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Determination of the dielectric constant of some materials

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Abstract : In this paper, the measurements of the dielectric constant of some materials are carried out in X-band of microwave spectrum. The theoretical analysis is based on the perturbation theory concerning the designed cavity controlled oscillator. Two rectangular cavities have been designed, namely, rectangular cavity with horizontal sample hole and rectangular cavity with vertical sample hole which are operating in TE_{101}-mode. Finally, the comparison between the theoretically calculated and experimentally measured values of dielectric constant has been made.

Keywords : Dielectric constant, cavity-controlled oscillator method, materials at microwave frequency.

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1. Introduction

The cavity perturbation technique has been extensively employed for studying the electric and magnetic properties of some materials at microwave frequency [1–4]. Anand Parkash and Abahi [5] have derived relations for evaluating the dielectric parameters from the changes in resonance frequency and Q-value of a cylindrical cavity for thin samples of length less than the height of the cavity. Mysore and Lakshminarayana [6] developed a simple microwave technique for independent measurement of sample size and dielectric constant using Gunn oscillator system.

In this paper, the measurements of dielectric constant of some materials are based on the cavity controlled oscillator method. Excellent results are obtained on using the material of known dielectric constant (teflon), thus confirming the validity of the method.

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2. The frequency shift for cavity controlled oscillator method

The relative frequency shift ($\Delta f/f_0$) for non-magnetic samples has the form [7,8],

$$-\frac{\Delta f}{f_0} = \frac{(\varepsilon'-1)\int_{v_s} E_u E_p \, dv}{2\int_{v_c} E_u^2 \, dv} \tag{1}$$

where, E's are the electric field intensities with subscripts 'u' and 'p' for unperturbed and perturbed values, v_c and v_s are the volumes of the cavity and the samples respectively and ε' is the real part of dielectric constant of used material.

For rectangular cavity resonating in TE_{101}-mode, where the sample is inserted into the center of the cavity through small hole parallel to maximum electric field, the relative frequency shift becomes,

$$-\frac{\Delta f}{f_0} = 2(\varepsilon'-1)\, A_s b/v_c . \tag{2}$$

If the sample is inserted perpendicular to electric field eq. (1) becomes

$$-\frac{\Delta f}{f_0} = \frac{2(\varepsilon'-1)}{(\varepsilon'+1)}\, A_s a/v_c , \tag{3}$$

where A_s is the cross sectional area of the sample and a, b are the dimensions of the cavity as shown in Figure 1.

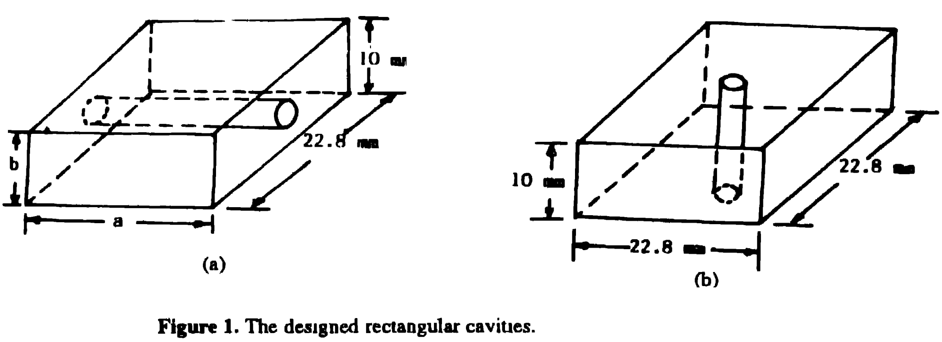

Figure 1. The designed rectangular cavities.
(a) The rectangular cavity with horizontal sample hole.
(b) The rectangular cavity with vertical sample hole.

From eqs. (1) and (2), the relative dielectric constant of the sample is,

$$\varepsilon' = \frac{a}{b}\,\frac{\left[(\Delta f/f_0)\right] r_{\parallel}}{\left[(\Delta f/f_0)\right] r_{\perp}} - 1, \tag{4}$$

where $r_{\parallel}$ and $r_{\perp}$ indicate to the sample is parallel or perpendicular to electric field.

