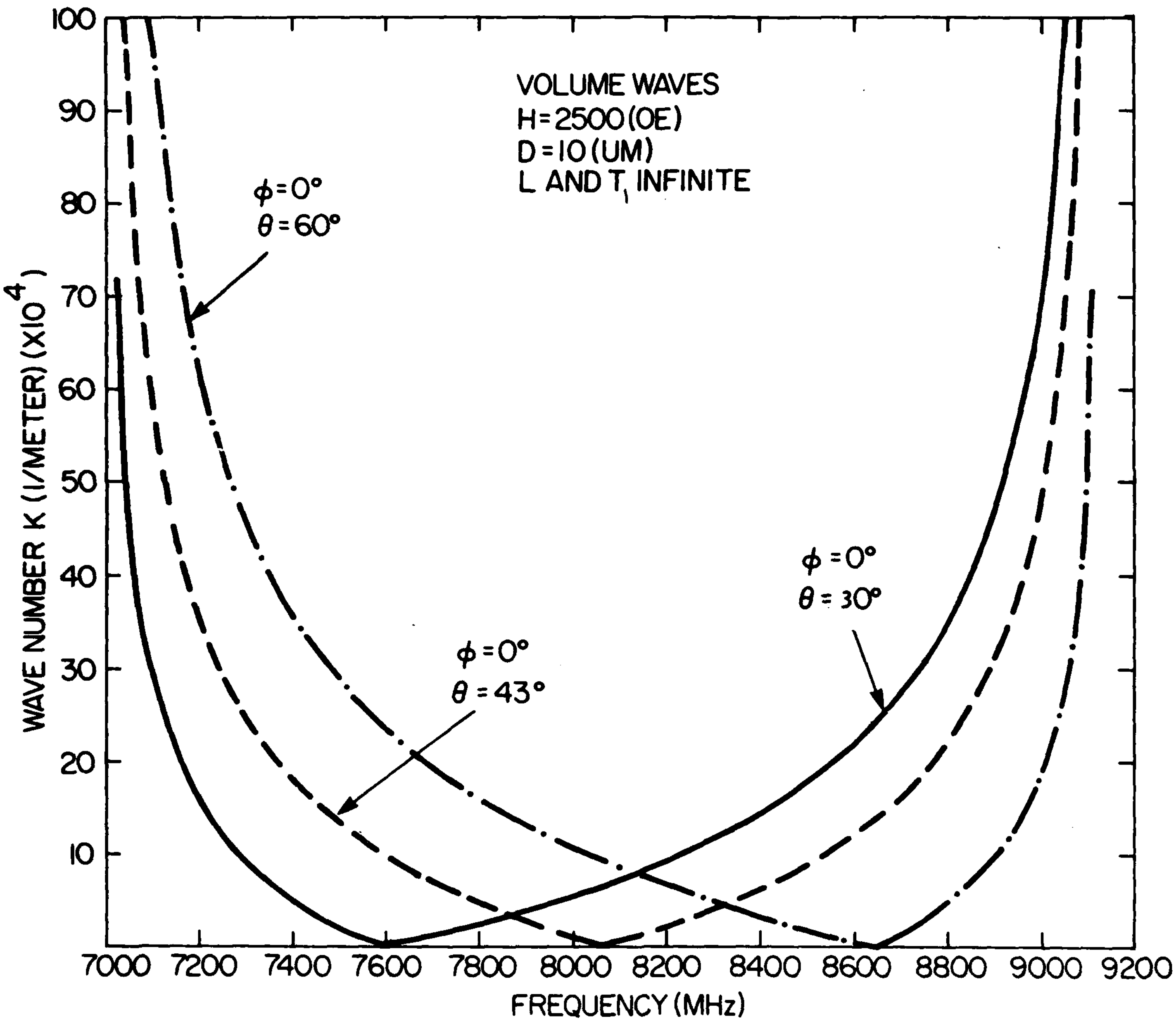

Figure 5 - Dispersion Relations - ϕ=o

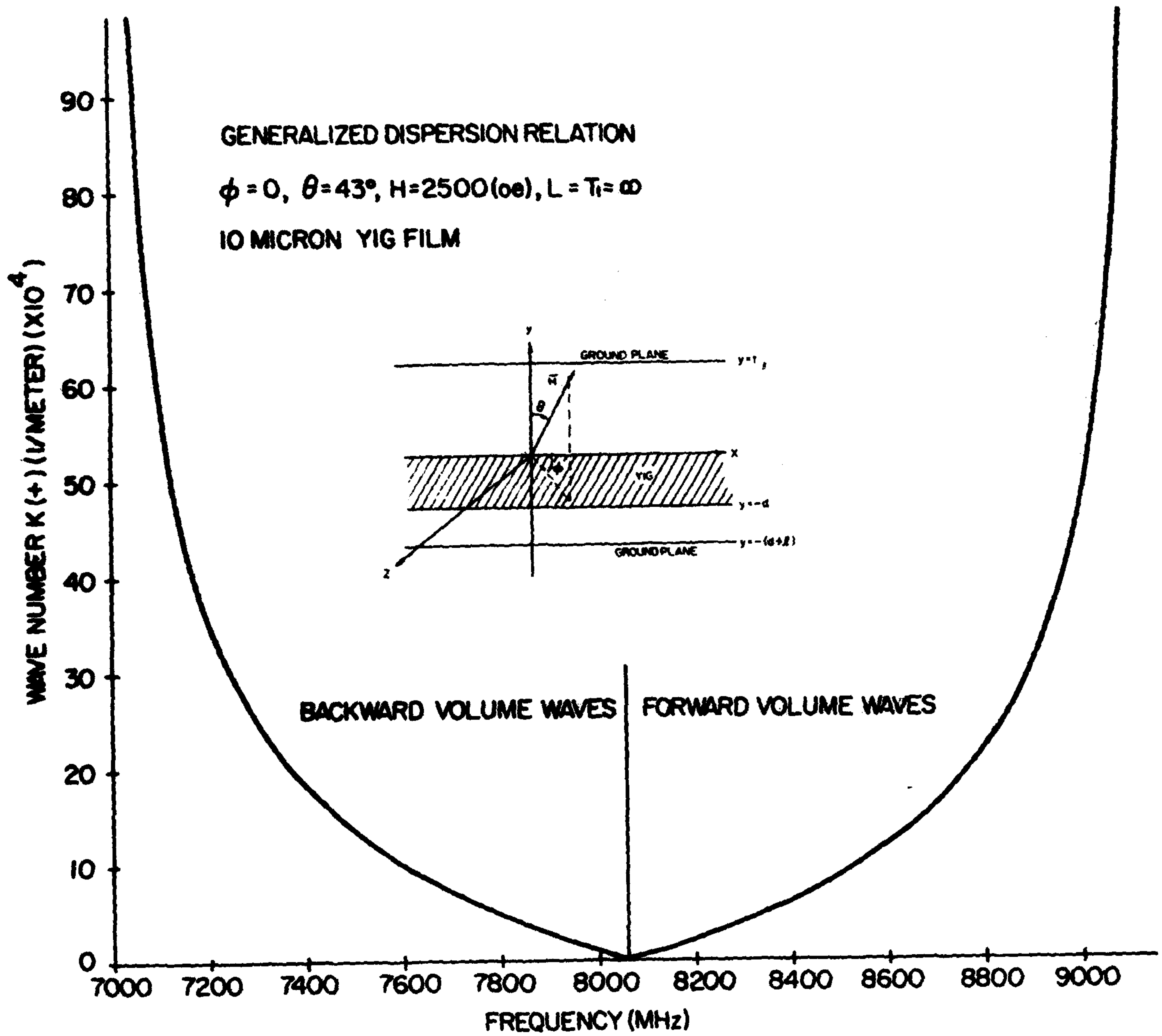

Figure 6 - Dispersion Relation - ϕ=o, θ=43^{o}

