DIELECTRIC PROBE FOR PERMITTIVITY AND PERMEABILITY MEASUREMENTS AT LOW MICROWAVE FREQUENCIES

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ABSTRACT

A new non-destructive method using a dielectric probe of cross section 1 cm^2 for measuring the complex electromagnetic parameters (ε and μ) of materials around 1 GHz is developped. The theoretical analysis uses the 3 dimensional Finite Element Method. The comparison between theoretical and experimental results provides the electromagnetic parameters of the sample under test. Results for a high loss material are presented respectively at 25°C and 100°C.

I - INTRODUCTION

Beside their conventional applications in the fields of telecommunications and radars, microwaves are rapidly expanding into new areas, in particular those dealing with industrial measurements. Dielectric and magnetic materials are used in these new developments and so, characterization of their electromagnetic parameters is now necessary. Numerous methods for measuring these electromagnetic characteristics are available at microwave frequencies. They can be generally divided into two groups :

- destructive methods which are requiring the machining of the sample under test [1][2]
- non-destructive methods which are maintainingthe sample in its integrity [3][4][5]

We can also differentiate these methods according to the measurement technique used :

- the waveguides and/or lines methods which necessit the measurement of scattering parameters [6]
- the resonant methods which necessit the measurement of the resonant frequency f_0 and the unloaded quality factor Q_0 [3][7]

In the present work, a non-destructive method using the resonant measurement technique is studied. This method is based on the utilization of a rectangular dielectric resonator, which is metalized on three faces, and which acts on a TEM mode at about 1 GHz. The use of such a device permits to reduce the cross section of the probe and so this of the sample to be tested. At 1 GHz the cross section of the probe is 1 cm^2.

The Finite Element Method (FEM) is used for theoretical analysis of the dielectric probe.

The comparison of f_0 and Q_0 measured values with the theoretical one's, will yield the electromagnetic parameters of tested materials.

II - DESCRIPTION AND THEORETICAL ANALYSIS OF THE STRUCTURE

1°) - __Description__

Figure 1 shows the structure used. It's composed of:

- a rectangular dielectric resonator, metalized on three faces, shown in figure 2, inserted into a rectangular box open at one extremity
- the sample under test which is laying on the top side of the probe

2°) - __Theoretical analysis of the structure__

A three dimensions FEM is applied to analyse theoretically the structure in free oscillations.

We have to solve the following wave equation derived from the Maxwell's ones:

$$\iiint_V \frac{1}{\mu}\left[\overrightarrow{\mathrm{rot}}\left(\vec{E}.\left(\overrightarrow{\mathrm{rot}}\right)\vec{\psi}\right)\right] dV = k_0^2 \iiint_V \varepsilon\, \vec{E}\,.\,\vec{\psi}\, dV \qquad (1)$$

$k_0^2 = \omega_0^2\, \varepsilon_\mu$; ψ is a test function ; $\varepsilon = \varepsilon' - j\varepsilon''$; $\mu = \mu' - j\mu''$

The FEM technique [8] consists in dividing the studied structure into tetrahedrical subdomains (in 3 dimensions) and then in approximing the exact function of each subdomains.

Software based on this numerical method was developed at I.R.C.O.M. [9]. For the cases of free oscillations and complex formulation, the software permits, the calculation of the following quantities :

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- the complex resonant frequency f_0
- the complex components of electromagnetic fields
- the losses on the metallic surfaces
- the complex stored energies and

From these quantities we evaluate the unloaded quality factor Q_0 of the structure.

Thus, we are able to draw a chart's catalog of resonant frequencies f_0 and unloaded quality factors Q_0 as a function of electromagnetical and geometric parameters of the sample under test.

Measured values by interpolation on charts will provide the electromagnetic parameters of the material.

The dimensions of this structure have been theoretically determinated as a function of the resonant frequency f_0 and the unloaded quality factor Q_0 desired.

3°) - <u>Chart's catalog</u>

For given dimensions of the system we have studied the variations of the resonant frequency f_0 and of the unloaded quality factor Q_0 when :

- the electromagnetic parameters ε and μ of the sample and/or
- the geometrical characteristics of the sample are moving

Therefore, we have drawn a chart's catalog of f_0 and Q_0 as a function of dielectric parameters (ε' ,ε'') and magnetic parameters (μ',μ'') of the sample.