3. The experimental set-up for measuring output power

The rectangular cavity is designed with dimensions shown in Figure 1 and a hole of 3.1 mm in diameter is drilled horizontally and vertically for two rectangular cavities and a Gunn flange is mounted with required cavity.

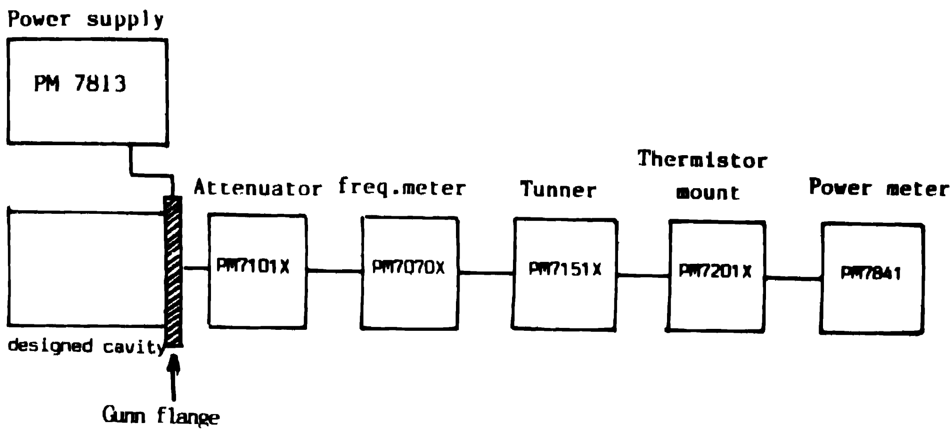

Figure 2. Experimental set-up for obtaining the characteristics of the designed cavities and out put power measurements.

The experimental set-up for measuring the output power is shown in Figure 2. This set-up is used for two cases :

Case A–1 : The output power for the hole in vertical position

The excitation of microwave oscillation is obtained at bias voltage between 6–9 volts. The measured resonance frequency is found to be 9.125 GHz and the maximum output power is 3 mw at bias voltage of 7.25 volt.

Case A–2 : The output power for the hole in horizontal position

The measured resonance frequency is found to be 9.014 GHz and the maximum output power has a value of 2.8 mw at bias voltage of 7.38 volt.

4. Experimental set-up for measuring dielectric constant using designed cavities

The experimental set-up is shown in Figure 3. In order to investigate the validity and to compare the theoretical and experimental results of the method used, a known material (teflon) with known relative dielectric constant ($\varepsilon' = 2.03$) is used, where the teflon rods having diameters of 0.5, 1, 1.5, 2, 2.5 and 3 mm are used. Figure 4 shows the experimentally measured values for the two cases A–1 and A–2, where the solid lines represent the calculated values of the frequency shift and the circles represent the measured values.

It is clear that the deviation between the theoretical and experimental curves are very small, where the solid lines are nearly the mean value of the measured points. The relative dielectric constant is calculated from experimental data using eq. (4), and is plotted against the diameters of the rods (d) as shown in Figure 5. The mean value of the obtained ε' is found to be 1.98, ,which shows that this method is adequate for measuring the relative dielectric constant.