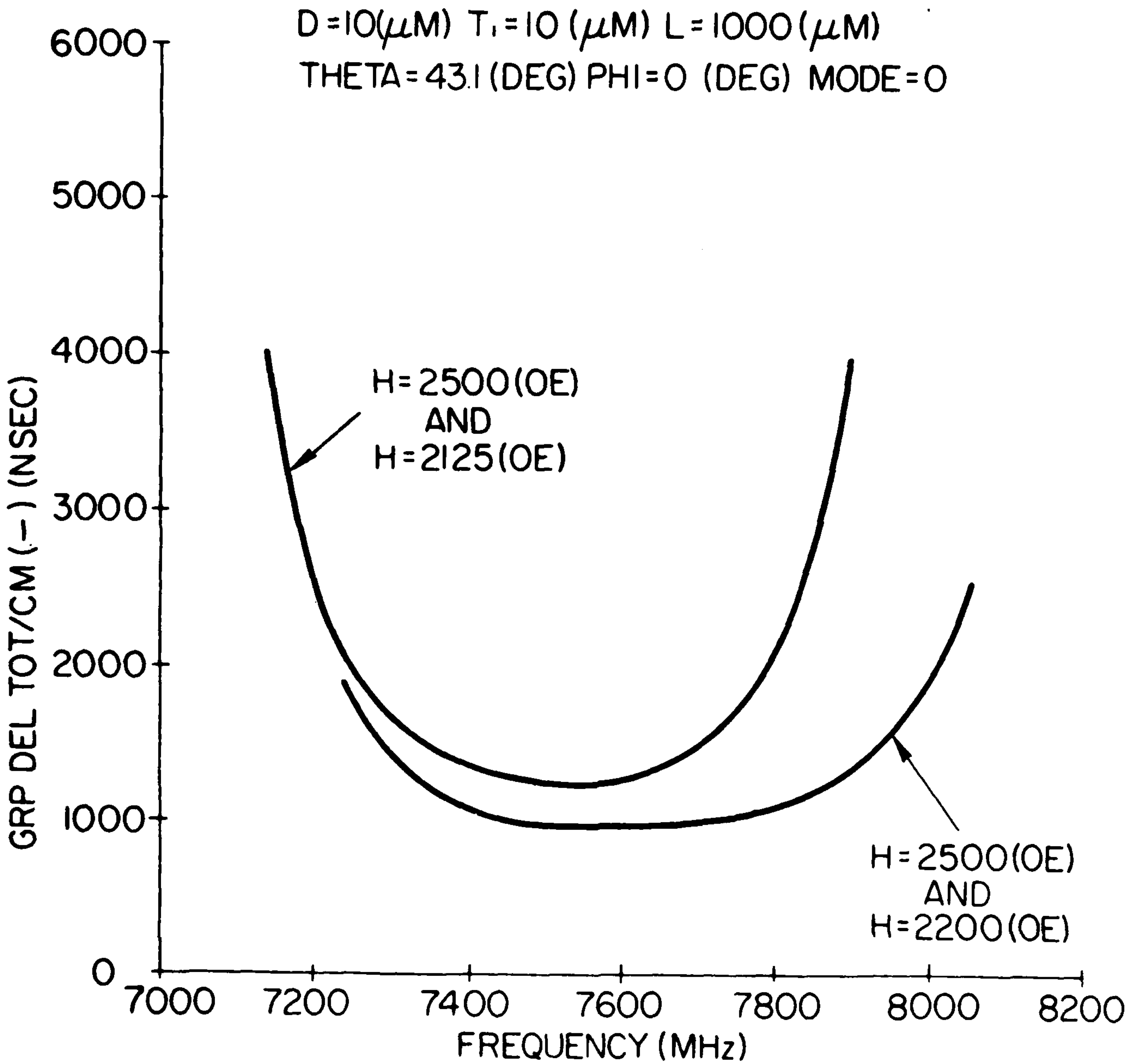

Figure 7 - Non Dispersive Time Delay Elements - ϕ=o, θ=43.1°

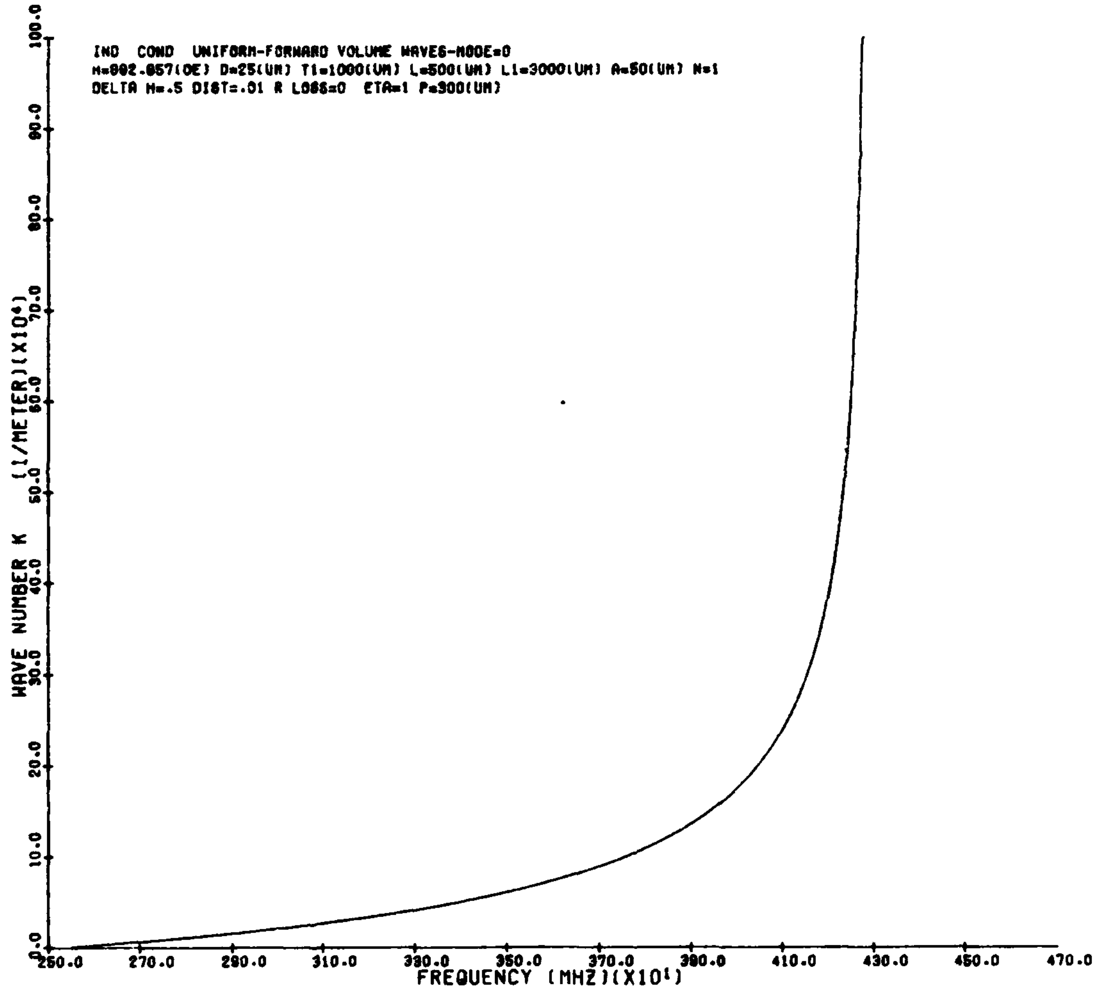

