Computer Program Descriptions

Waveguide Bend Spurious Mode Program

PURPOSE: To calculate the magnitude and phase of propagating modes in H-plane waveguide bends using annular modal analysis [1]. This program can be used for the design of waveguide bends used in high powered multimode microwave systems where it is necessary to suppress spurious mode generation.

LANGUAGE: FORTRAN IV G Level.

AUTHORS: G. Govindarajan and E. Bahar, the Department of Electrical Engineering, University of Nebraska, Lincoln, NE 68588.

AVAILABILITY: ASIS/NAPS Document No. 03001. Available from the authors at a cost of $35.00 for a period of two years from the date of publication.

DESCRIPTION: The main program employs the standard fourth-order Runge–Kutta method [2], to solve a system of first-order coupled differential equations with complex coefficients. The dependent variables in these equations are the annual mode amplitudes in waveguide bends [1].

The principal input parameters are the waveguide width $2h/\lambda$ and $\eta(\xi)$, the expression for the bend centerline. Auxiliary input data include the derivatives $\eta'(\xi)$, $\eta''(\xi)$, and $\eta'''(\xi)$. These are used to calculate the radius of curvature $R(\xi)$, its derivative, and the mode coupling coefficients. The amplitude of the incident TE_{10} mode at the input port is assumed to be unity.

The subroutines used include SPMN, MODEQ, HANK, and COLVER. Subroutine SPMN is used to calculate the complex coupling coefficients involving Bessel functions. When $\nu_n/z \to \beta_n/k$, where ν_n is the order and $z = kR$ is the argument of the Bessel function, β_n is the nth mode propagation coefficient in rectangular waveguides, and k is the free-space wavenumber, the asymptotic expressions for the coupling coefficients are used [1].

Subroutine MODEQ is used to solve the modal equation for ν_n as a function of distance between the waveguide ports. The Newton Raphson method which is used to solve the modal equation involves differentiation of the Hankel function, with respect to order. This differentiation is performed numerically instead of using infinite series expansions (for $dH_{\nu_n}^{(1)}(z)/d\nu_n$ and $dH_{\nu_n}^{(2)}(z)/d\nu_n$) found in handbooks. For any waveguide width $2h/\lambda$, a set of values for ν_n/kR is computed as a function of λ/R for $0 \le \lambda/R \le \lambda/R_{\min}$ where $R_{\min}$ is the minimum value of R considered. These values for ν_n/kR are stored for later use to evaluate the complex coupling coefficients and to solve the coupled differential equations.

For large radii of curvature, we note that

$$\nu_n/z \to \beta_n/k \equiv S_n = [1 - (n\lambda/4h)^2]^{1/2}.$$

Subroutine HANK is used to evaluate the Hankel functions of the first and second kind, $H_{\nu_n}^{(1)}(z)$ and $H_{\nu_n}^{(2)}(z)$ using subroutine COLVER [3].

The main program calls subroutines SPMN and MODEQ which in turn call subroutines COLVER and HANK. The main program and all of the subroutines except COLVER employ double precision complex arithmetic while COLVER employs single precision arithmetic. A detailed discussion on the computational accuracy of the COLVER subroutine is given elsewhere [3].

The computer time needed to execute the main program that employs the Runge–Kutta method depends very much upon the number of elementary segments into which the bend is divided. This in turn is determined by the degree of accuracy specified. The calculations in this program are accurate to three significant figures. The storage required and the execution time for the main program are also dependent on the number of significant propagating modes in the bend. For a waveguide with a sinusoidal centerline,

$$\eta(\xi) = w/\lambda\pi \cdot \sin(\pi\lambda x/\lambda w)$$

the number of elementary segments used depends on the parameter w/λ, the distance between the waveguide ports.

For small w/λ, more segments per wavelength are needed since there is stronger coupling between the modes. For example, with $2h/\lambda = 1.75$ and $w/2h = 8.0$, the number of segments needed is 150 whereas for the same specified degree of accuracy, only 200 segments are needed when $w/2h = 16.0$ [4]. A typical run employing 150 segments and $w/2h = 8.0$, $2h/\lambda = 1.75$ requires a storage of 100K and a running time of 67 s. These calculations were performed on an IBM 360/65 computer at the University of Nebraska Lincoln Computing Facility.

Manuscript received August 1975; revised October 1975.

See NAPS document no. 03001 for 16 pages of supplementary material. Order from ASIS/NAPS c/o Microfiche Publications, P.O. Box 3513, Grand Central Station, New York, NY 10017. Remit in advance for each NAPS accession number. Institutions and organizations may use purchase orders when ordering, however, there is a billing charge for this service. Make checks payable to "Microfiche Publications." Photocopies are $5.00. Microfiche are $3.00 each. Outside the United States and Canada, postage is $3.00 for a photocopy or $1.00 for a fiche.

References

[1] E. Bahar, "Fields in waveguide bends expressed in terms of coupled local annular waveguide modes," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-17, pp. 210–217, Apr. 1969.

[2] M. Abramowitz and I. A. Stegun, Ed., *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables* (Applied Mathematics Ser. 55). Washington, D.C.: Dep. Commerce, National Bureau of Standards, June 1964.

[3] J. A. Cochran and E. J. Murphy, "The computation of Bessel functions in the complex plane using Olver's expansions," 3T-BESOL, Bell Labs., Murray Hill, NJ.

[4] E. Bahar and G. Govindarajan, "Rectangular and annular modal analyses of multimode waveguide bends," *IEEE Trans. Microwave Theory Tech. (1973 Symposium Issue)*, vol. MTT-21, pp. 819–824, Dec. 1973.