Figures 3, 4, 5 show charts of $\varepsilon = \varepsilon' - j\,\varepsilon''$ for three values of thickness of metalized samples of permeability $\mu'_r=1$ and figures 6, 7, 8 charts of $\mu = \mu' - j\,\mu''$ for three values of thickness of metalized samples of permittivity $\varepsilon' = 1$.

We notice that this method of characterization is available for metalized samples such as $10^{-3} < \mathrm{tg}\delta_e = \dfrac{\varepsilon''}{\varepsilon'} < 5$ or $10^{-3} < \mathrm{tg}\delta_m = \dfrac{\mu''}{\mu'} < 5$.

Furthermore, we observe that for $\varepsilon' \in [1\,;\,30]$ whatever $\varepsilon'' \leq 1$, the resonant frequency f_0 is independant of dielectric losses.

Consequently, for samples such as $1 \leq \varepsilon' \leq 30$, $\varepsilon'' < 1$ and $\mu'_r=1$, a measured value of f_0 permits to obtain ε' and a measured value of Q_0 permits to obtain ε''.

In the same way, f_0 has a constant value for :

$$\left|\begin{array}{l} \mu' \in [1\,;30] \\ \mu'' \leq 0{,}1 \end{array}\right. \quad \text{or} \quad \left|\begin{array}{l} \mu' \in [5\,;30] \\ \mu'' \leq 0{,}5 \end{array}\right.$$

Hence, for samples such as $1 \leq \mu' \leq 30$ and $\mathrm{tg}\delta_m \leq 0{,}1$, a measured value of f_0 will provide μ', regardless of μ'', and a measured value of Q_0 will provide μ''.

Results are the same when the samples aren't metalized on one face.

III - MEASUREMENT SETUP

1°) - <u>Description of the experimental structure</u>

The experimental setup used for measuring the electromagnetic parameters of an unknown material is described in figure 9.

The excitation structure of the dielectric resonator FEM mode consists of a microstrip line.

We present here a high-loss material characterization for two different temperatures.

The measured values of f_0 and Q_0 for the sample X_2 (such as $\varepsilon''=0$, $\mu'=0{,}1$) are :

23°C : $f_0 = 1{,}375$ GHz ; $Q_0 = 13$
100°C : $f_0 = 1{,}385$ GHz ; $Q_0 = 8{,}5$

To present the fact that the face of resonator and that of the sample aren't a flat surface we introduce a gap between the probe and the material X_2 under test. Thus, we consider an air gap effect. The structure is shown figure 10.

By interpolation on abacus shown figure 11 we obtain :

	23°C	100°C
ε'	11,5	11
μ''	7,6	4,5

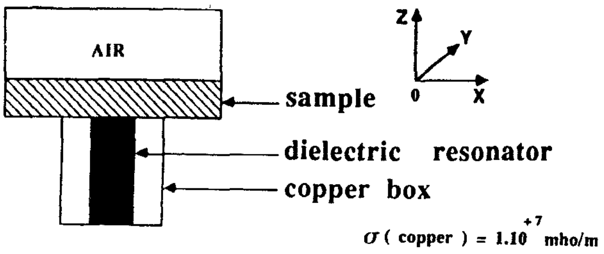
IV - CONCLUSION

In this paper, a new non-destructive method has been explained.

The theoretical resonant frequency f_0 and the unloaded quality factor Q_0 are calculated by the finite element method. By comparison to the measured values and interpolation on theoretical charts, we obtain the electromagnetic parameters of tested materials.

method currently available. They are as follows :

- The method is non-destructive with only a small flat surface required for contact. The contact is not really important because we have the possibility to take into account an air gap between the probe and the tested sample.
- It's possible to characterize samples around the frequency of 1 GHz with a probe structure of acceptable dimensions.
- We can measure properties of rather lossy materials ($tg\delta_e > 10^{-3}$ and $tg\delta_m > 10^{-4}$).



