II-1. A Theory for the Operation of the Tetrahedral Junction Ferrite Switch

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In January 1960, a ferrite switch was described[1] which had very attractive characteristics. These included an "off" insertion loss of 60 decibels and an "on" insertion loss of under 0.1 decibels. The name given to the switch was the tetrahedral junction ferrite switch. Figure 1 is a sketch of the switch. The ferrite rod is centrally located along the longitudinal axis of the junction. The switch is turned "on" and "off" by the application and removal of a magnetic field which is generated by a magnetizing coil. The length of the rod is the same as that of the junction with one-inch tapers extending into the input and output waveguides for matching purposes.

Theory of Operation. Operation of the switch may be explained by joint consideration of: (a) propagation in ferrite media; and (b) propagation in asymmetric waveguide structures. Propagation in ferrite media[2] involves the application of the ferrite tensor permeability to Maxwell's equations. This leads to a pair of coupled wave equations, whose solution involves an uncoupling procedure and incorporation of the appropriate boundary conditions. As straightforward as this may sound, it is virtually impossible to accomplish for anything but exceedingly simple geometrical configurations. For propagation in asymmetric waveguide, we are concerned only with the inequality of propagation velocities for orthogonal modes.

The ferrite rod performs two tasks. Because of the initial rise in the magnitudes of both μ and K of the tensor permeability (see Fig. 2)[3] upon the application of a dc field, it is possible to bring the small dimension of port 1 above cutoff, thereby allowing both perpendicular modes to propagate. (The

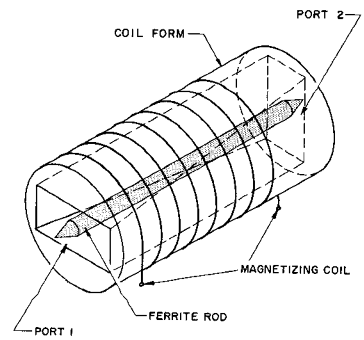

Fig. 1 The tetrahedral junction ferrite switch.

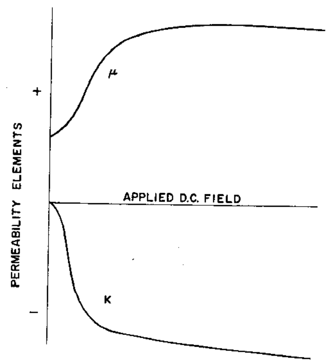

Fig. 2 μ and K vs applied dc field.

term perpendicular rather than orthogonal is used since the two modes in the switch are not uncoupled.) Care must be taken in naming these modes, since pure transverse electric or magnetic modes may not propagate in an inhomogeneous guiding structure where the inhomogeneity is an air-ferrite combination. We will therefore call these hybrid modes HE_v and HE_h, where subscripts v and h refer to vertical and horizontal polarity.

The diameter of the ferrite rod is quite significant. Upon the application of a dc field, the diameter must be large enough to allow propagation of the HE_h mode, but small enough so that higher-order dielectric modes may not propagate. The presence of higher-order dielectric modes would result in propagation that would be essentially independent of the tetrahedral junction, since most of the energy and fields of these modes would be confined within the ferrite rod. This would not give the required difference in propagation velocities for the two perpendicular modes mentioned earlier.

The second function of the ferrite is to provide coupling between the HE_v and HE_h modes. This is accomplished by virtue of the off-diagonal component, K, of the tensor permeability. Since K is zero in the absence of a dc field, there is no coupling between modes. As the dc field is increased, K increases in magnitude (see Fig. 2) and energy is then "shared" by the two modes. This is not the normal type of Faraday rotation, since normal Faraday rotation is usually discussed under conditions where the propagating velocities of the perpendicular modes are equal, as in circular or square waveguides.

The first half of the junction acts as a mode converter from the linearly polarized HE_v mode to a circularly polarized combination of HE_v and HE_h modes. The wave is circularly polarized after it has travelled one-half of the way through the junction. At this point the cross section of the junction is square. In the second half of the switch, the wave is converted back to a linearly polarized HE_h wave. If the switch were cut at its center, where the cross section is square, the output could be rotated with respect to the input about the longitudinal axis without any variation in output power. Since output power is independent of input-output angle, choice of this angle may be determined by the non-propagating or "off" condition. At zero applied dc field, the off-diagonal component K of the tensor permeability is zero. It is obvious, then, that the optimum input-output angle for maximum isolation is $90°$.

The low insertion loss of the switch may be attributed to the fact that a good portion of the fields propagate outside of the ferrite. This was discussed earlier, and it is now apparent that it has virtue beyond operation of the switch.

Another interesting characteristic of the switch is its relative independence of applied dc field above the "on" field level. This is caused by the flatness of both μ and K in the region above the "on" field value.

