MICROWAVE CROSS-BRIDGE FOR LIQUID MATERIALS PARAMETERS MEASUREMENTS

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ABSTRACT

Results of a numerical study of a Cross Bridge electrodynamical structure as a cell for material dielectric parameters measurements are presented. Investigation of scattering characteristics of the structure is based on the rigorous model developed earlier. Physical parameters of the materials under study are of interest for applications.

I. INTRODUCTION

Problems of nondestructive control of industry materials with high frequency technique attract attention of specialists today [1, 5]. Unfortunately certain difficulties arise on the way of implementation of this technique in practice. The main obstacle is an absence of enough good mathematical background of the real processes taking place in the electrodynamical structure filled with the sample under study.

Accurate models, that show the relationship between the scattering parameters and dielectric properties of a sample, are needed for measurements of complex permittivity, especially when applying in the wide frequency range [1-2]. Usually, such a sample presents a dielectric cylinder or dielectric tube filled with the material under test. The scattering of electromagnetic waves by the obstacle of this type placed in a rectangular waveguide has received considerable attention [3-4]. In this work we present results of a numerical experiment based on the rigorous model for a lossy composite cylinder centered in the coupling cavity of the symmetrical H-plane four port waveguide junction. Outside the cylinder, the square coupling region can be also filled with dielectric.

The algorithm ensures the effective determination of scattering characteristics in the full range of available values of the geometrical and electrical parameters of the unit.

Numerical experiments presented in this manuscript deal with study of such multi-point junction (Cross Bridge). Such Cross Bridge cell (CB-cell) promises to exhibit certain advantages in the fluid dielectric parameters control while application in industrial and technological areas.

The advantages of the structure described in the manuscript are the following:

- Rather simple tuning of the CB-cell on the working frequency dependently of the material losses value.
- Technological simplicity of manufacturing of real CB-cell that can be easily integrated into technology lines with objects under testing.
- The possibility of real time dielectric parameters control by fitting a programmable single-chip computer to the technological CB-cell.

II. NUMERICAL EXPERIMENT AND DISCUSSION

The model of the Cross Bridge we describe in the paper is presented in Fig.1.

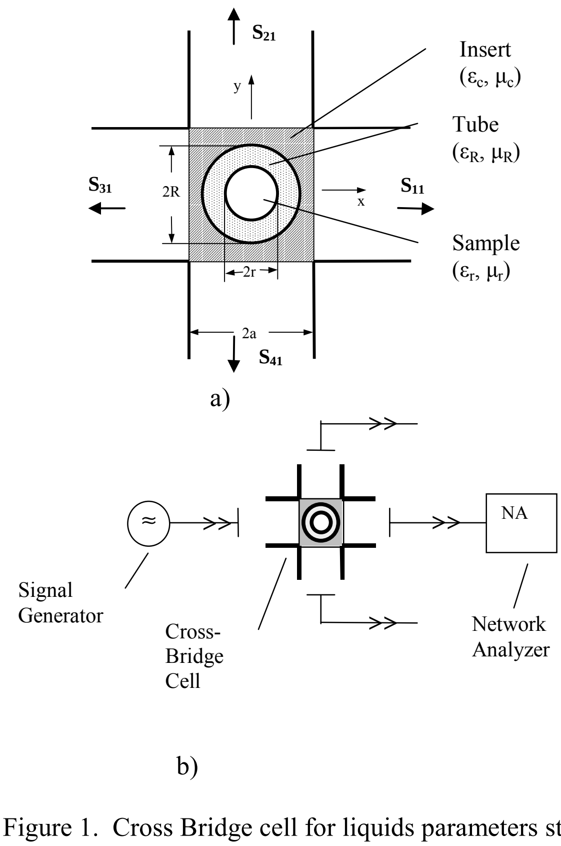

Figure 1. Cross Bridge cell for liquids parameters study.
a) Cross section of CB-cell;
b) Line-diagram of experimental unit for the liquid material parameters study.