cutaway cross section

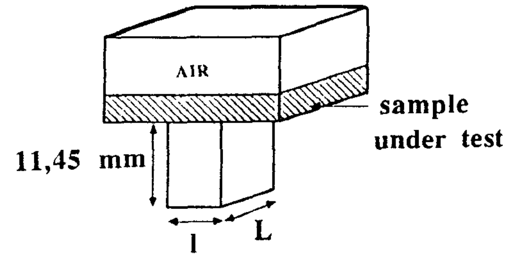


Figure 1 : Configuration of the characterization structure

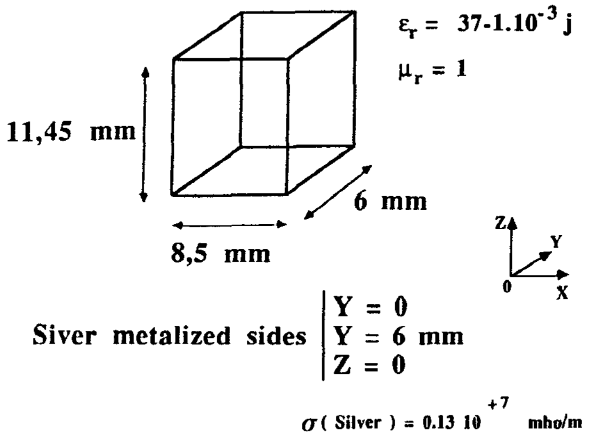


Figure 2 : Dielectric resonator

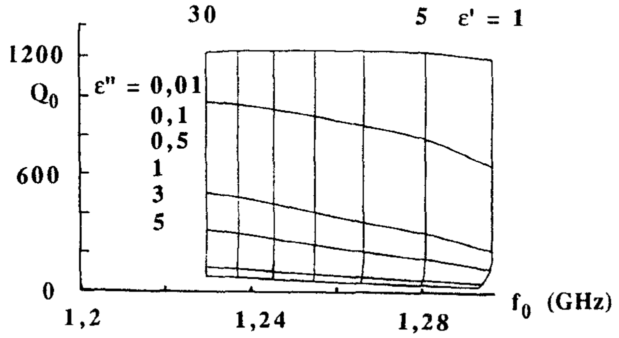


Figure 3 : TEM mode permeability = 1 - j0

material thickness = 0.25 mm

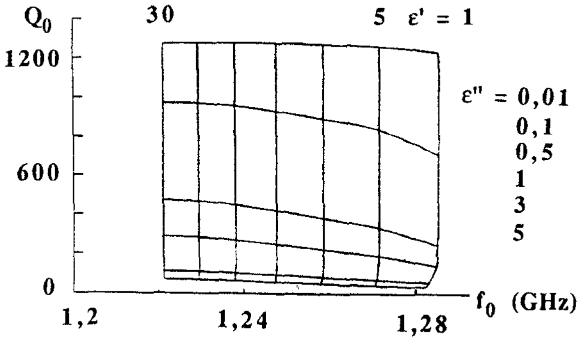


Figure 4 : TEM mode permeability = 1 - j0

material thickness = 0.5 mm

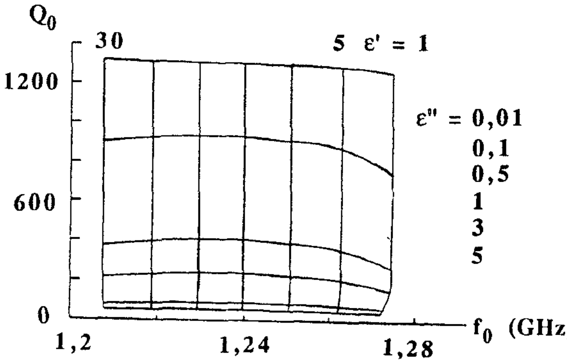


Figure 5 : TEM mode permeability = 1 - j0

material thickness = 1 cm

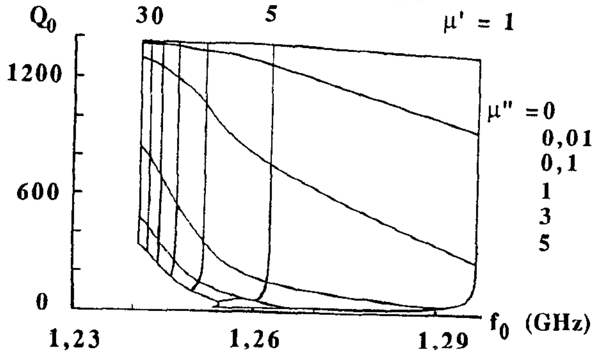


Figure 6 : TEM mode permittivity = 1 - j0

