namics and performance limitations of ferrite digital phase shifters," *IEEE Trans. Microwave Theory Tech. (1967 Symposium Issue)*, vol. MTT-15, pp. 709–713, Dec. 1967.
[5] F. E. Gardiol and A. S. Vander Vorst, "Computer analysis of *E*-plane resonance isolators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 315–322, Mar. 1971.
[6] F. E. Gardiol, "Anisotropic slabs in rectangular waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 461–467, Aug. 1970.
[7] B. Lax and K. Button, *Microwave Ferrites and Ferrimagnetics.* New York: McGraw-Hill, 1962, p. 337.
[8] W. P. Clark, "A technique for improving the figure-of-merit of a twin-slab nonreciprocal ferrite phase shifter," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-16, pp. 974–975, Nov. 1968.
[9] W. J. Ince, D. H. Temme, and F. G. Willwerth, "Toroid corner chamfering as a method of improving the figure of merit of latching ferrite phasers," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-19, pp. 563–564, June 1971.
[10] E. Schlömann, "Microwave behavior of partially magnetized ferrites," *J. Appl. Phys.*, vol. 41, pp. 204–214, Jan. 1970.
[11] J. L. Allen, "The analysis of ferrite phase shifters including the effect of losses," Ph.D. dissertation, Georgia Institute of Technology, Atlanta, May 1966.
[12] T. Kohane and E. Schlömann, "Linewidth and off-resonance loss in polycrystalline ferrites at microwave frequencies," *J. Appl. Phys.*, vol. 39, pp. 720–721, Feb. 1968.
[13] Q. H. F. Vrehen, H. G. Beljers, and J. G. M. De Lau, "Microwave properties of fine grain Ni and Mg ferrites," *IEEE Trans. Magn.*, vol. MAG-5, pp. 617–621, Sept. 1969.
[14] C. E. Patton, "Effective linewidth due to porosity and anisotropy in polycrystalline yttrium iron garnet and Ca-V substituted yttrium iron garnet at 10 GHz," *Phys. Rev.*, vol. 179, pp. 352–358, Mar. 1969.
[15] J. Nicolas, A. Lagrange, and R. Stroussi, "Problèmes de pertes dans les ferrites aux hyperfréquences," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, Mar. 1972).
[16] W. J. Ince, J. DiBartolo, D. H. Temme, and F. G. Willwerth, "A comparison of two nonreciprocal latching phaser configurations," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-19, pp. 105–107, Jan. 1971.
[17] W. J. Ince, private communication.

Letters

Comments on "Modes of Propagation in a Coaxial Waveguide with Lossless Reactive Guiding Surfaces"

R. A. WALDRON

Many authors have attempted to simplify the study of the mode spectrum of a waveguide with a complicated wall structure by the use of a surface-impedance boundary condition, and the above paper[1] is a classic example of the exercise. The method depends on two assumptions—that it is proper to express a ratio between the tangential E and H fields as a boundary condition, and that such a ratio can be expressed unambiguously in terms of the form of the waveguide wall. That these assumptions are valid is always taken for granted by users of the method, including the present authors, but I have never seen a proof of their validity. Unless such a proof can be given, the results of calculations by the surface-impedance method cannot be trusted.

The results given by the authors in their Fig. 1 appear unusual, and do not agree with the results to the same problem obtained much more simply by applying perturbation theory [1] to the coaxial line, treated as a waveguide [1, sec. IV. F]. This suggests that the assumptions underlying the surface-impedance method require examination. That the method has been widely used does not establish the validity of the assumptions on which it is based.

I have made such a study in [2] where it is shown that there is no value of surface impedance that can be substituted into the characteristic equation obtained by the surace-impedance method that will make it identical with the true characteristic equation. It is also shown that, while approximate agreement between the characteristic equations can be obtained for *small* surface impedances, the value to be chosen for the surface impedance to secure this agreement is a complicated function of frequency and depends on the mode of propagation. Thus "surface impedance" is not, as has always been supposed, a property of the surface, and its value cannot be known until the solution to the problem under consideration is known. It is therefore of no help in solving a problem. It also follows that the assumption that any desired reactance can be realized is unfounded.

