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Tetrahedral Junction

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The term *tetrahedral junction* refers to a class of waveguide junctions having the symmetry properties of a tetrahedron, and loaded by a ferrite rod magnetized axially. The structure possesses a combination of properties which make it suitable as a gyrator or switch and, with appropriate modifications, as an isolator or circulator. It exhibits characteristically low dissipative loss, high mechanical symmetry, and moderate band width. A first attempt to construct a simple theoretical model has yielded a correlation with the most conspicuous observed properties of the junction.

INTRODUCTION

THE class of waveguide structures for which the term *tetrahedral junction*[1] is proposed is a ferrite-loaded transition connecting two transmission lines, such as rectangular waveguide, whose principle axes are mutually crossed, and having the symmetry properties of a tetrahedron. The simplest example is a butt joint of the two guides. A somewhat more elaborate one is a taper composed of planes joining the corresponding edges of the two guides, as shown in Fig. 1(a). Coupling from one guide to the other is produced by a ferrite element, such as a rod, mounted on the common axis of the two and magnetized longitudinally.

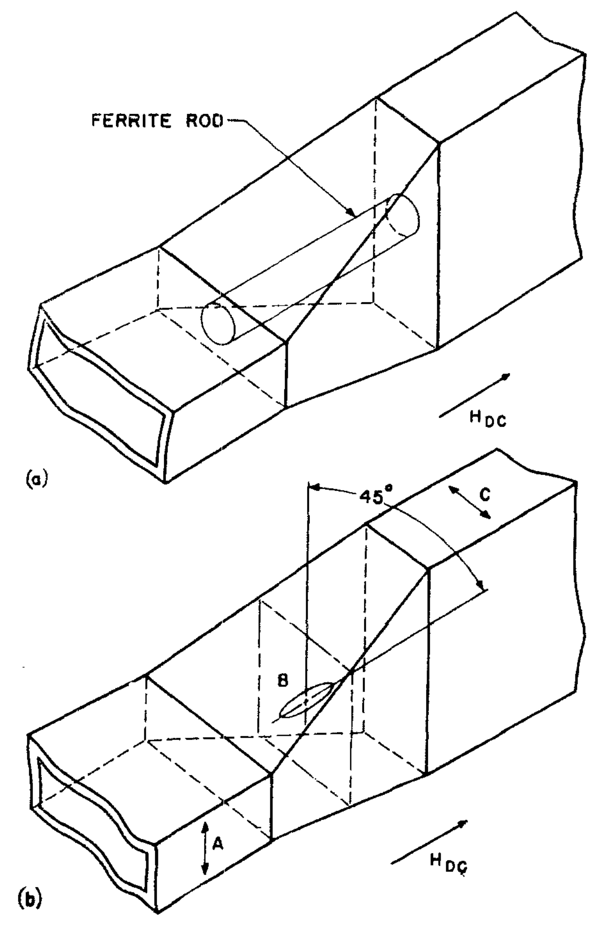

FIG. 1. Basic structure and polarization characteristics of the tetrahedral junction.

[1] J. A. Weiss, "The Tetrahedral Junction as a Waveguide Switch," to be published in IRE Trans. PGMTT 8 (January, 1960).

OBSERVATIONS

By experimenting with the ferrite and taper geometry and the magnetizing field in the structure of Fig. 1, it is possible to produce transmission with exceptionally low insertion loss: less than 0.1 db over a considerable band (at least 5%). On the other hand, the taper lends itself to precise machining and by its propagation characteristics permits the connecting guides to be accurately decoupled from one another. Thus, extremely high insertion loss values, as high as 60 db, are observed when the ferrite is demagnetized. This combination of high and low transmission loss is useful in difficult switching applications, such as in the protection of masers, where the low loss of the device in the transmitting state leads to only a small thermal noise contribution, and its high loss in the nontransmitting (reflecting) state protects the active maser material (e.g., ruby) from saturation effects. This switching mechanism has the additional advantage of requiring relatively small magnetizing fields applied over a small volume, which, together with the longitudinal orientation of the field, suggests the possibility of switching at high speeds with relatively little energy.

