X-7. ANALYSIS OF A GROUNDED JUNCTION CIRCULATOR

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The operation of a novel stripline circulator,[1] which incorporates a single disk of yttrium aluminum iron garnet on one side of the center conductor and a large metallic short circuit on the other side, is described in terms of a resonance mode of the junction. The basic design of this circulator is shown in Figure 1. As seen in the figure the short circuit can be the magnet necessary to bias the garnet disk to the optinum point for circulation. Quarter wavelengths of low impedance line are used to couple the junction to the 50 ohm input lines. The performance of this circulator is typically 30 db of isolation and 0.2 db of insertion loss over an 18% bandwidth.

The conventional stripline circulator has been described in terms of the rotation of the lowest mode or dipolar mode by Bosma[2] and Fay and Comstock.[3] However, in the grounded junction circulator, the lowest mode, TM_{010}, has no field variation in the circumferential direction and cannot be used for three-port circulator design. In this case the second lowest mode, TM_{110}, is used for the circulator.

In order to study the normal modes of the circulator, the grounded junction structure is considered to contain the grounded center conductor in an enclosing circular cavity filled with a scalar dielectric material, as shown in Figure 2a. For ease of analysis this structure is assumed to consist of two cylindrical cavities without side walls, stacked on top of each other (Figure 2b). The radius of these cavities is chosen to compensate for the field curvature around the edge of the center conductor in the actual structure. The fields in the upper cavity are assumed to end abruptly at the periphery and then begin again at the same value in the lower cavity and continue to the short circuit. With the cylindrical coordinate system (r, Φ, z), the above continuity conditions and boundary conditions for the TM modes may be expressed as follows:

1. $E_z^1 = -E_z^2$ or $H_r^1 = -H_r^2$ at $r = R$

2. $H_\Phi^1 = H_\Phi^2$ at $r = R$

3. $E_z^2 = 0$ at $r = r_o$

where the superscripts, 1 and 2, indicate fields in the upper and lower cavities respectively. The fields in cavities 1 and 2 may be found as follows:

$$E_{zn}^{1} = AJ_n\,(k_c r)\quad \cos n\,\Phi$$

$$H_{rn}^{1} = j\,\frac{n}{\omega\mu r}\,AJ_n\,(k_c r)\,\sin n\,\Phi$$

$$H_{\Phi n}^{1} = -j\,\frac{A}{\eta}\quad J_n{}'\,(k_c r)\,\cos n\,\Phi$$

$$E_{zn}^{2} = \{BJ_n\,(k_c r) + CY_n\,(k_c r)\}\quad \cos n\,\Phi$$

$$H_{rn}^{2} = j\,\frac{n}{\omega\mu r}\,\{BJ_n\,(k_c r) + CY_n\,(k_c r)\}\quad \sin n\,\Phi$$

$$H_{\Phi n}^{2} = -j\,\frac{1}{\eta}\,\{BJ_n{}'\,(k_c r) + CY_n{}'\,(k_c r)\}\quad \cos n\,\Phi$$

where $J_n{}'\,(k_c r) = \frac{d}{d(k_c r)}\,\{J_n(k_c r)\},\ k_c = \omega\sqrt{\mu\varepsilon}$

The following characteristic equation may be obtained from the field equations and the boundary and continuity conditions:

$$\frac{Y_n\,(x)}{J_n\,(x)} = \frac{Y_n\,(y)}{2J_n\,(y)} + \frac{Y_n{}'\,(y)}{2J_n{}'\,(y)}$$

where $x = k_c r_o,\quad Y = k_c R$.

The characteristic equation is solved for n = 0 to n = 2 with its higher order solutions. The resonance frequency for the first few modes vs. r_o/R is shown in Figure 3. The field patterns for the first two modes, which have been confirmed by experiments, are shown in Figure 4.

An explanation of the operation of the grounded junction circulator follows from the analogy of the TM_{110} mode to the dipolar mode described by Fay and Comstock.[3] Energy entering port 1 of the circulator excites the folded TM_{110} mode. In the vicinity of the ferrite disk the field pattern is similar to the normal dipolar mode. The field pattern is rotated 30 degrees toward port 3 by the ferrite disk in a manner similar to the conventional circulator. As detailed in reference 3, this creates a null at port 3 and allows the energy to exit through port 2.

