III-2 HIGH POWER UHF Y JUNCTION CIRCULATOR

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1. General Considerations

The nonlinearity and characteristics deviation of ferrite caused by rising temperature should be considered in a CW high power circulator. The nonlinearity of ferrite operated at above resonance occurs at a comparatively low power level in a polycrystal. Such a phenomena is not observed in a single crystal, as shown in Fig. 1 (a), which shows the experimental results of low power simulation by a lumped element circulator. And the nonlinearity takes place only under CW power and not under pulsed power, as illustrated in Fig. 1 (b).

The above phenomena are supposedly caused by the local heating by the spin wave generation around pore regions of polycrystals where the internal DC field is below resonance by the demagnetizing and anisotropic field in their vicinities.

First the threshold power P_{crit}, the bandwidth ratio $\mathcal{W}$ the insertion loss L and the frequency shift ratio $\mathcal{W}_t$ caused by the temperature fluctuation are obtained as Eq. (1) ~ (4) and are related to the volume τ, filling factor K_f and the permeability of ferrite by variational technique, considering that the internal reactive energy under the same phase excitation is not necessary in an ideal case.

$$P_{crit} = K\, h_{crit}^2 (\mu_+ - \mu_-)\, \tau\, \omega \qquad (1)$$

$$\mathcal{W} = 2\sqrt{3}\, K_f\, \eta \cdot 10^{-\frac{A}{10}}, \qquad \eta = \frac{\mu_+ - \mu_-}{\mu_+ + \mu_-} \qquad (2)$$

$$L = \frac{2.5}{\eta}\left(\frac{1}{Q_+} + \frac{1}{Q_-}\right) \doteqdot \frac{5}{Q_{eff}\,\eta} \qquad (3)$$

$$\mathcal{W}_t = -K_f\, \frac{\delta(4\pi M_s) - \frac{p}{\alpha + p}\,\delta H_{ex}}{\alpha\, H_{res}} \qquad (4)$$

$$\alpha = \frac{|\gamma|\, H_{in}}{\omega} \qquad p = \frac{4\pi\,|\gamma|\, M_s}{\omega}$$

$\delta(4\pi M_s)$ and δH_{ex} are the deviation of saturation magnetization and external field caused by change in temperature.

It is understood that τ should be increased in order to increase the threshold power, and the minimum insertion loss depends only on the strength of the applied DC field and does not on τ and K_f. The material should take the high h_{crit} and the insensivity for temperature fluctuation.

2. Example of UHF High Power Circulator

To increase τ and surface of ferrite, the construction shown in Fig. 2 is discussed.

2.1 Analysis

Eigen frequencies and stored energies in the states satisfying the zero impedance and open impedance respectively for the same phase and the rotational phase excitation, are obtained.

Same phase excitation The approximate value of eigen frequency is obtained as Eq. (6) by the variational technique using the trial function of Eq. (5) corresponding to TM mode existing under the assumption $\overleftrightarrow{\mu} = \mu_{eff}$.

$$\left.\begin{aligned} \varphi_1 &= C_1 \cos k_{z1}(h-z) \left\{ J_0(k_\rho \rho) + C_3 \cos 3\phi \cdot J_3(k_\rho \rho) + C_5 \cos 5\phi \cdot J_5(k_\rho \rho) \right\} \\ & \qquad \qquad (\text{region } 1) \\ \varphi_2 &= C_2 \cos k_{z2} z \left\{ J_0(k_\rho \rho) + C_3 \cos 3\phi \cdot J_3(k_\rho \rho) + C_5 \cos 5\phi \cdot J_5(k_\rho \rho) \right\} \\ & \qquad \qquad (\text{region } 2) \end{aligned}\right\} \quad (5)$$

$$\omega_1 = \frac{1.4}{a\sqrt{\epsilon \mu_{eff}}} \sqrt{\frac{\epsilon_s (1-t') + t'}{t' + \frac{1}{\mu_s}(1-t')}} \left(1 + \frac{\eta^2}{2(1+\tilde{\mu})}\right) \quad (6)$$

Positive and negative rotational excitation After obtaining the values of ω_+ and ω_- assuming $\overleftrightarrow{\mu}$ to be scalar quantities μ_+ and μ_- , the error between tensor and scalar quantities is corrected by the perturbation technique. So we get

$$\omega_\pm = \frac{1.841}{a\sqrt{\epsilon \mu_\pm}} \sqrt{\frac{\epsilon_s (1-t') + t'}{t' + \frac{1}{\mu_\pm'}(1-t')}} \left\{ 1 \mp \frac{\eta}{(1+\tilde{\mu}) \pm \eta} \right\} \quad (7)$$

From calculated values of the time average of total reactive energy $\tilde{W}_{t\pm}$ and Eq. (7), eigen values of admittances Y_+ and Y_- at ω becomes

$$Y_\pm = j(\omega - \omega_\pm)\frac{2}{3}\tilde{W}_{t\pm} = j\,0.0484 \frac{a^2}{h\lambda\left(1-t'+\frac{t'}{\epsilon_s}\right)} \frac{\omega - \omega_\pm}{\omega} \quad (8)$$