The CB consists of two crossed waveguides. The insert represent itself a rectangular bar the filling the cross section of CB-cell.
Inside this insert a technological tube with external radius *R* and internal radius *r* is located. Tube is infinitely long in z-direction. The liquid sample under study flows inside the tube in z-direction also.
We suggest that the CB-cell under design operates in 10GHz frequency band.
Here the dielectric constant $\varepsilon = \varepsilon' + i\varepsilon''$, where ε' is the real part of permittivity; ε'' is the imaginary part of permittivity;
ε_R is the dielectric constant for tube;
ε_r is the dielectric constant for sample;
ε_c is the dielectric constant for insert;
μ_R is the permeability for tube;
μ_r is the permeability for sample;
μ_c is the permeability for insert;
λ is the working wavelength;
olb≡a/λ is the frequency parameter.
In particular we chose for calculation next ranges of variation for geometrical and material parameters:
for olb - (0.25-0.5)
for ε'' - (0.0001-0.1)
for ε_c - (0, 3)

The main goal of our calculations is to define a band of dielectric parameters for insert and technological tube for which it is possible to design real construction of CB-cell. As well a band of dielectric parameters of sample under study for which their measuring will be correct have been estimated. We have estimated also possible sensitivity of the CB-cell under design.
Calculations we have carried out are grouped in a few graphs below. Let analyze results of these calculations in details.

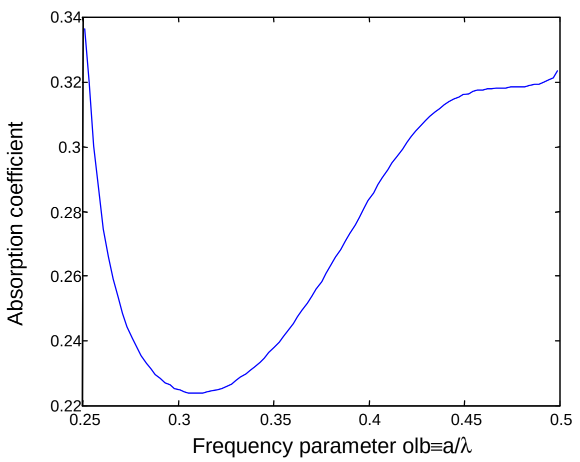

Figure 2. Absorption coefficient versus the frequency parameter olb≡a/λ for r/a=0.67, R/a=0.83, ε_c=1, ε_R=2, μ_R=1, μ_r=1, μ_c=1 and ε_r=3-0.05i

In Fig.2 the results of computation of S- parameters and an absorption coefficient AC for CB-cell as a function of working frequency f are presented.
We assign that the absorption coefficient

$$AC = \sqrt{1 - |S_{11}|^2 - |S_{12}|^2 - |S_{13}|^2 - |S_{14}|^2} \qquad (1)$$

We suggest that f changes in the limits 6.25GHz-12.5GHz. So a/λ - varies in the limits (0.25-0.5).
As we can see from Fig.1 the absorption coefficient changes sharply for olb band (0.25-0.28). At the same time the absorption coefficient demonstrates rather weak dependence on frequency in the band of olb as (0.3-0.35)
So we can make a conclusion here. The sensitivity of CB-cell depends on the working frequency. Thus it is possible to control the CB-cell sensitivity with slow variation of working frequency.

In order to estimate the CB-cell sensitivity for different specimen dielectric losses we have analyzed AC dependence on ε_r'' for ε_r''=0.0001-0.1. Results are presented in Fig.3. Calculations have been executed for teflon tube ($\varepsilon_R' \approx 2$) with infinitesimal losses. Working frequency f=10.0GHz (olb=0.4).