Figure 8 - Dispersion Relation - Forward Volume Waves

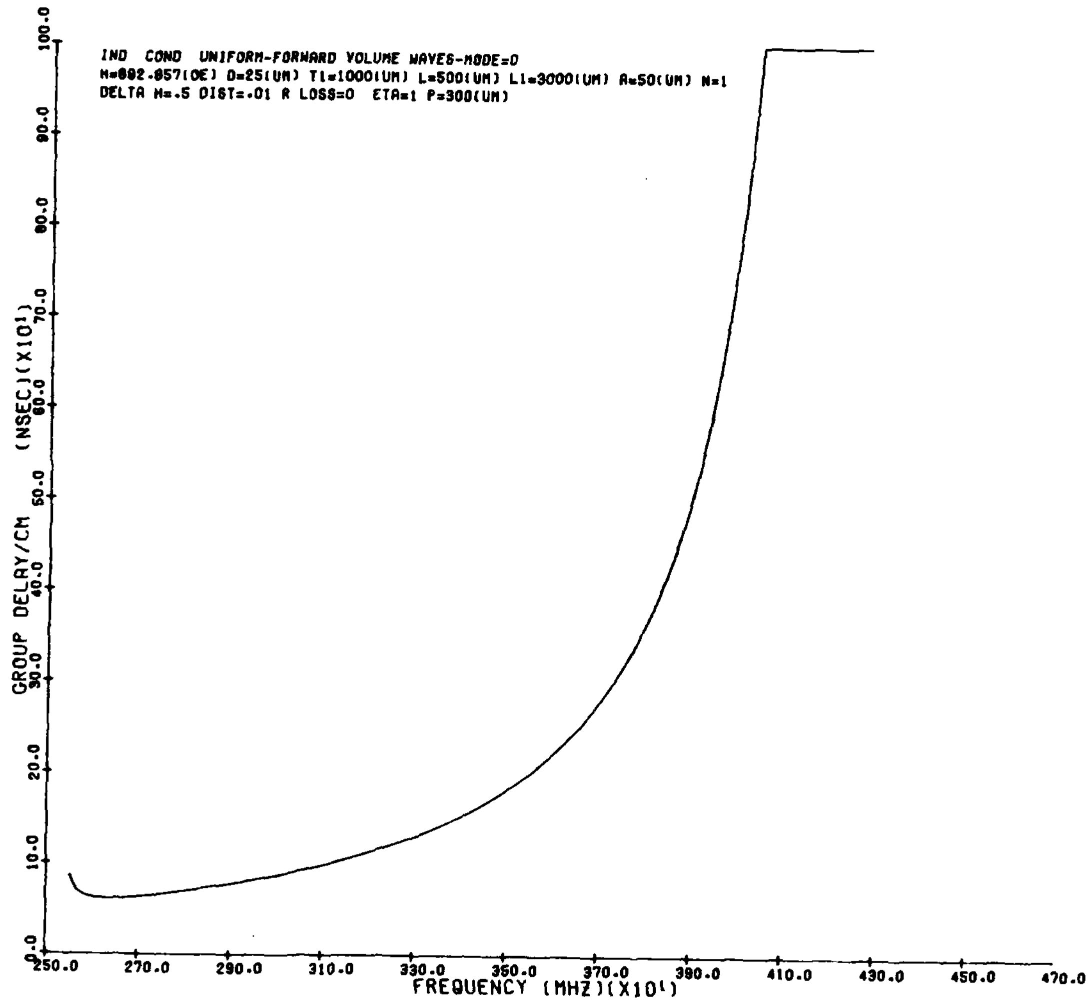

Figure 9 - Group Delay - Forward Volume Waves

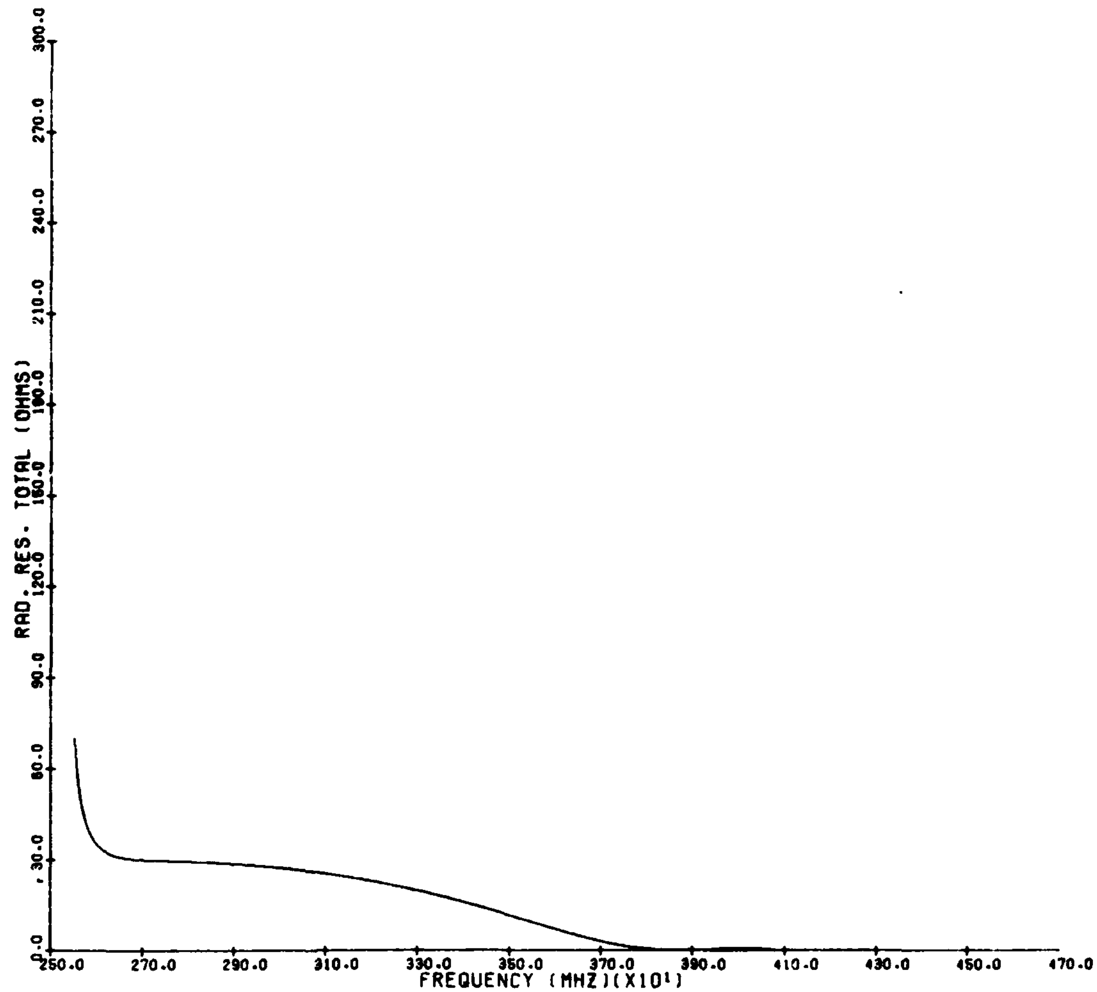