Some interesting characteristics of a new type of cavity utilizing the folded TM_{010} mode are described. The electric field is maximum at the center of the unshorted side of the cavity. As can be seen in Figure 4, the separation of the TM_{010} mode and the next higher mode, TM_{110}, is a function of r_o/R. When r_o/R is less than 0.1, the separation of the two resonance frequencies becomes more than 2.57. This separation should be compared with 1.59 of an ordinary cylindrical cavity operating in the TM_{010} and TM_{110} modes. The theoretical Q_0's of both cavities for the same height are about the same. The radius of the cylindrical cavity operating at same frequency is more than 3.4 times larger than that of the folded cavity. An example of a two-port folded cavity with capacitive coupling elements is shown in Figure 5.

[1]Bonfeld, M. D., Linn, D. F., and Omori, M., "A Novel Stripline Circulator," Trans. IEEE on Microwave Theory and Tech., Vol. MTT-14, No. 2, 1966.

[2]Bosma, H., "On Strip Line Y-Circulation at UHF," Trans. IEEE on Microwave Theory and Tech., Vol. MTT-12, p. 61, January 1964.

[3]Fay, C. E. and Comstock, R. L., "Operation of the Ferrite Junction Circulator," Trans. IEEE on Microwave Theory and Tech., Vol. MTT-13, No. 1, p. 15, January 1965.

