MICROWAVE PROPERTIES OF PARTIALLY MAGNETIZED FERRITES

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With the surge of design activity of ferrite components for phased array radars, a knowledge of the microwave characteristics of partially magnetized ferrites is a very useful asset. Phase shifters, circulators, and switches are most economically designed if the biasing field can be kept small. A preferred configuration consists of the microwave ferrite being latched into a major or minor loop (flux drive) remanent state. For such operation the internal dc magnetic field is quite small (the order of the coercive force). Anisotropy and demagnetizing effects due to sample shape and local inhomogeneities such as pores and second phase prevent the material from being completely magnetized, and hence the sample is in a partially magnetized state.

The microwave properties of the partially magnetized state can be characterized by a tensor permeability $\overleftrightarrow{\mu}$ which has much of the same symmetry properties as it does for the completely magnetized state. However, the three tensor components (μ, κ, μ_z) can no longer be described by theoretical formulas obtained from solutions to the torque equation. Rado[1] was the first to propose that the real part, κ', of the off-diagonal element is approximately given by $\kappa' = \gamma 4\pi M/\omega$ where $4\pi M$ is the average magnetization. This has been substantially verified experimentally. In calculations it had been customary to take $\mu' = \mu_z' = 1$. We have found that μ' and μ_z' can be significantly different from unity. From measurements of numerous materials, the following formulas have been developed for the behavior of μ_z' and μ'

$$\mu' = \mu_o' + (1 - \mu_o')(M/M_s)^{3/2}$$

(empirical)

$$\mu_z' = \mu_o'^{\left[1-(M/M_s)^{5/2}\right]}$$

(empirical)

$$\mu_o' = \frac{2}{3}\,\frac{\sqrt{1-\gamma^2(4\pi M_s + H_a)/\omega^2}}{\sqrt{1-\gamma^2 H_a{}^2/\omega^2}} + \frac{1}{3}$$

(Schlömann[2])

where H_a is the effective anisotropy field.

The loss parameters μ'', κ'', and μ_z'' depend not only upon the normalized magnetizations $\gamma 4\pi M_s/\omega$ and $\gamma 4\pi M/\omega$ but also upon composition and the microstructure of the particular material. To achieve a low loss design, it is necessary to keep $\gamma 4\pi M_s/\omega \le .75$. For this range we have been able to show that $|\kappa''|$ is sufficiently less than μ'' that the material can be characterized by a single loss parameter, μ''. Furthermore, the value of μ'' changes very little about the hysteresis loop so that the loss can be characterized by the value of μ'' in the demagnetized state, μ_o''. Values of μ_o'' will be listed for a number of commercially available materials.

The high power nonlinearities which occur with parallel and transverse pumping of a completely magnetized ferrite also carry over into the partially magnetized state. The threshold for parallel pumping is considerably lower than that for perpendicular pumping, and as the material demagnetizes, the two thresholds merge into a single threshold for the demagnetized state. Materials can be characterized by their parallel pump threshold for the state for which the sample is magnetized, but the internal field is near zero. Values of the spin wave linewidth for this state will be given for numerous commercial materials.

References

1. Rado, G. T., "Theory of the Microwave Permeability Tensor and Faraday Effect in Nonsaturated Ferromagnetic Materials," Phys. Rev. 89, 529 (1953).

2. Schlömann, E., "Microwave Behavior of Partially Magnetized Ferrites," J. Appl. Phys. 41, 204 (1970).

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