Figure 10 - Radiation Resistance - Forward Volume Waves

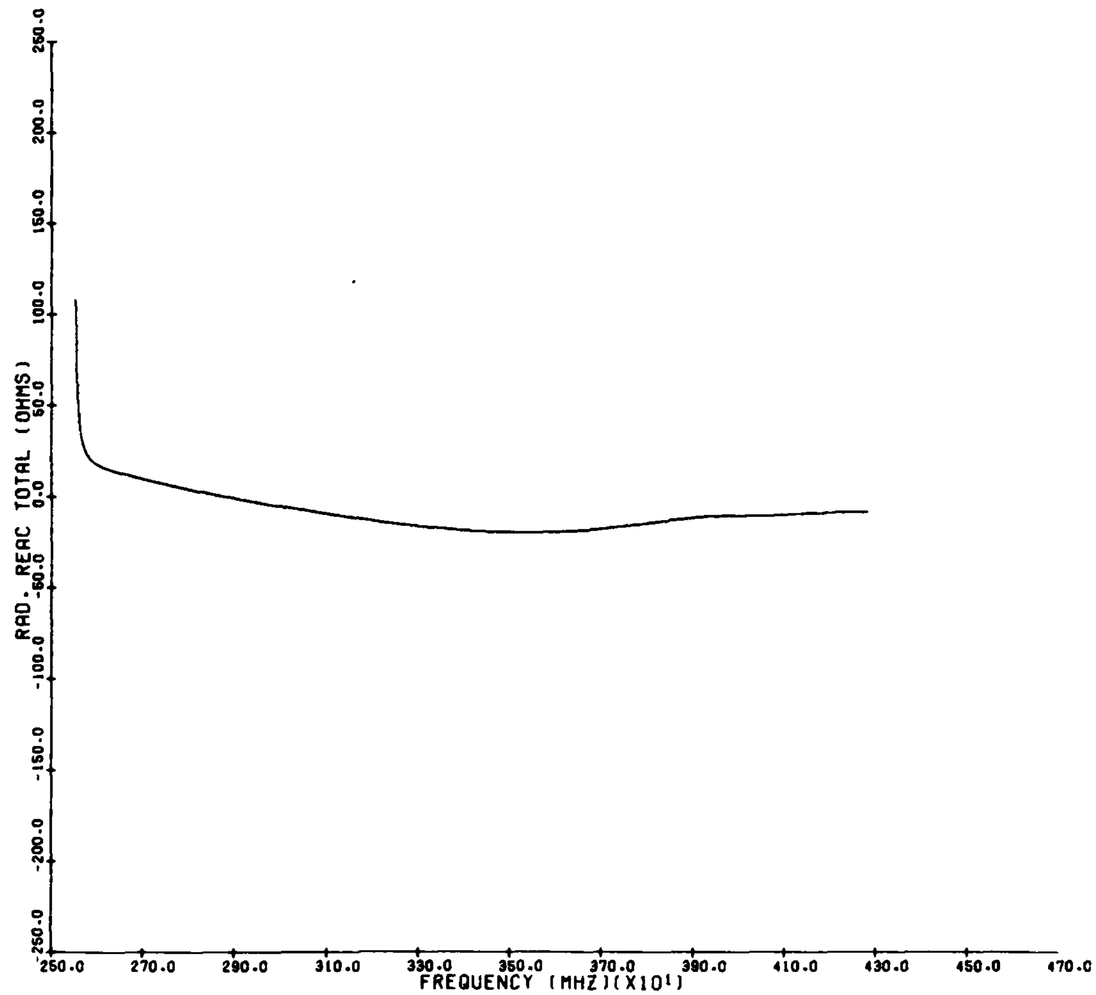

Figure 11 - Radiation Reactance - Forward Volume Waves