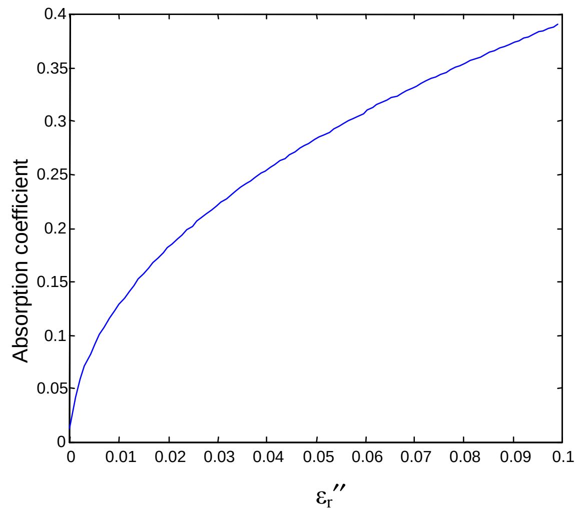

Figure 3. Absorption coefficient versus the sample losses for r/a=0.67, R/a =0.83, ε_c=1, ε_R=2, μ_R=1, μ_r=1, ε'_r=3, μ_c=1, olb=0.4.

Note that the dependence AC=f(ε_r'') has monotonous character. This fact is of great importance for experiment, because it provides uniqueness of the measurements data. It is obviously from Fig.3 that CB-cell sensitivity is quite large for the range ε_r''~(0.0001-0.01). Then the sensitivity decreases at least in 4 times for the range ε_r''(0.008-0.1). So the sensitivity of CB-cell is much larger for low-loss materials than for high-loss ones.

demonstrate the applicability of the electrodynamical structure designed for technology goals.

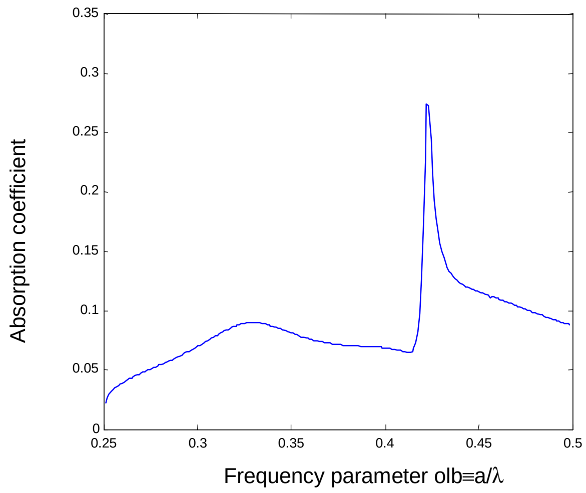

Figure 4. Absorption coefficient for CB-cell with quartz insert for r/a =0.67, R/a =0.83, ε_c=1, ε_R=2, μ_R=1, μ_r=1, ε_r=3-0.005i and μ_c=1.

In order to increase the sensitivity of CB-cell with the sample we propose to use insert (see Fig.1a) fabricated from quartz ($\varepsilon'\approx 3$), possesses very small dielectric losses ($\varepsilon''\leq 10^{-4}$). For such insert we calculated the absorption coefficient in dependence on working frequency for the same tube parameters and for fixed material losses $\varepsilon_r''=5\times 10^{-3}$. Results are shown in Fig.4.

As a remarkable fact we have to note the presence of a sharp peak in this dependence. This peak represents an electrodynamical resonance, which takes place in the given CB-cell construction. Note that the intensity of this peak increases with ε_r'' increasing. At the same time the peaks width decreases.

So this figure demonstrates the fact that, for real materials it is easy to define the frequency band where the sensitivity of CB-cell becomes small and the frequency band where the sensitivity becomes very high.

In particular for areas of olb=(0.35-0.4) and olb=(0.42-0.43) sensitivity changes more than 15-20 times. To change CB sensitivity from very small to very high value it is enough to provide not too large frequency shift in the vicinity of single-mode operation regime.

III. CONCLUSIONS

Numerical investigation of Cross Bridge cell for testing the dielectric parameters of liquid materials has been carried out.

It is shown that CB-cell possesses rather high variation of the absorption coefficient for single-mode operation. Rather high change of this characteristic with frequency provides the easy control of sensitivity of CB-cell.

Results of calculations for 10GHz-frequency band and for material parameters, which are closely to the real ones, demonstrate the applicability of the electrodynamical structure designed for technology goals.

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