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DIELECTRIC CONSTANT MEASUREMENT AT X-BAND

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Abstract: Microwave bench is used for measurement of Dielectric Constant at X-band. Width at the twice minima method is used for measurement of free space wavelength (λ_0) and guide wavelength (λ_g). The forward or backward rotation of the motor, first minima and second minima are controlled through PC. The stepper motor move the probe of slotted section of X-band microwave bench. The positions (starting or ending) of probe are sensed by an optical sensor (MOC 7811). PC based measurement technique moves probe of the slotted section through 0.00625 mm per step when the stepper motor is operated in full stepping mode and 0.003125 mm when the stepper motor is operated in half stepping mode in forward or backward directions. This technique gives the better accuracy than manual movement of probe (i.e. 1mm).

Keywords: Microwave properties; microwave bench; PC; optical sensors; stepper motor;

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INTRODUCTION

The microwave bench is used for measurement of any parameter in microwaves such as frequency, power, attenuation, voltage standing wave ratio (VSWR), phase, impedance, insertion loss, dielectric constant and noise factor [1]. The set up of microwave bench is shown in fig 1.

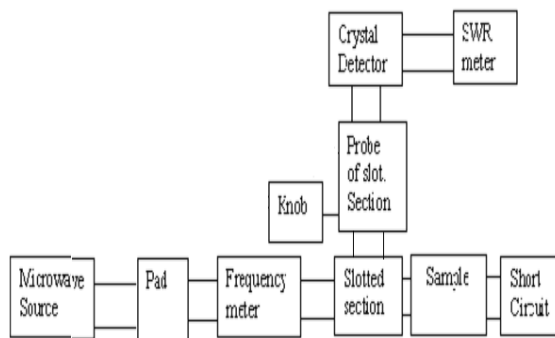


Fig. 1. Set-up of microwave bench

The electromagnetic properties of non-magnetic material or a medium can be completely specified by its permeability (μ), electrical conductivity (σ) and dielectric constant (ϵ') [1]. Dielectric constant (ϵ') is the measure of efficiency of transfer of electric force through the sample. In the present work, Dielectric constant (ϵ') can be measured by Robert and Von-Hippel method [1, 2]. Generally, the microwave bench is operated manually. In the present work, Personal Computer (PC) based automatic measurement technique measures the microwave parameters. In this automatic technique, the PC based stepper motor is assembled to control the movement of the probe in the slotted section. The stepper motor moves in forward or backward direction in steps, as per digital pulses given to it. The stepper motor is connected to the probe in slotted section of the microwave bench. The PC is used to operate the stepper motor and by software program written in C language [3-5], the stepper motor displaces the probe in the slotted section of the microwave bench in proper direction to locate the position of minima. The crystal detector is connected with data acquisition card (DAC). DAC converts output of crystal detector into digital form and send it to PC through parallel printer port [6]. The number of steps of the motor in certain direction and the difference between the two maxima and minima are displayed on the monitor. The distance covered by the motor on the scale of the slotted section in forward or backward direction is also displayed on the monitor. The block diagram of PC based measurement technique is shown in fig.2

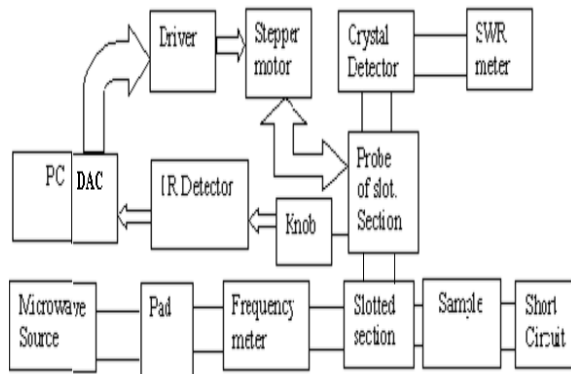


Fig 2. Complete set-up of PC based measurement system.

II. Methods and Materials

a. Sample Preparation

Samples of varying thickness and of rectangular shape 0.9 inches by 0.4 inches which is the size of rectangular waveguide in X-band microwave bench were prepared. Rubber sample is also made by cutting the firmer into 0.9 by 0.4 inches sizes of desired thickness.

b. Dielectric constant measurement at microwave frequency

For accurate measurement of dielectric constant width at twice minima method was used. Following steps were followed in this method [1, 7].