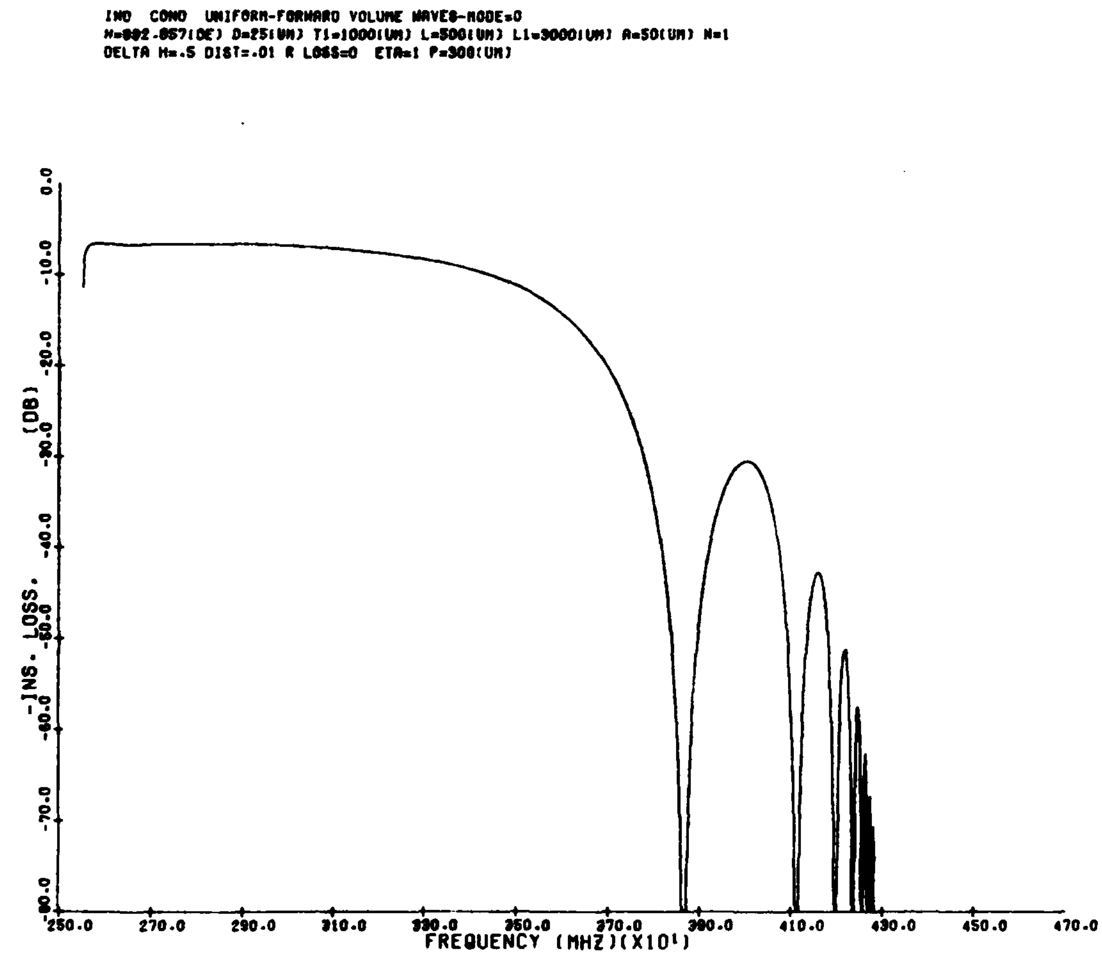

Figure 12 - Insertion Loss - Forward Volume Waves

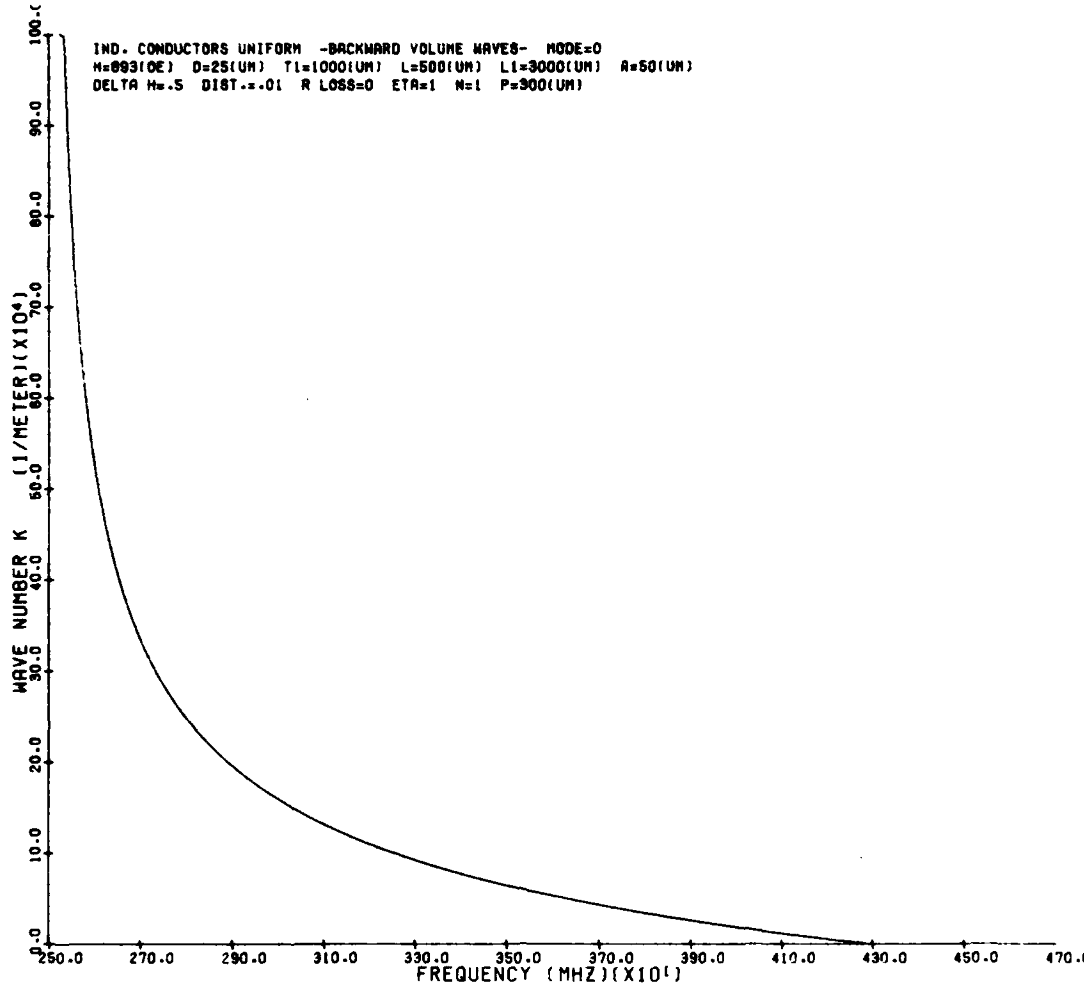

