APPLICATION NOTE

Test for Complex Dielectric Constant

Introduction

At microwave frequencies, the dielectric property (ε) or permittivity of ferrimagnets are the results from 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*):

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

Where:

ε' = Real part of the permeability.
j = Imaginary unit.

Energy dissipation is usually expressed as:

$$\tan^{\delta} e = \varepsilon'' / \varepsilon' \qquad \textbf{(2)}$$

Where:

$^{\delta}e$ = Energy loss.
ε = Real part of the permeability.

The energy loss is then proportional to ε".

Several methods can be used to evaluate the ε' and ε" of a medium. For microwave ferrimagnetic materials, the cavity perturbation technique is generally accepted.

Cavity Method

A TE_{10n} (n odd and 3 or greater) cavity resonant in the X-band region is used as the cavity method. The Loaded Quality factor (Q_L) of the empty cavity should be 2000 or greater. The ferrite sample is in the form of a rod that has a diameter of approximately 0.042 inches, and is placed parallel to the microwave electric field in a region of substantially uniform electric and zero microwave magnetic fields.

Figure 1 shows a typical TE_{103} cavity with an empty resonant frequency of 9300 MHz.

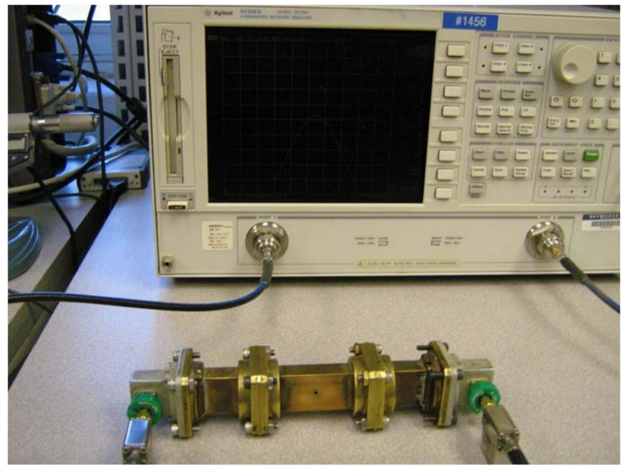

Figure 1. Typical TE_{103} Cavity Resonant at 9300 MHz

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

The governing equations are:

$$\frac{\Delta f}{f} = -2(\varepsilon' - 1) \times \frac{V_S}{V_C} \qquad \textbf{(3)}$$

$$\Delta\left(\frac{l}{Q}\right) = 4\,\varepsilon'' \times \frac{V_S}{V_C} \qquad \textbf{(4)}$$

Where:

Δf and Δl/Q = Respectively, the difference in cavity resonant frequency and cavity Q, with and without the sample.
f = Resonant frequency of the empty cavity.
ε = Real part of the permeability.
V_S = Sample volume (within the cavity).
V_C = Cavity volume.

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

Measurement

Figure 2 is a schematic diagram of the typical equipment required for measurement. 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) and a crystal detector and 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

Note: *Refer to the Permeability Spectra of Ferrimagnetic Materials Application Note, Document Number 202867.*

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 wave meter (or other suitable means) at (B). The +3 dB of attenuation is removed, and the two frequencies located at 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 using a frequency stabilized source (C). The Q_L 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, the 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:

$$Q = \frac{f}{\Delta f}\,(10^{\alpha/10} - 1)^{1/2} \quad \textbf{(5)}$$

Where:

Q = Cavity Q.
f = Resonant frequency of the empty cavity.
Δf = Difference in cavity resonant frequency.

By choosing a value that is sufficiently large, it is possible to make the measurement of Δf with a precision wave meter and eliminate the need of the heterodyning technique.

Sample in Cavity

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

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

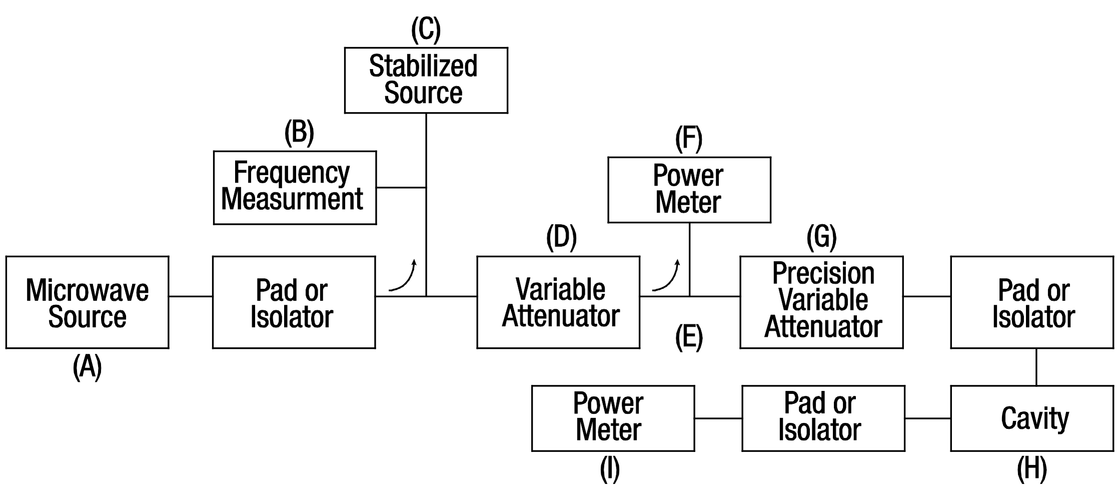

Figure 2. Typical Equipment Setup Diagram