- i. The frequency of source was determined by taking micrometer reading of cavity resonator when dip in output is produced. Then the cavity resonator was detuned.
- ii. The guide wave length λ_g , was measured by short circuiting waveguide section and taking readings of minima.
- iii. The distance, ΔX shown in fig 3 was measured by width at twice Minima method.
- iv. The position of minima A, without sample was recorded (fig 3).
- v. Dielectric Sample (rubber) was then introduced in the wave guide touching the short circuit end.
- vi. The distance ΔX_s (that is width twice minima with sample) was measured.
- vii. The position of minimum B of standing wave pattern with the sample was recorded, fig 3.
- viii. Shift in minima Δl (difference between ΔX_s and ΔX), was calculated.

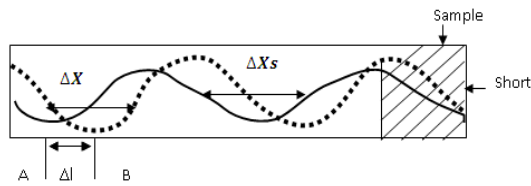


Fig 3. Standing waves in the waveguide with and without sample.

c. Theoretical Calculations

i) **Dielectric constant (ϵ'):** Dielectric constant (ϵ') is given by the following formula,

$$\epsilon' = (\chi\lambda_0/2\pi d)^2 + (\lambda_0/\lambda_c)^2 \text{ ---- (1)}$$

Where, λ_0 is the free space wavelength (=3.03cm), λ_c the cutoff wavelength (=4.582cm), d the thickness of the sample and χ multi-valued function and its value is chosen from the tables of $(\tan X/X)$ given by Von Hippel [1, 2].

ii) **Loss tangent ($\tan\delta$):** The loss tangent was calculated using the formula.

$$\tan\delta = \{|\Delta X_s - \Delta X|/\epsilon' d\} (\lambda_0/\lambda_g)^2 \text{ --- (2)}$$

Where ΔX_s = width at twice minimum with sample,

ΔX = width at twice minimum without sample

iii) **Loss factor (ϵ''):** The loss factor ϵ'' , is determined from the following formula

$$\epsilon'' = \epsilon' \tan\delta \text{ ---- (3)}$$

III. Experimental Section

a. Stepper motor

The stepper motor is operated in two types of stepping modes – full and half [8]. In full stepping mode, only one coil winding is energized at a given instant of time. The stator is energized according to the sequence (or fig)

A → B → C → D OR AB → BC → CD → DA

In the half stepping mode, there is a combination of both full wave and full step (1 and 2 phases on) drive modes. Every second step only one phase is energized and during the other steps one phase in each stator. The stator is energized according to the following sequence.

AB → B → BC → C → CD → D → DA → A

b. Stepper motor driver

The NPN transistor SL100 is used to drive stepper motor. The Driver circuit is shown in figure 4.

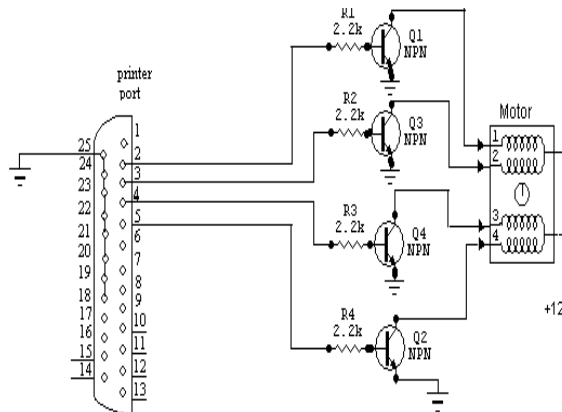


Figure 4. stepper motor driver circuit

The stepper motor driver unit is a switching circuit consisting of medium power transistors. These transistors are used in the switching mode as shown in Figure 4. The power transistors provide the necessary current to the field coils of the motor. Four power transistors are used to drive the coils of motor. The 4-bit (D0-D3) output of the printer port is fed to the bases of the power transistors, which in turn are used to control the movement or the rotation of the motors, under the software control.

c. IR detector

The MOC 7811 is used as a position detector which is generally used in printer to detect page. The IR detector is used for detecting the starting and end position of probe.

d. Experimental Setup for measurement of dielectric constant

The experimental set up is shown figure 5. This specially prepared hardware of the system mainly consists of three parts:

Control board

Data acquisition Card (DAC)

Low cost Stepper motor controller

These parts are fully compatible with IBM PC. The DAC converts the analog current from the probe into digital form. The stepper motor facilities for full step/half step rotation in clockwise/anticlockwise direction is provided by suitable software which is written in "C" language. PC based measurement technique moves probe of the slotted section 0.00625 mm per step when the stepper motor operated in full stepping mode and 0.003125 mm when the stepper motor operated in half stepping mode. For moving the probe of slotted section of microwave bench, the nut is welded to the probe of slotted section whereas the shaft to the stepper motor to facilitate the displacement of the probe. Here we measure the shift in the minima of standing wave produced when a sample of dielectric is placed in front of the short circuit. Initially the guide wavelength is determined. The thickness of the dielectric is measured by means of a micrometer as accurately as possible. The exact position of the first and second minima from the short circuit end is noted using VSWR noted. The short circuit is then removed and the dielectric sample is inserted into the aperture of the wave guide touching the short circuit. Then the position of the first minima from the short circuit end is once again measured. The shift in minima of the standing wave caused by the dielectric is determined.

