respectively; $y^e=0$ and $z^o=A_2$. The equivalent circuit is shown in Fig. 3:

$$Y = \frac{1}{2}\left(\begin{array}{c|c} A_2^{-1} & -A_2^{-1} \\ \hline -A_2^{-1} & A_2^{-1} \end{array}\right). \tag{19}$$

The equivalent circuit of (19) exists even if A_2 is singular. The transfer scattering matrix and $[A\ B\ C\ D]$ matrix are

$$T = \left(\begin{array}{c|c} I - A_2 & A_2 \\ \hline -A_2 & I + A_2 \end{array}\right) \tag{20}$$

and

$$[A\ B\ C\ D] = \left(\begin{array}{c|c} I & 2A_2 \\ \hline 0 & I \end{array}\right) \tag{21}$$

respectively.

References

[1] L. B. Felsen and W. K. Kahn, "Network properties of discontinuities in multimode circular waveguide," *Proc. Inst. Elec. Eng.*, Feb. 1962.

[2] C. L. Ren, "Network representation for lossless symmetrical discontinuities in a multimode waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-14, pp. 81–85, Feb. 1966.

Computer Program Descriptions

Permeability Tensor of Magnetized Ferrites from Waveguide Measurements

PURPOSE: By means of this program the complex eigenvalues of the permeability tensor of magnetized ferrites can be calculated from measurements of the propagation constants of right- and left-handed rotating HE_{11} waves in circular cylindrical waveguides containing axial longitudinally magnetized ferrite rods.

LANGUAGE: Fortran IV; source program deck length 342 cards.

AUTHOR: H. Entschladen, Institut für Hoch- und Höchstfrequenztechnik der Ruhr-Universität Bochum, 4630 Bochum, Germany.

AVAILABILITY: ASIS-NAPS Document No. NAPS-01818.

DESCRIPTION: The structure of a circular cylindrical waveguide containing an axial longitudinally magnetized ferrite rod allows the measurement of the microwave material parameters of ferrites, i.e., the permeability tensor, by using fairly large ferrite specimens [1], as opposed to very small specimens such as spheres used in conventional perturbation technique measurements. The propagation constants $\gamma_\pm = \alpha_\pm + j\beta_{g\pm}$ of right- and left-handed rotating HE_{11} waves in the ferrite-loaded waveguide are measured as function of a longitudinally applied static magnetic field. From these measurements the complex eigenvalues $\boldsymbol{\mu}_\pm = \mu_\pm' - j\mu_\pm''$ of the permeability tensor of the ferrite can be evaluated. The relation between the propagation constants of the waves and the dimensions of the waveguide structure, the permeability tensor of the ferrite rod, and the material parameters of the surrounding medium (in this special case the surrounding medium was air with the assumed vacuum dielectric constant ϵ_0) is given by the characteristic equations of the problem [2]. Consequently the calculation of the four material parameters $\mu_\pm'$, $\mu_\pm''$ requires the solution of these characteristic equations forming a system of four transcendental equations. The structure of the computer program of this problem is shown in the simplified flow chart of Fig. 1. The source program consists of five parts—the main program and four subprograms. The main program includes the COMMON statement for common storage arrays, the READ and WRITE statements for the data input and output, and the CALL and EXTERNAL statements for the subprograms. In the subprograms FUNCTION *CFMUEP* and FUNCTION *CFMUEM* the characteristic equations for the right- and left-handed rotating H_{11} waves are programmed. The subprogram SUBROUTINE NEWTON is used to solve the system of the four transcendental equations by applying Newton's method [3]. By means of the subprogram SUBROUTINE COMBES, the Bessel functions of first and second kind with order 0 and 1 of complex argument occurring in the characteristic equations are calculated.

The computer run starts with reading in a data card with the actual values of the following parameters:

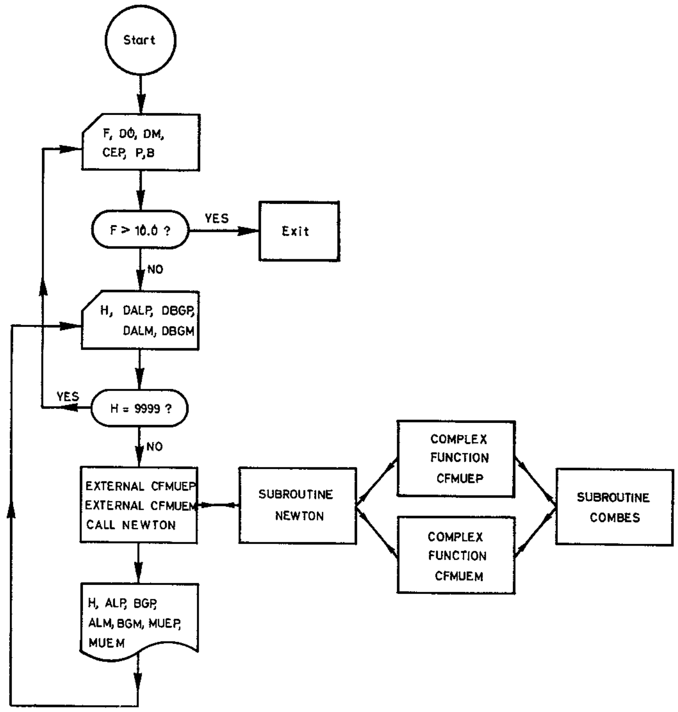

Fig. 1. Simplified flow chart of the computer program.