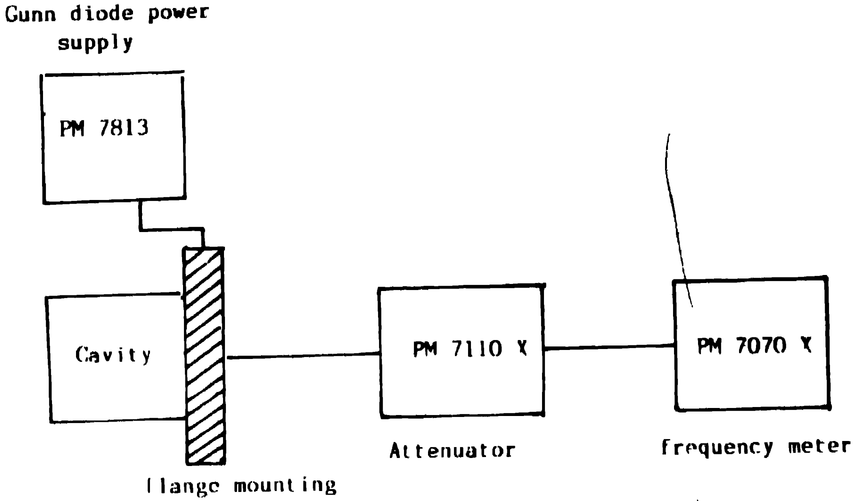

Figure 3. Experimental set-up for measuring the frequency shift using the designed cavities.

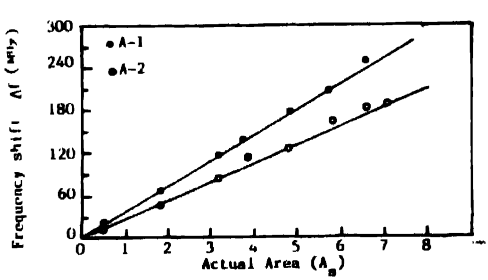

Figure 4. Relation between frequency shift Δf and the actual areas A_s in mm for the cases A–1 and A–2 for teflon rods.

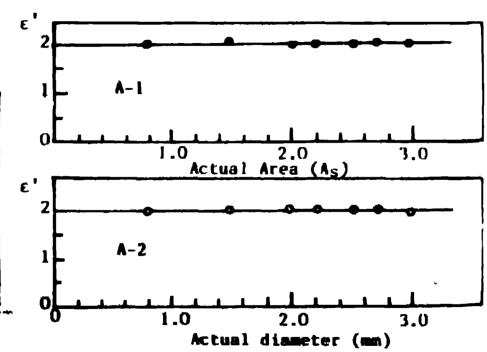

Figure 5. Calculated relative dielectric constant against actual diameter for teflon rods in TE_{101}-mode rectangular cavities.

Materials including Trolitul, Timber, plexiglas, Hard rubber, PVC (polyvinylchloride) Hard tissue and Hard paper are to be examined. The measured frequency shift for different values of diameters (0.8, 1.5, 2, 2.2, 2.5, 2.7, 2.9 mm) are plotted against the actual areas of the rods as shown in Figures 6–12. The mean values of the relative dielectric constant is

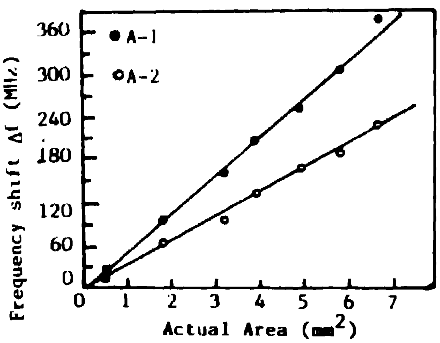

Figure 6. Relation between frequency shift Δf and the actual areas A_s in mm^2 for the cases A-1 and A-2 for trolitul rods.

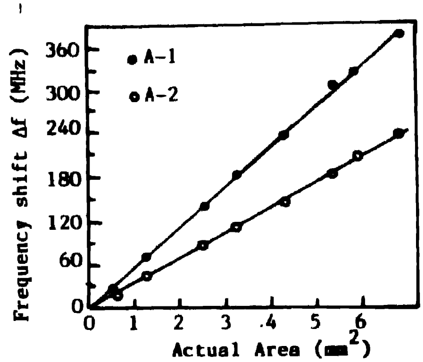

Figure 7. Relation between frequency shift Δf and the actual area A_s in mm^2 for the cases A-1 and A-2 for timber rods