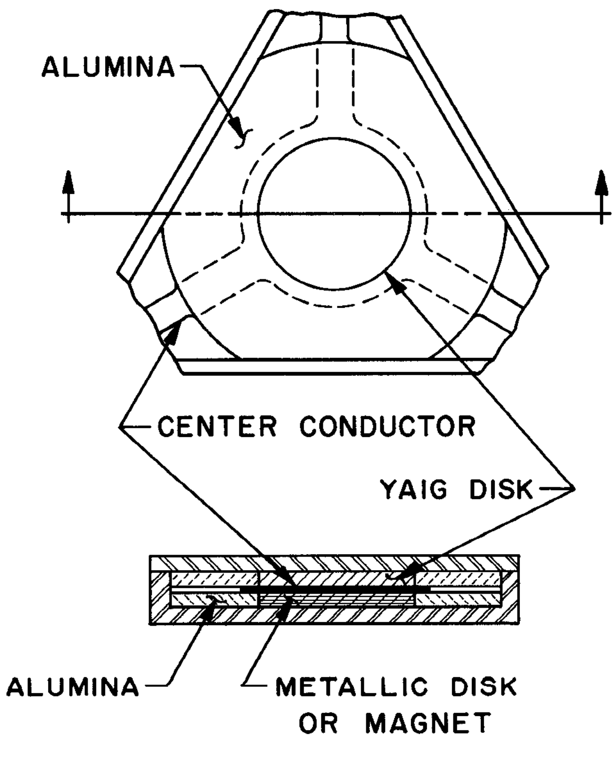

Figure 1. The grounded junction circulator

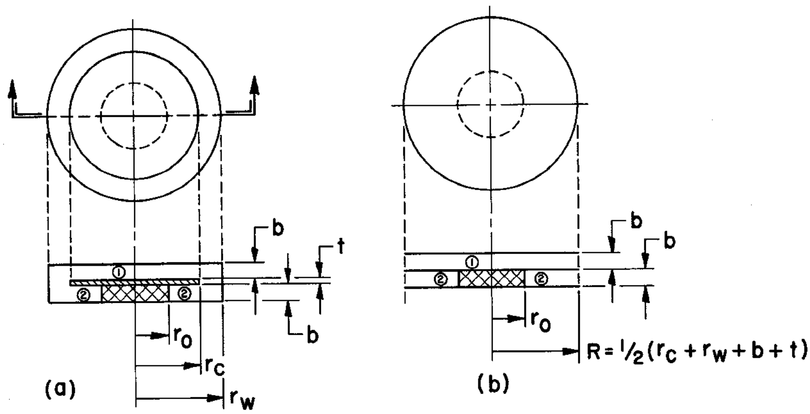

Figure 2. Model for analysis of the resonant modes of the junction

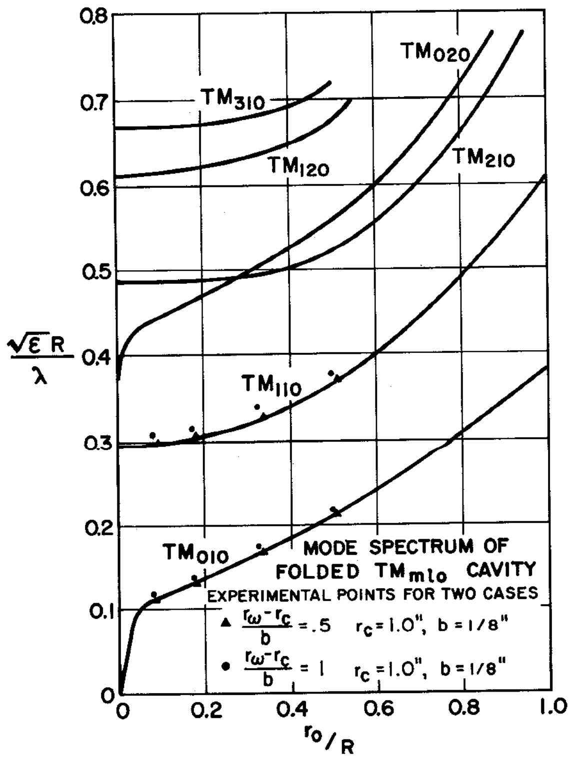

Figure 3. Mode spectrum of the junction

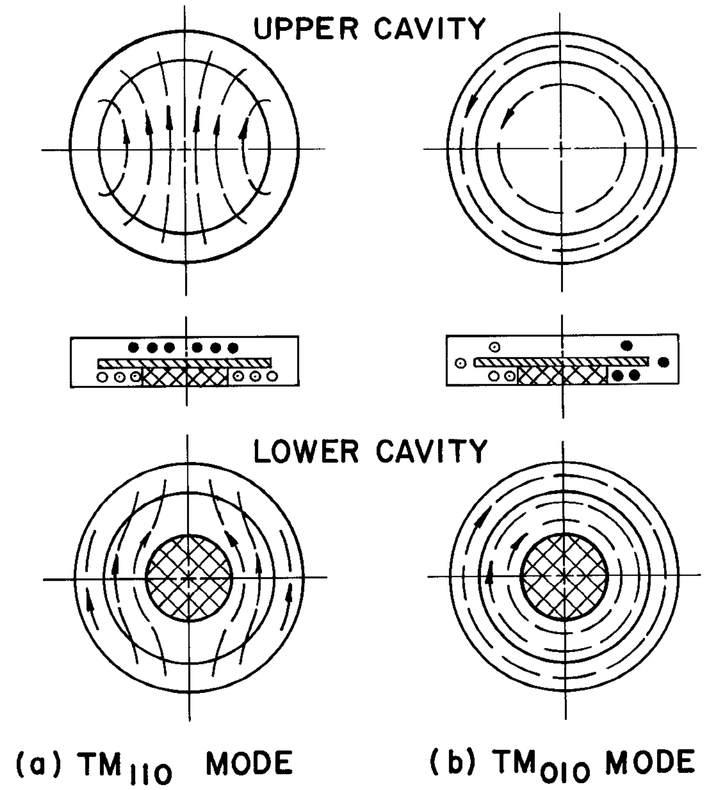

Figure 4. Magnetic field patterns of the two lowest modes

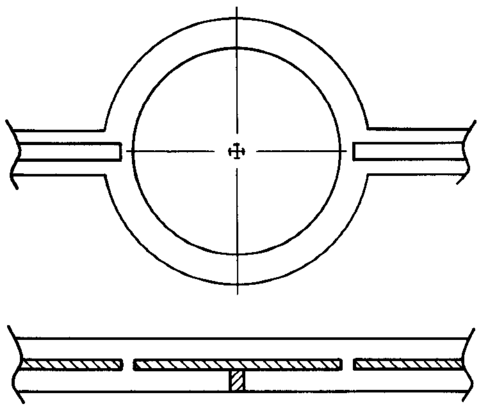

Figure 5. Two port resonant cavity