Experimental Results. Four tetrahedral junctions were constructed for use at C-band frequencies, i.e., the input and output ports were made the same size as the inner dimensions of 2" × 1" C-band waveguide. The isolation properties of these junctions (*without ferrite*) were measured from 5.4 Gc. to 5.9 Gc. Figures 3 and 4 are the results of measurements on 1.5 and 3.0 inch junctions. Each graph has two curves, representing data taken at two slightly different orientations of the junction.

With a ferrite rod in the switch and with zero applied field, all rf fields incident on the input port see a large mismatch and are reflected. As a longi-

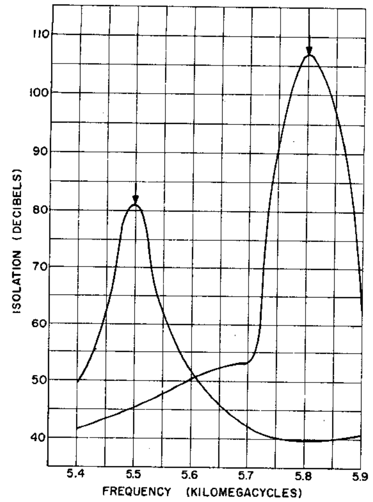

Fig. 3 Isolation vs frequency for a 1.5" long tetrahedral junction.

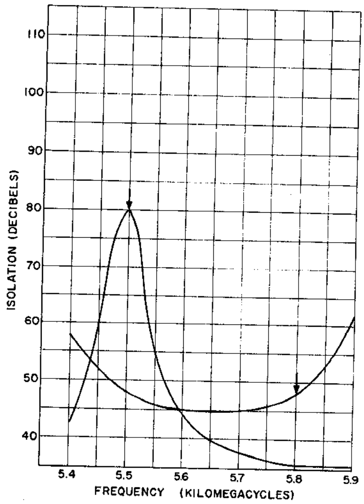

Fig. 4 Isolation vs frequency for a 3" long tetrahedral junction.

tudinal dc field is applied to the ferrite, the reflected energy decreases and the output power increases. Figures 5 and 6 indicate the insertion loss *vs* applied dc field for the two previously mentioned tetrahedral junctions, with four different diameter rods for each junction. The best results were achieved with a 1.50" long junction and a 0.340" diameter rod.

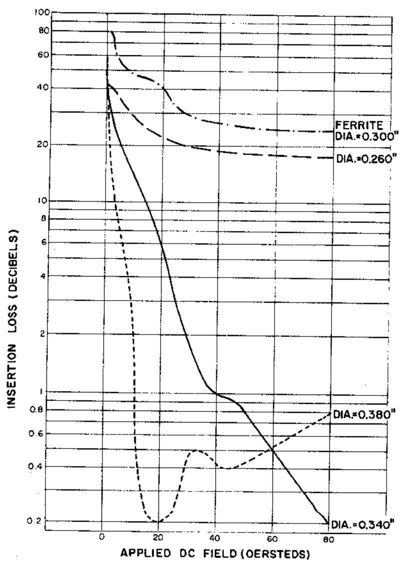

Fig. 5 Insertion loss vs applied dc field for a switch length of 1.5".

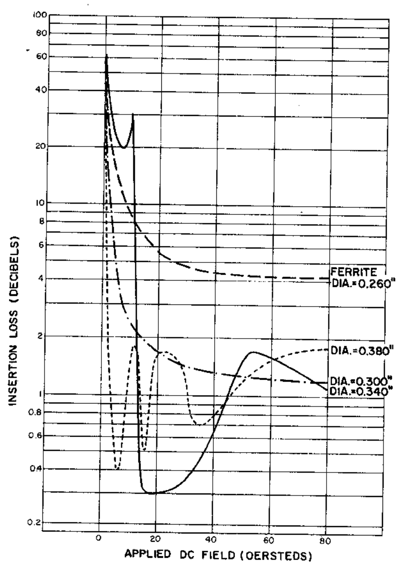

Fig. 6 Insertion loss vs applied dc field for a switch length of 3".

For this particular configuration, an isolation of 52 db was achieved at zero field with an insertion loss of less than 0.2 db at a field of 80 oersteds or above. This insertion loss remained constant for dc fields well over 100 oersteds. All measurements for the data shown in Figure 4 were made at a frequency of 5.65 Gc. The material used was a polycrystalline yttrium iron garnet.

Conclusion. The experimental results reported in this paper are by no means an exhaustive and complete set of data. It is felt, however, that interpretation of this data, plus the application of the presented qualitative explanation of the switch, would enable the successful fabrication of a highly attractive solid state microwave switch with excellent isolation and insertion loss characteristics.

REFERENCES

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