Therefore the transform ratio n takes the value of Eq. (9)

$$n^2 = 15 \frac{h\lambda\left(1-t'+\frac{t'}{\epsilon_s}\right)\left\{(\tilde{\mu}_s - 1)t' + 1\right\}}{a^2 \eta \tilde{\mu}_s} \quad (9)$$

From the above results, P_{crit}, $\mathcal{W}$ and L are obtained as the values substituted into Eq. (1) ~ (4) by K = 1.73, $K_f = \dfrac{\tilde{\mu}_s t'}{2(\tilde{\mu}_s t' + 1 - t')}$.

τ takes the maxium value at $t' = \dfrac{1}{1+\sqrt{\tilde{\mu}_s}}$ under h is constant.

2.2 Wideband and Temperature Compensation

$\mathcal{W}$ becomes a little narrower by making K_f smaller to increase τ . However, it is clear from the calculation of reactive energies that the eigen value for the same phase excitation is insensitive for the variation of frequency and permeability, whereas it is very sensitive for the rotational phase excitation. So the added cavity containing ferrite coupled only to same phase excitation contributes to increase the reactive energy and results in adding the equivalent series resonance as in Fig. 3. The proper design make it possible to make wideband 3.55 times in chebycheff and $\sqrt{3}$ times in Wagner Char. at 20 dB isolation band. In this case, equal values of the filling factor K_f' in compensating cavity contributes to make insensitive for the temperature fluctuation with the same characteristics for frequency wideband.

2.3 Practical Performance

The characteristics of circulator with the ferrite of 150 mm in diameter, 5 mm in width and 0.4 in t', is 0.2 dB in insertion loss and 25 Mc in bandwidth for 20 dB isolation and is available to 10 kW CW.

3. Another example

Considering heat problem, another constructions shown in Fig. 4 are also developed.

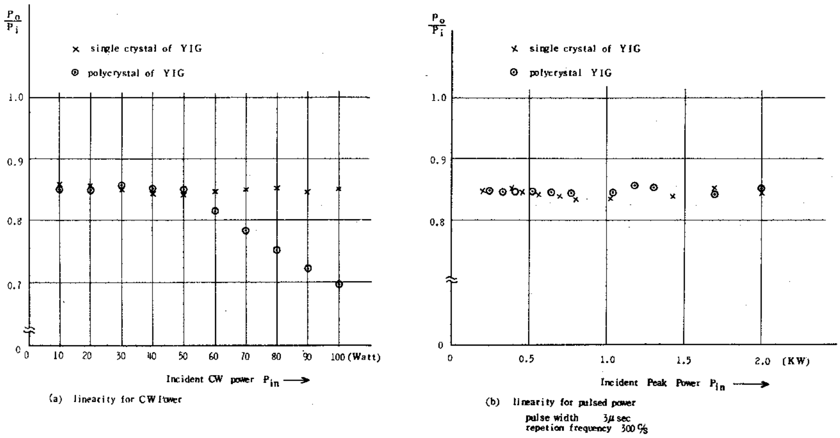


FIG. 1 - Measured Values of Linearity of Circulator with Single and Polycrystal

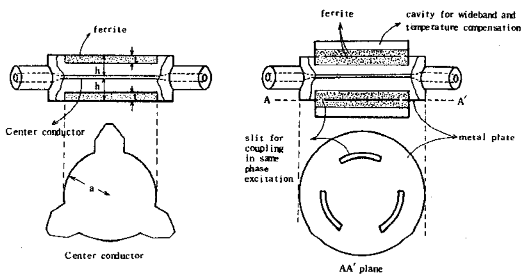
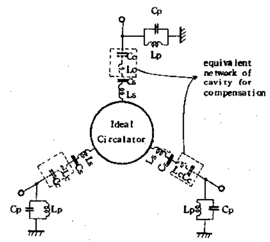


FIG. 2 - Example of UHF High Power Circulator



$$L_s = \frac{60 h\lambda \left(1 - t' + \frac{t'}{\epsilon_s}\right)}{\omega a^2} \ (H)$$

$$C_s = \frac{1}{\omega^2 L_s} \ (F)$$

$$C_p = \frac{0.0242\, a^2}{\omega h\lambda \left(1 - t' + \frac{t'}{\epsilon_s}\right)} \ (F)$$

$$L_p = \frac{1}{\omega^2 C_p} \ (H)$$

FIG. 3 - Equivalent Network of the Circulation

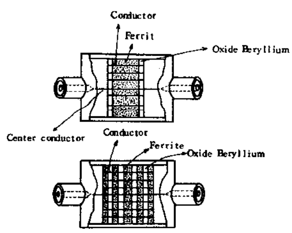


FIG. 4 - Examples of High Power Circulator