material thickness = 0.25 mm

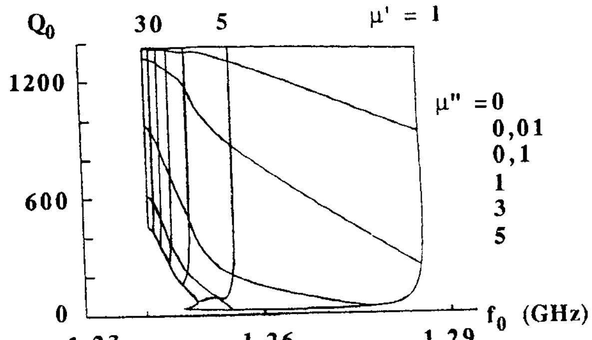


Figure 7 : TEM mode permittivity = 1 - j0

material thickness = 0.5 mm

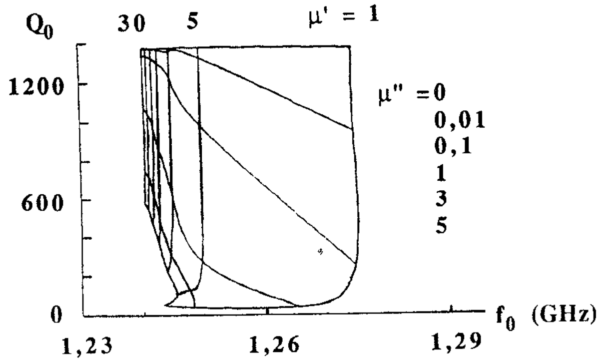


Figure 8 : TEM mode permittivity = 1 - j0

material thickness = 1 cm

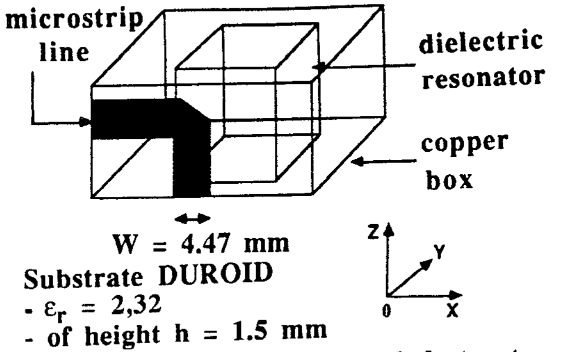


Figure 9 : Experimental unloaded structure

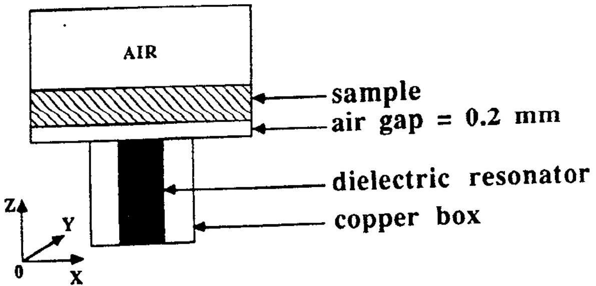


Figure 10 : Cutaway cross-section A configuration of the structure with an air gap

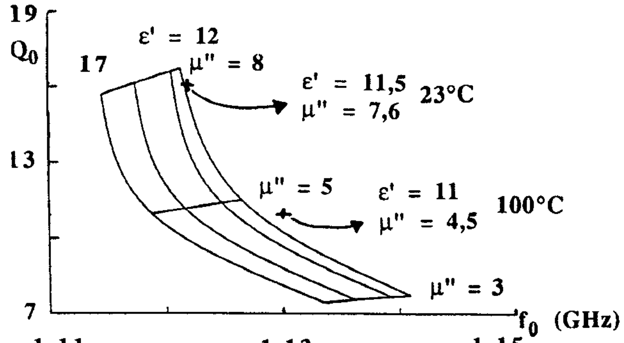


Figure 11 : TEM mode mu' = 0.1 eps" = 0

material thickness = 4.8 mm gap = 0.2 mm

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