In short, the assumptions on which the surface-impedance method is based are invalid, and it is to this fact that the many strange results can be attributed that have been published by a number of authors. In view of the findings of [2], all results obtained by the surface-impedance method should be treated with caution.

Manuscript received May 8, 1972; revised July 31, 1972.
R. A. Waldron is with the Post Office Research Department, Martlesham Heath, Ipswich, Suffolk, England.
[1] R. K. Arora, S. Vijayaraghavan, and R. Madhavan, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 210–214, Mar. 1972.

References

[1] R. A. Waldron, *Theory of Guided Electromagnetic Waves.* Princeton, N. J.: Van Nostrand-Reinhold, 1970, ch. 6.
[2] ——, *The Theory of Waveguides and Cavities.* London, England: Maclaren, 1967, ch. 5.

Reply[2] *by R. K. Arora*[3]

Waldron in his comment, as well as in [2] cited above, has assailed the use of surface impedance as a boundary condition.

The concept of surface impedance is several decades old and its use as a boundary condition has been made by many investigators. The conditions under which a surface may be characterized by an impedance-type boundary condition have been discussed by Senior [1] and Godzinski [2], and a further discussion of the usefulness of these conditions in solving practical problems is available in Barlow and Brown [3]. It is clear from [1] that it is possible, at least in principle, to devise structures with a prescribed value of surface impedance, and so the use of surface impedance as a boundary condition is justifiable on physical grounds. Though it is true that the surface-impedance description is not valid right at the discontinuity, experimental verification is obtained in microwave model experiments for ground-wave propagation [4], [5].

The surface-impedance method has proved to be of value in the solution of many problems of practical interest. No contradictions are

[2] Manuscript received July 25, 1972.
[3] R. K. Arora is with the School of Radar Studies, Indian Institute of Technology, Hauz Khas, New Delhi, India.

likely to arise if the results obtained by this method are taken in the proper context. Thus the results reported in the paper under discussion may not be compared with those cited by Waldron for the problem of a coaxial line, as the two problems are different.

ACKNOWLEDGMENT

The author wishes to thank Dr. J. R. Wait for a private communication on this subject.

REFERENCES

[1] T. B. A. Senior, "Impedance boundary conditions for imperfectly conducting surfaces," *Appl. Sci. Res.*, vol. 8, sec. B, pp. 418–436, 1961.
[2] Z. Godzinski, "The surface impedance concept and the structure of radio waves over real earth," *Proc. Inst. Elec. Eng.*, vol. 108, pt. C, pp. 362–373, Mar. 1961.
[3] H. M. Barlow and J. Brown, *Radio Surface Waves.* Oxford, England: Clarendon Press, 1962, pp. 15–17.
[4] J. R. Wait, "Nature of the electromagnetic field reflected from a coastline," *Electron. Lett.*, vol. 1, pp. 65–66, May 1965.
[5] R. J. King, S. W. Maley, and J. R. Wait, "Groundwave propagation along three-section mixed paths," *Proc. Inst. Elec. Eng.*, vol. 113, pp. 747–751, May 1966

Computer Program Descriptions

Prefabricated Multilayer Section Design Program

PURPOSE: PMSDP searches within the transitional section of an electromagnetic window configuration for the arrangement of prefabricated multilayers that yields the best broad-band frequency-matching condition.

LANGUAGE: Fortran IV; source deck length 250 cards.

AUTHOR: D. L. Huffman, Wright-Patterson Air Force Base, Ohio 45433.

AVAILABILITY: ASIS–NAPS Document No. NAPS-01940.

DESCRIPTION: It is well known that suitably designed transitional sections can reduce the reflection from electromagnetic windows (radomes). The windows treated here are ideal one-dimensional, structures, built up of dielectric materials that are lossless. From the viewpoint of fabricating transitional sections, practical considerations usually dictate that they be composed of N homogeneous layers. In this computer program it is assumed that the N layers have been prefabricated, and the broad-band program is directed toward assembling the N layers in the proper order so that the lowest broad-band reflection coefficient is obtained from the assembled multilayered section. There are $N!$ (factorial) ways of positioning the layers in the multilayered section, and $N!$ multilayered sections are treated.