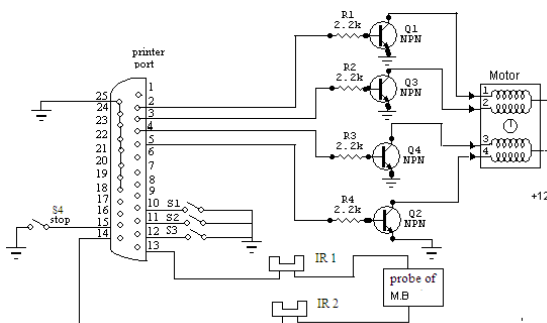


Figure 5 experimental set-up of dielectric constant measurement

The IR detector is used for detecting the starting position and end position of probe of slotted section. The pin no 13 and 14 of parallel printer port are used for detecting the position. The four switches are used for controlling the movement of probe of slotted section. The details of pin allocation of parallel printer port to switches and IR detector given in table1.

e. Software

It is possible to study the various stepping modes of the stepper motor. The program to control the stepper motors is written in C programming language. The software, written in C

programming language, is user-friendly and easy to understand as compared to the other programming languages. A menu driven software is written to accept the following modes:

1. Reset System
2. Full Stepping Mode
3. Half Stepping Mode
4. Initial position
5. End position
6. Start
7. Stop

The flowchart is given fig. 6

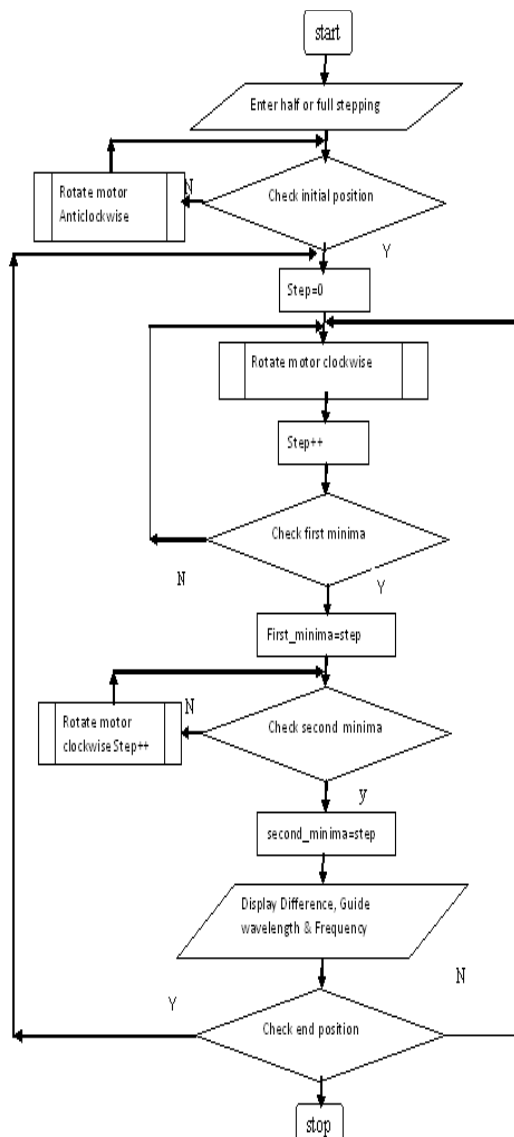


fig 6. flowchart of "C" language program

IV. RESULTS AND DISCUSSION

The dielectric constant and loss tangent were determined at X-band microwave frequency for rubber, the experimental value ($\epsilon' = 4.91$) is found to agree well with the literature value ($\epsilon' = 2.6 - 5$) [2]. It can also be mention that the material studied is good dielectrics as the value of dielectric constant observed is large and dielectric loss factor is low. PC based automatic

measurement technique works properly and measures the dielectric constant of any solid materials.

The PC based measurement technique measures the dielectric constant of solid materials accurately. This method takes lesser time to measure the dielectric constant as compared to other methods. So, this measurement technique is very useful for measuring the dielectric constant of any solid materials fast and accurate. Further accuracy of this technique can be increased when the stepper motor is operated in micro-stepping mode.

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