I-2 ATTENUATING FILMS IN RECTANGULAR WAVEGUIDES

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The complete solution for normal modes in a resistive-film-loaded rectangular waveguide is due to H.L. Knudsen[1]. He showed how to solve the boundary-value problem of a guide divided into homogeneous regions by a number of vanes (of various resistivities) parallel to the side walls. Solutions were found in terms of longitudinal-section electric (LSE) and magnetic (LSM) modes. Boundary conditions in the loaded guide are that electric field transverse to the film must be continuous across it and that the discontinuity in magnetic field along the film must equal the sheet conduction current.

As a special case of greatest practical significance, the theory was simplified for TE_{0n}-type modes (which correspond to LSE modes with no field variations parallel to the narrow walls) in a guide with only one film, the two separated regions having identical electrical properties. Knudsen considered the propagation characteristics in some detail for a range of resistivities and plotted theoretical field patterns. Perfect contact between the film edges and waveguide walls was assumed.

Recently, other relevant work has been reported by Ishida and Mushiake[2]. Unfortunately, their theory was restricted to TE_{0n}-type modes and the experimental E-field plots were made on such high film resistivities (230 and 1130 ohm/square) that the resulting fields were determined primarily by the thick bakelite substratum and only marginally by the film itself. No convincing corroboration of Knudsen's theory has yet been reported.

This paper deals with complex (rather than purely real) film impedances. Eigenvalue equations are derived for arbitrary film position. LSE and LSM mode solutions, for centrally-located films, are mapped by plotting film impedance in the first quadrant of the transverse propagation constant plane. Such plots are useful for locating solutions, for discerning patterns of propagation characteristics, and for numbering these complex modes in a sensible and unambiguous way. For example, LSE modes are numbered by locating solutions between pairs of constant reactance contours passing through neighboring saddle points. These boundaries enclose one solution for each possible film impedance. The solution corresponding to the infinite-film impedance or empty-guide mode (LSE_{mn}, in which m and n are known) gives its name to others in the same region of the complex plane. As previously mentioned, when m= 0 these may be known alternatively as TE_{0n} modes although, when the film impedance is finite, they usually bear little resemblance to the empty-guide modes. Knudsen's mode nomenclature is consistent with this extension to complex films. Similar comments apply to LSM modes.

Theoretical field patterns and propagation constants are compared with experimental results obtained by probing the loaded guide. Film resistivities of 50, 100, and 200 phms/square were used. Film to waveguide contact was assured by painting the junction between the two with a conducting strip of silver paint. Excellent agreement with Knudsen was then obtained. These modes are characterized by an electric-field dip at the vane position, nonuniform phase front, and complex propagation constant. Also, at no longitudinal section does an electric-field null occur for higher-order modes.

Some solutions for complex-impedance films behave like surface waves. They exhibit an exponential field dependence and a phase constant greater than that in free-space. An attentuating film with an inductive component may be approximated by a semi-conducting slab, the inductance being due to skin effect. Films not in contact with the guide walls have capacitive components due to the gaps. A simple expression gives a useful first approximation to the gap capacitance. Series reactance was shown to have a marked effect on the propagation constant when the resistivity was 100 ohms/square or less. Contrary to expectation, it was demonstrated both theoretically and experimentally that the introduction of even very small gaps can cause a greatly increased attentuation and phase constant. Because of this, Knudsen's hope that the perfect-contact solution would act as a first approximation to the no-contact case remains largely unfulfilled. Surface waves and mode-interference effects were observed experimentally. Attenuation and phase constants were measured as a function of gap.

References

[1]H.L. Knudsen, Champ dans un Guide Rectangulaire a Membrane Conductrice, L'Onde Electrique, no. 313, pp. 217-34; April, 1953.

[2]T. Ishida and Y. Mushiake, Characteristics of Loaded Rectangular Waveguides, IEEE Trans. on Microwave Theory and Techniques, vol. MTT-13, pp. 451-7; July, 1965.