Figure 13 - Dispersion Relation - Backward Volume Waves

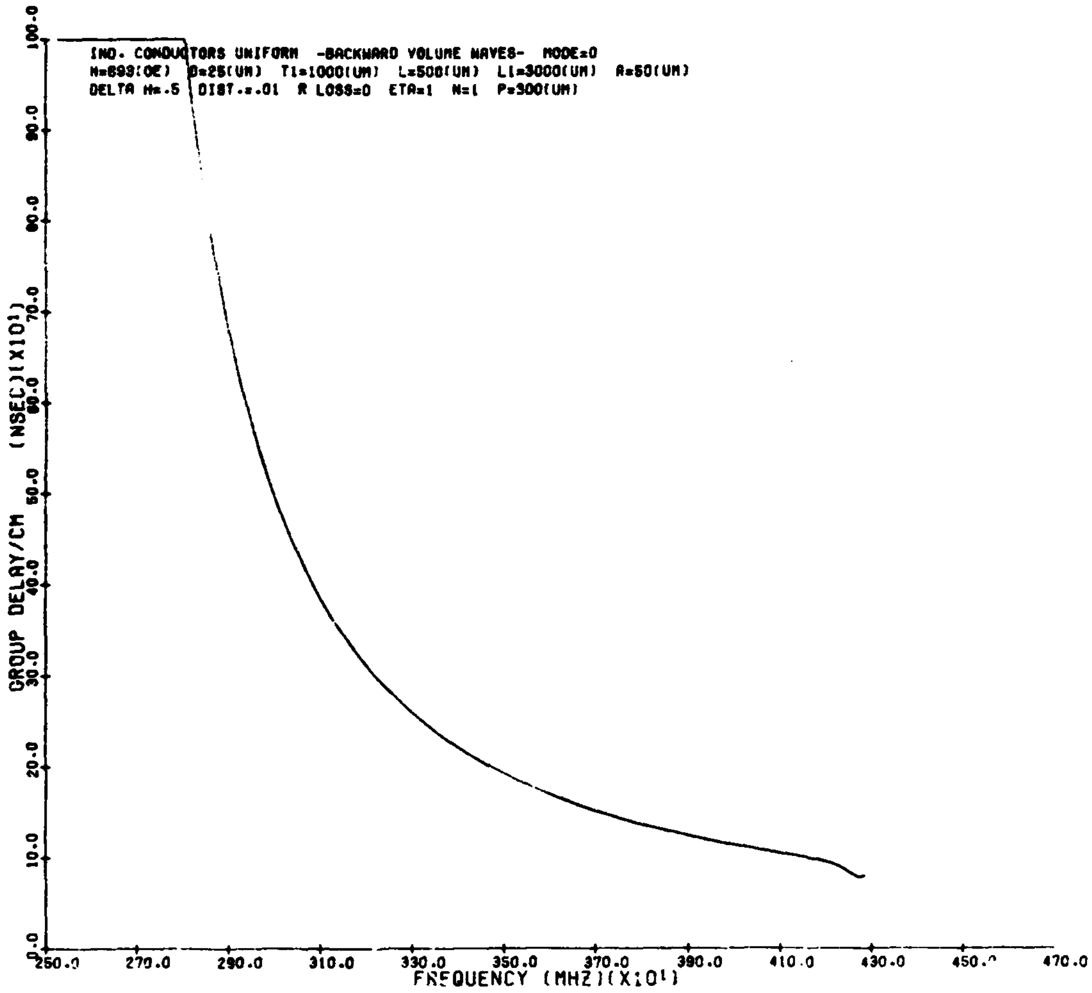

Figure .4 - Group Delay - Backward Volume Waves

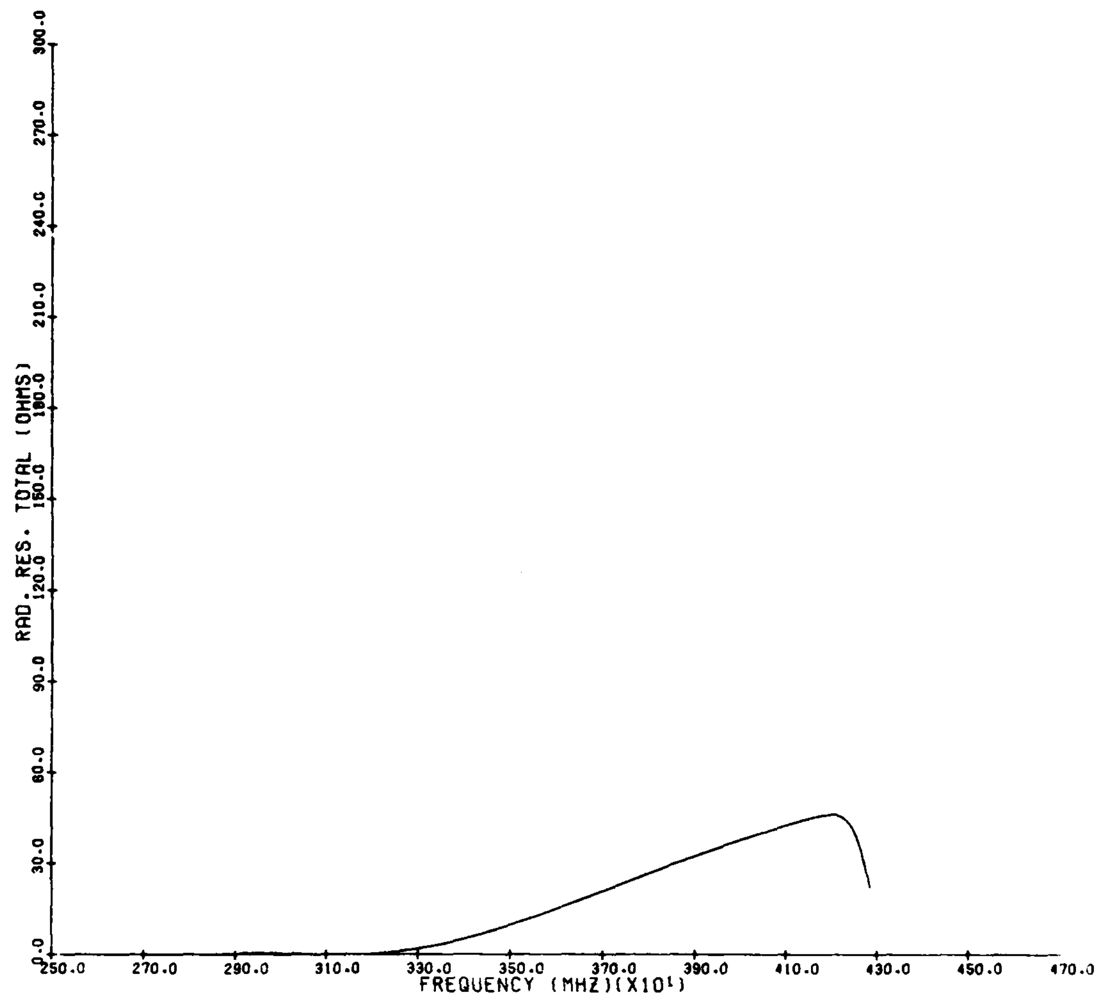