A further characteristic of the junction in its transmitting state is that the polarization of the wave at the center plane is in general elliptical with major axes oriented at 45° with respect to the symmetry planes of the structure [Fig. 1(b)]; under certain conditions the ellipse is observed to degenerate into linear polarization. This state of polarization persists over a wide range of magnetizing fields. From the symmetry of the junction and the gyromagnetic property of the ferrite, it is apparent that the device is a gyrator, and that whether the wave is polarized at plus or minus 45° depends on the direction of propagation, or alternatively, on the direction of the magnetizing field. This additional property of the junction suggests a variety of applications to nonreciprocal devices such as switchable isolators and circulators. For example, a film of dissipative material placed in the vicinity of the center plane and oriented at 45° makes the device into an isolator which, in principle at least, ought to combine the desirable properties of low forward loss, high reverse loss, insensitivity to variations in applied field, and, perhaps, bandwidth of the same order as that of the switch. Some caution is called for here because exhaustive studies of the rather complicated effects of the taper and ferrite on scattering and polarization have not yet been carried out. A still more difficult design problem, namely the addition of a third, and perhaps a fourth, port at the center plane, offers the possibility of yielding a compact circulator possessing values of isolation, "forward" loss, and bandwidth similar to those quoted above for the switch. The following additional observations on the experimental device are significant: (i) its transmission characteristics (i.e., transmission as a function of frequency and magnetizing field) are quite insensitive to the position and length of the ferrite rod, indicating that the coupling between the two guides takes place almost entirely at the center plane; (ii) the transmission is not dependent in any essential way on the length of the taper, but presents the same basic appearance over the range from zero to several wavelengths; (iii) the useful range of ferrite rod diameters extends below the minimum amount of loading required to permit Faraday rotation to occur in rectangular guide.

ANALYSIS

A simple scattering problem which represents schematically the situation at the tetrahedral junction can be set up on the basis of the resemblance between the ferrite-waveguide configuration in this structure and that of the Reggia-Spencer phase shifter.[2,3] As discussed in reference 3, a longitudinally magnetized ferrite rod on the axis of rectangular guide supports a single, elliptically polarized mode which is experimentally observed to be readily matched to the dominant mode in empty rectangular guide. There exists a second mode, also in general elliptically polarized, which is, however, in cutoff under the operating conditions of the phase shifter, and makes no significant contribution to its observed properties. In the present structure, on the other hand, this nonpropagating mode is strongly excited at the discontinuity between the two coupled guides. The model uses the same simplifying assumptions as those of reference 3, namely to make a conceptual replacement of the composite ferrite-air-waveguide structure by a homogeneous medium possessing the permeability specified by the Polder tensor, and a phenomenological anisotropic dielectric constant which represents the elliptic symmetry of the guide cross section. The problem is then that of computing the scattering coefficients for plane waves at the interface between two such media having their anisotropy axes mutually crossed.

The calculation yields some rather involved formulas for the coefficients in terms of the magnetic parameters of the medium, the anisotropic "dielectric" parameters, and the propagation constants for the two types of modes. They contain, among other things, two special cases in which the junction transmits with no reflection. Of these, one is that of circular symmetry with Faraday rotation, in the usual sense, through 90°. The other case occurs under conditions quite different from those ordinarily associated with the Faraday effect: the symmetry of the guide is far from circular, in the sense discussed in reference 3, and the condition of match requires the presence of the evanescent modes referred to above. This latter case seems to correspond to the observation mentioned earlier that the scattering occurs in a small region close to the center plane. A further result of the model in this case is that the state of polarization at the center plane is, as observed, elliptically polarized at 45°, and under special assumptions, linear.

REMARKS

The correspondence between the device and the theory is not complete. Particularly in the case of the tapered junction, the observed properties have features (e.g., inteference effects[4]) which might be described as intermediate between the extremes of scattering at a single plane, on the one hand, and Faraday rotation on the other. The theory contains some doubtful features, particularly relating to the states of polarization of the modes, which may stem from the schematic character of the model. The principle is altogether a complicated one, and yet, in view of its unusual and useful properties, worthy of considerable further investigation.

[2] F. Reggia and E. G. Spencer, Proc. Inst. Radio Engrs. **45**, 1510–1517 (1957).

[3] J. A. Weiss, Proc. Inst. Radio Engrs. **47**, 1130–1137 (1959).

[4] J. A. Weiss, "An interference effect associated with Faraday rotation···" *Proceedings of the Conference on Magnetism and Magnetic Materials, Boston, 1956* (American Institute of Electrical Engineers, New York, 1957), AIEE Spec. Publ. T-91, pp. 580–585.