The order of the dielectric constants and the thicknesses for the prefabricated layers are represented by DK(I) and TH(I), with $I=1, \cdots, N$. A portion of the computer program generates the $N!$ permutations of layer position for the N-layered section. Another portion of the program calculates the input reflectivity for NF sampled frequencies. This input reflectivity calculation is repeated until all $N!$ multilayered sections have been considered. All $NF \cdot N!$ input reflectivity values are stored in a two-dimensional matrix. Another portion of the computer program processes the stored input reflectivity matrix data. For each multilayered section, the computer arranges in a descending order of magnitude the values of input reflectivity, that is, the values of input reflectivity that have been calculated for different sampled frequencies. Then the column elements of the processed input reflectivity matrix are listed in ascending value, according to the magnitude of the first row elements as arranged above. Fig. 1 indicates the multilayered transitional section.

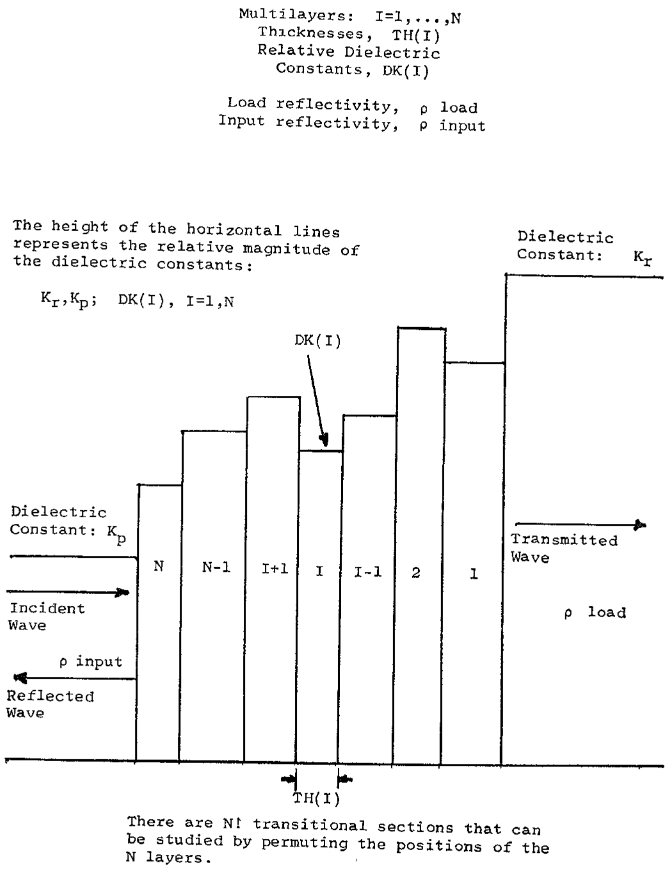

Fig. 1. Geometry of transitional section for an electromagnetic window configuration.

APPLICATION

A large number of electromagnetic window configurations can be studied by the permutation search method. The computer program is written for the normal incidence case and only the possibility of a single transitional section is discussed here. Required changes needed to study other general window configurations can easily be provided in the computer program. Experience with the program has indicated that, with $N!$ cases for permutation search available, some transitional sections can be found that produce the desired low reflectivity over a wide frequency range.

The distinct advantage of this permutation search method is that overall design requirements of space or weight are not involved because any improvement in the broad-band performance can be attributed to the positional arrangement of the prefabricated multilayers. Other optimization methods [1] develop improved broad-band performance by modifying the values for the dielectric constants or the thicknesses of the layers. Such modifications may require an investigation to determine whether the use of the optimum transitional section is feasible.

RESULTS AND COMPUTING TIMES

The basic computer program was executed on Wright-Patterson Air Force Base's CDC 6600 computer. The storage capacity of this computer is 400 000 octal words, thus permitting the chosen number of layers N to be as large as seven. For an electromagnetic window

Manuscript received May 23, 1972; revised August 25, 1972.
For program listing, order NAPS-01940 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 $8.00 per photocopy.