Figure 15 - Radiation Resistance - Backward Volume Waves

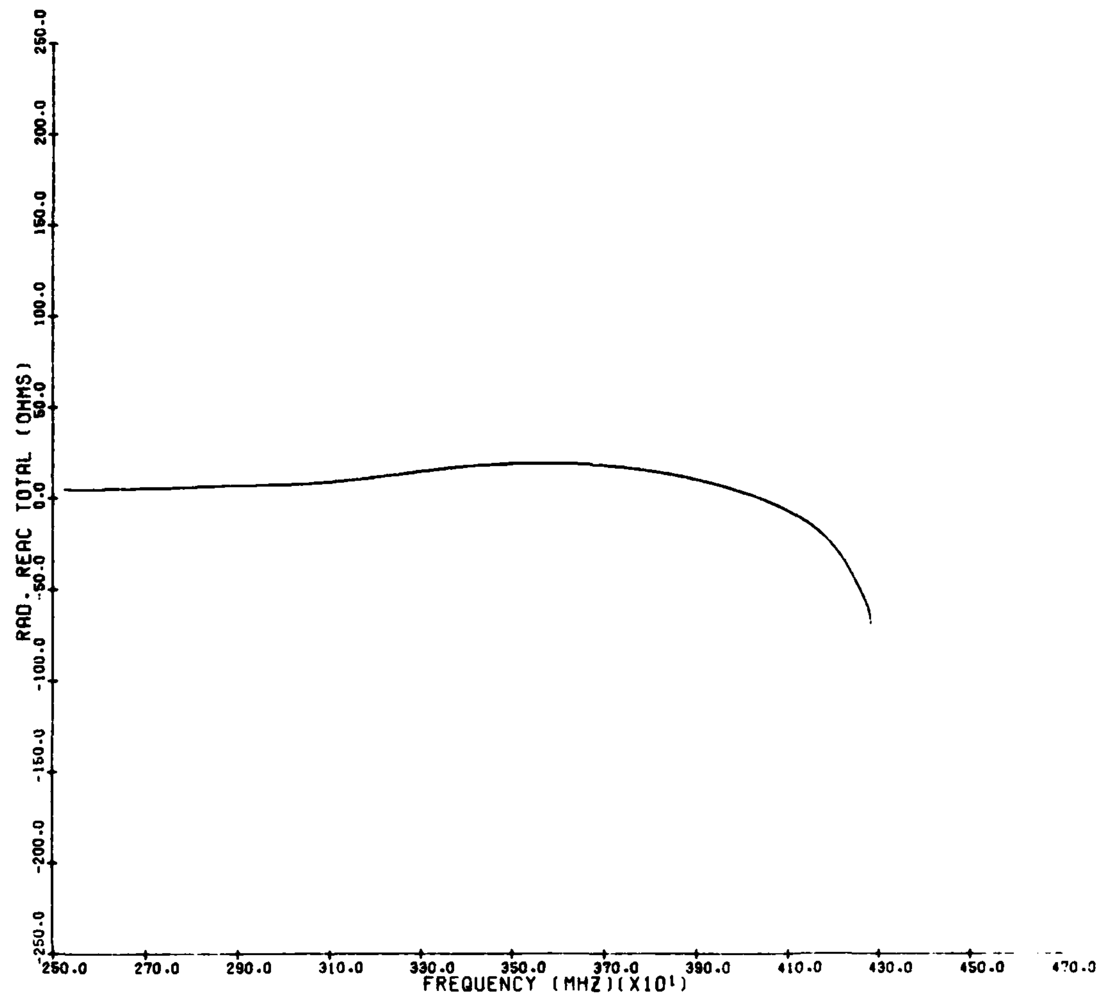

Figure 16 - Radiation Reactance - Backward Volume Waves

