APPLICATION NOTE

No. 661: Test for Complex Dielectric Constant

Introduction

At microwave frequencies the dielectric property (ε) or permittivity of ferrimagnets result from the electronic polarizability (α_e) and ionic polarizability (α_i).

Within the temperature-frequency limits of interest to the microwave device engineer, ε is essentially constant in microwave ferrimagnetic materials. The residual dielectric losses are taken into account by the complex constant (ε^*).

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \qquad (1)$$

where ε' is the real part of the permittivity. Energy dissipation can be expressed as $\tan^{\delta}{}_{e} = \varepsilon''/\varepsilon'$. The energy loss is then proportional to ε''.

Several methods can be employed to evaluate the ε' and ε'' of a medium. For microwave ferrimagnetic materials the cavity perturbation technique is gaining general acceptance.

A TE_{10n}, (n odd and 3 or greater) cavity resonant in the X-band region is employed. The loaded Q of the empty cavity should be 2000 or greater. The ferrite sample is in the form of a rod approximately 0.042 inch diameter. It is placed parallel to the microwave electric field in a region of substantially uniform electric and zero microwave magnetic fields. A typical TE_{103} cavity with an empty resonant frequency of 9300 me is shown in Figure 1.

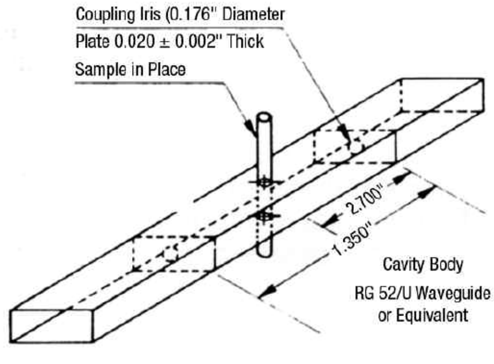

Figure 1. Typical TE_{103} Cavity Resonant at 9300 me

Inserting the sample in the cavity results in (1) a shift of cavity resonant frequency to a lower value, and (2) a reduction of cavity Q.

The governing equations are:

$$\frac{\Delta f}{f} = -2\,(\varepsilon' - 1) \cdot \frac{V_S}{V_C} \qquad (2)$$

$$\Delta\left(\frac{1}{Q}\right) = 4\,\varepsilon'' \cdot \frac{V_S}{V_C} \qquad (3)$$

where Δf and ΔQ are, respectively, the difference in cavity resonant frequency and cavity Q with and without the sample; f is the resonant frequency of the empty cavity; V_s is the sample volume (within the cavity); V_c is the cavity volume.

It is seen that ε' is determined from the cavity resonant frequency shift and ε'' found from the reduction of cavity Q.

Measurement

Figure 2 is a schematic diagram of typical equipment required. Power from a suitable unmodulated or amplitude modulated microwave source (A) is run through a variable attenuator (D) and kept at a constant level throughout the measurement with the aid of a directional coupler (E), a crystal detector, and a power indicating meter (F). This constant power is run through a precision variable attenuator (G) to the cavity (H), and the cavity output power is detected and indicated on a suitable meter (I)

Empty Cavity

An attenuation of 3 dB is introduced with the precision attenuator. The microwave frequency is adjusted to cavity resonance, as indicated by maximum power output with respect to frequency variation. The indication of the output power level is noted, and the resonant frequency f is measured with a wavemeter, or other suitable means, at (B). The 3 dB of attenuation is removed and the two frequencies located at which the output power is the same as at cavity resonance with the 3 dB attenuation in. The separation in frequency of these two half-power points is determined at (B) by a heterodyning technique utilizing a frequency stabilized source (C). The loaded Q of the cavity is then given by $f/\Delta f_{1/2}$ where $\Delta f_{1/2}$ is the frequency separation of the half-power points.

Alternatively, instead of the 3 dB of attenuation specified above, a larger amount, α decibels may be used. If Δf is the separation of the two frequencies at which the output power without attenuation is the same as the output power at cavity resonance with the α decibels of attenuation inserted, the Q is given by:

$$Q = \frac{f}{\Delta f}(10^{\alpha/10} - 1)^{1/2} \qquad (4)$$

By choosing a value of a sufficiently large, it is possible to make the measurement of Δf with a precision wavemeter, eliminating the need of the heterodyning technique.

Sample in Cavity

Repeat the measurements of f and Q. The change in f is the desired Δf, and the change in I/Q is the desired Δ (I/Q).

The microwave magnetic field is a minimum, but not precisely zero at the sample location. This can introduce magnetic loss into the measurement. A suitable magnetic bias can be applied to the ferrite to avoid this loss contribution.

Reference

American Society for Testing and Materials (ASTM) tentative standard C525-63T.

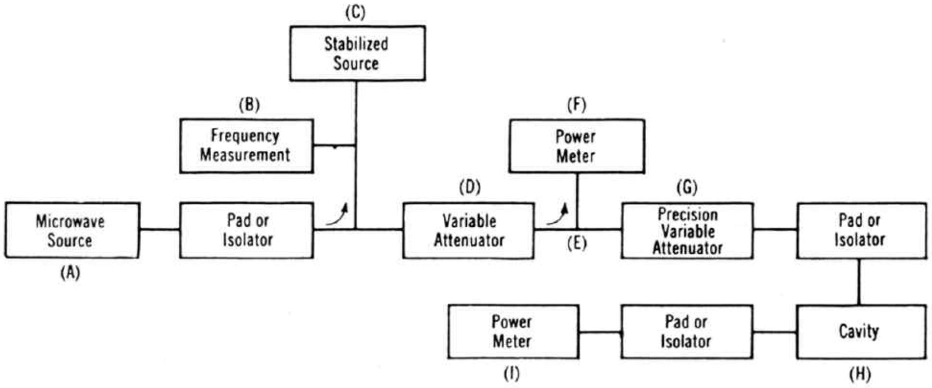

Figure 2. Diagram of Typical Equipment Set up

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