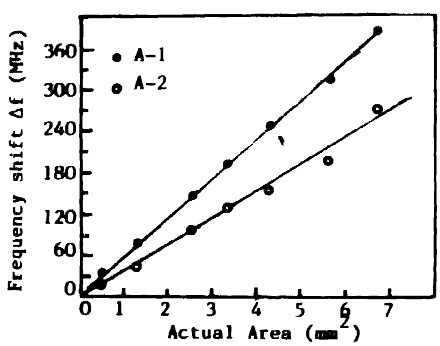

Figure 8. Relation between frequency shift Δf and the actual area A_s in mm^2 for the cases A-1 and A-2 for plexiglas rods

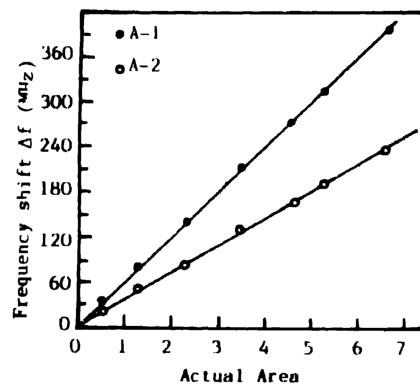

Figure 9. Relation between frequency shift Δf and the actual areas A_s in mm^2 for the cases A-1 and A-2 for hardrubber rods.

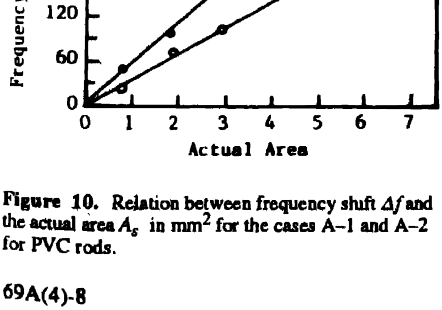

Figure 10. Relation between frequency shift Δf and the actual area A_s in mm^2 for the cases A-1 and A-2 for PVC rods.

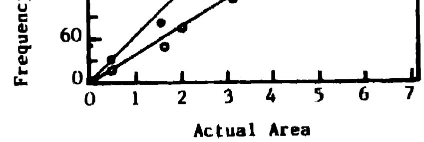

Figure 11. Relation between frequency shift Δf and the actual area A_s in mm^2 for the cases A-1 and A-2 for hard tissue rods.

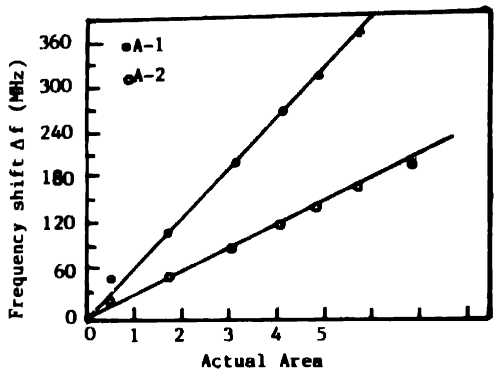

Figure 12. Relation between frequency shift Δf and the actual area A_s in mm^2 for the cases A–1 and A–2 for hard paper rods

calculated from nearly almost fourteen measured experimental values and the results of measurements are :

material	ε'
Trolitul	2.631
Timber	2.519
Plexiglas	2.643
Hard rubber	2.719
PVC	2.725
Hard tissue	2.806
Hard paper	3.989

5. Conclusions

From the theoretical and experimental studies of relative dielectric constant for different materials at X-band of microwave spectrum, the following conclusions can be deduced :

(i) The experimental tests of the cavity shows that the shift between the theoretical resonance frequency and that measured experimentally, lies between 0.0165 GHz and 0.0231 GHz.

(ii) The measured output power of the cavity-controlled oscillator as a function of bias voltage indicate that the optimum bias voltage ranges between 7.25–7.38 volt.

(iii) Examining the validity of the method by using material of known relative dielectric constant (teflon), the theoretical calculated frequency shift is found to be a mean value of that measured experimentally.

(iv) The measurements of dielectric constant of tested materials show that this method is adequate at X-band of microwave spectrum.

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