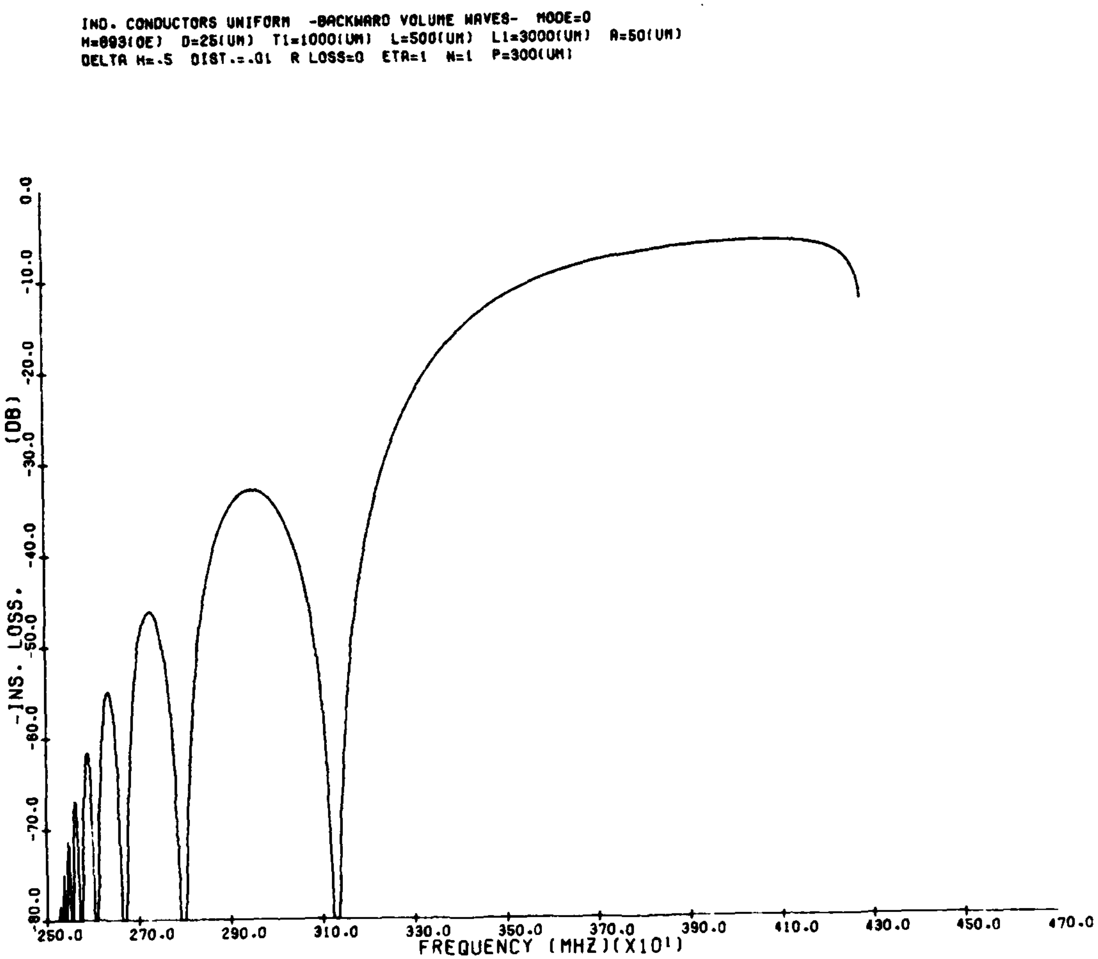

Figure 17 - Insertion Loss - Backward Volume Waves

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