THE DESIGN OF RECIPROCAL FERRITE PHASE SHIFTERS

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The design of a reciprocal ferrite phase shifter in a rectangular waveguide, using perturbation theory with a quasi-stationary approximation for the field perturbation of the system is considered. The theoretical results are compared with experimental data and with a design carried out without using the quasi-stationary approximation [5]. The simplicity of the proposed method and the good agreement between the theoretical and experimental results enable it to be used in solving engineering problems.

INTRODUCTION

The reciprocal ferrite phase shifter provides a large phase shift for weak energizing fields, making it suitable for use in electrically-controlled beam-scanning antennas [1-3]. Many theoretical and experimental investigations of such phase shifters have been made. The experimental adjustment of the phase shifter is made difficult by the large number of variables which have to be determined. The exact solution of the electrodynamical problem of a thick ferrite rod close to conducting walls has not been obtained. Therefore approximate methods of design are used, using perturbation methods [5-8] and Ritz's method [9]. The latter method has the disadvantage that it is a numerical one, and does not give an analytic expression connecting the characteristics of the material and the physical arrangement. Also, the calculation becomes more cumbersome as the agreement between theory and experiment is improved. Using perturbation theory, an analytic expression can be obtained relating the phase shift with the components of permeability and permittivity tensors of the ferrite material. However, as the thickness of the sample and the magnitude of the applied magnetic field is increased, there is a greater difference between theory and experiment, and when using the perturbation method described in [5-8]. This difference is apparently explained by the fact that the calculations do not allow for the influence of the nondiagonal component of the magnetic permeability tensor upon the phase shift of the electromagnetic wave in the phase shifter. This explanation is supported by the experimental data relating to the increase in phase shift with increase in the nondiagonal component.

In this paper the dependence of the phase shift upon all the components of the permeability tensor of the ferrite is studied. In applying the perturbation method, the quasi-stationary approximation of the perturbation of the electromagnetic field of the phase shifter is used. The results are compared with experiment and with the results of calculations not using the quasi-stationary approximation [5].

CALCULATION OF PHASE SHIFT

A diagram of the phase shifter considered is given in Fig. 1. The increase in the propagation constant, \( \Delta \gamma \), is determined by perturbation theory [10] as

\[
\Delta \gamma = \frac{1}{\omega} \int_{S_0} \frac{\Delta \mu}{S_1} \cdot \bar{H}_0 \cdot \bar{H}_0^* \, dS,
\]

where \( S_1 \) is the cross sectional area of the ferrite, \( S_0 \) is the cross sectional area of the waveguide, \( \omega \) is the frequency of the electromagnetic wave,

\[
\Delta \mu = \begin{vmatrix}
\mu - \mu_f & -i \mu_a & 0 \\
- i \mu_a & \mu - \mu_f & 0 \\
0 & 0 & \mu_e - \mu_f
\end{vmatrix}
\]

\( \mu, \mu_a, \mu_e \) are the diagonal, nondiagonal, and longitudinal components of the permeability tensor of the ferrite, \( \mu_f \) is the permeability of the demagnetized ferrite, and \( H_0, E_0^* \) are the complex conjugates of the amplitude of the unperturbed field.

The unperturbed field is assumed to be the field propagated in the waveguide with a demagnetized ferrite material. A perturbation is introduced into the steady magnetic field applied to the ferrite in the direction \( Z \). In the unperturbed system the amplitudes of the fields of the fundamental mode have the form given in [5], i.e.,

in region I

\[
E_y = A \cos \left( k_{dx} \left( \frac{t}{2} - x \right) \right),
\]

\[
H_z = \frac{i k_{dx}}{\omega \mu_f} \frac{A}{A} \sin \left( k_{dx} \left( \frac{t}{2} - x \right) \right); \tag{2}
\]

in region II

\[
E_y = \sin k_{ox} x; \quad H_z = \frac{i k_{ox}}{\omega \mu_f} \cos k_{ox} x; \tag{3}
\]

in region III

\[
E_y = \sin \left( (t - x) k_{ox} \right); \quad H_z = -\frac{i k_{ox}}{\omega \mu_f} \cos \left( (t - x) k_{ox} \right), \tag{4}
\]

where

\[
A = \frac{\sin k_{ox} t_2}{\cos \left( k_{dx} \left( \frac{t}{2} - t_2 \right) \right)}, \quad k_{ox} = \sqrt{k^2 - \frac{1}{4^2}},
\]

\[
k = \frac{2\pi}{\lambda}, \quad k_{dx} = \sqrt{\varepsilon \mu_f k^2 - \frac{1}{4^2}},
\]

and \( \varepsilon/\varepsilon_0 \) is the permittivity of the ferrite.
Fig. 2

Fig. 3