- *F* measuring frequency;
- *D*0 inner diameter of the cylindrical waveguide;
- *DM* diameter of the ferrite rod;
- *CEP* complex permittivity of the ferrite;
- *P*, *B* 6 sign word to mark the specimen.

A further READ statement reads in a second data card with the following input variables:

- *H* intensity of the static magnetic field;
- *DALP* difference between the attenuation constants of the right-handed rotating HE_{11} wave in the ferrite-loaded waveguide and of the H_{11} wave in the empty waveguide;
- *DBGP* difference between the phase constants of the right-handed rotating HE_{11} wave in the ferrite-loaded waveguide and of the H_{11} wave in the empty waveguide;
- *DALM*, *DGBM* corresponding to *DALP* and *DBGP* with left-handed rotating HE_{11} and H_{11} waves.

With the CALL statement for the subprogram NEWTON the complex eigenvalues $\boldsymbol{\mu}_+$, $\boldsymbol{\mu}_-$ (*MUEP*, *MUEM*) of the permeability tensor are calculated. The subprograms *CFMUEP* and *CFMUEM* containing the complex characteristic equations—inserted at the same time with EXTERNAL statements—call the subprogram COMBES for the calcula-

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For program listing, order document NAPS-01818 from ASIS National Auxiliary Publications Service, c/o CCM Information Corporation, 909 Third Avenue, New York, N. Y. 10022; remitting $2.00 per microfiche or $5.00 per photocopy.

tion of the complex Bessel functions. In the CALL statement of the subprogram NEWTON, starting values of μ_+ and μ_- are required. For the first run (data card with $H=0$) they are taken as 0.5 or 1.5, respectively; in the following runs they are equal to *MUEP* and *MUEM* computed by the previous runs. According to Newton's method these starting values will be varied (maximum of 50 steps) until the desired accuracy has been obtained.

The so determined results of μ_+, μ_- are printed together with the propagation constants $\gamma_\pm$ and the intensity of the static magnetic field. The output variables are:

- *H* same as input variable *H*;
- *ALP* attenuation constant for the right-handed rotating HE_{11} wave in the ferrite-loaded waveguide;
- *BGP* phase constant for the right-handed rotating HE_{11} wave in the ferrite-loaded waveguide;
- *ALM*, *BGM* corresponding to *ALP* and *BGP* with left-handed rotating HE_{11} wave;
- *MUEP* complex eigenvalue $\mu_+=\mu_+'-j\mu_+''$ with real part *MUESP* and imaginary part *MUESSP*;
- *MUEM* complex eigenvalue $\mu_-=\mu_-'-j\mu_-''$ with real part *MUESM* and imaginary part *MUESSM*.

Then a return instruction follows for reading in a further data card with new input variables *H*, *DALP*, *DBGM*, *DALM*, *DBGM*, and so on, until an end card (data card with $H=9999$) finishes the calculation of $\mu_\pm(H_0)$. A further return instruction follows for reading in new parameters *F*, *D*0, *DM*, and *CEP* to start a new calculation of $\mu_\pm(H_0)$. The end card (data card with $F>10.0$) will finish the complete computer run.

By substituting the complex eigenvalues *MUEP* and *MUEM* for the input variables *DALP*, *DBGP*, *DALM*, *DBGM* and by making some simple adaptions, this program can also be applied in the reversed way to calculate the propagation constants of the right- and left-handed rotating HE_{11} waves in the circular cylindrical waveguide containing axial longitudinally magnetized ferrite rods. The subroutines NEWTON and COMBES are programmed in such a way that they are applicable in many other problems.

This program was developed for use on a Telefunken TR440 with a time-sharing system. On this computer the word-storage requirements for the program are 47 K of the core, 54 K of the drum, and 100 K of the plate storage. One computer run for a $\mu_\pm(H_0)$ series with 50 values of the static field H_0 takes a running time of around 450 s.

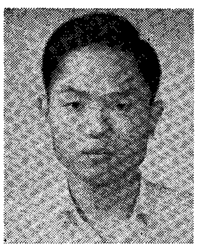
References

[1] H. Entschladen, "Messung des Permeabilitätstensors von Ferriten an Stäben in der Rundhohlleitung," Thesis, Ruhr-Universität Bochum, Bochum, Germany, 1971.

[2] M. L. Kales, "Modes in wave guides containing ferrites," *J. Appl. Phys.*, vol. 24, pp. 604–608, 1953.

[3] V. L. Zaguskin, *Handbook of Numerical Methods for the Solution of Algebraic and Transcendental Equations*. Oxford: Pergamon, 1961.

Contributors



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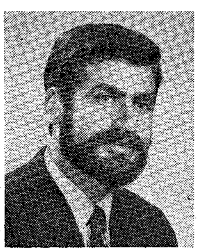

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