

# Automated Measurement of Dielectric Constant at Microwave Frequencies

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*Abstract-Techniques based on the perturbation of cavity resonators are commonly used to measure the permittivity and loss tangent of samples of dielectric and ferrite materials at microwave frequencies. This paper presents an automated cavity perturbation technique at X-band using VNA and LabVIEW software. Being an automated procedure, the method is repeatable and avoids any uncertainties of manual measurements. The computer algorithm for automation of data acquisition and the overall experimental setup is presented. This paper overcomes the assumptions error made in the theory of these techniques and provides estimates of the errors of measurement arising from them. And implement an empirical formula based on practical experiments to correct the relative difference.*

**Keywords –** Cavity perturbation, Dielectric constant, loss tangent, LabVIEW.

## I. INTRODUCTION

Cavity perturbation technique [1,2] has been widely used for the measurement of dielectric properties at microwave frequencies. The fundamental concept of this technique is that the presence of a small volume of dielectric sample in the resonant cavity will not significantly perturb the electromagnetic field around the loaded sample and the shift in resonant frequency of the loaded cavity has been computed with these assumptions. The dielectric constant and loss tangent of the specimen can be calculated from the shifts of resonant frequency and the change in quality factor[1,2]. The LabVIEW[3] is a high level graphical programming language that is designed for data acquisition and control. This paper describes an automated procedure based on LabVIEW software to measure the dielectric properties of the material as dielectric constant and loss tangent. The measurement setup uses rectangular waveguide TE<sub>103</sub> cavity resonator, HP8510 Network Analyzer and personal computer.

## II. CAVITY PERTURBATION TECHNIQUE

In cavity perturbation method the sample under test is introduced to the place of maximum electric field in a resonant cavity and measure the change of resonant frequency and Q of the cavity in loaded and unloaded condition. using a standard resonant rectangular cavity in TE<sub>103</sub> mode. Sample under test is fabricated in the form of a thin rod. Weak Circular aperture coupling in the cavity is used to enhance Q of the cavity. The  $\epsilon_r = \epsilon_r' - j\epsilon_r''$  is the relative complex permittivity.

The real and imaginary part of the relative permittivity are calculated from measurable quantities as follows [2]:

$$\epsilon_r' = [V_c (f_c - f_s) / 2V_s f_s] + 1 \quad (1)$$

$$\epsilon_r'' = [V_c / 4V_s] (1 / Q_s - 1 / Q_c) \quad (2)$$

$$Q_c' = Q_c [1 + (\epsilon_r' - 1) V_s / V_c] \quad (3)$$

$$1 / Q_d = \tan \delta = \epsilon_r'' / \epsilon_r' \quad (4)$$

where  $f_c$  and  $f_s$  are the resonant frequencies without and with sample respectively, and  $Q_c$  and  $Q_s$  are the quality factors of the cavity without and with the sample inside the cavity, respectively,  $V_c$  and  $V_s$  are the volumes of cavity and the sample, respectively. The rectangular X-band waveguide cavity used in this work is shown in fig 1. the cavity is coupled to WR90(X-band) waveguide through circular inductive irises at both ends of the cavity. The sample is inserted through a non-radiating hole at the center of the broad side of the cavity. The resonant frequency and Q of the cavity with and without the sample are measured and  $\epsilon_r'$ , and  $\tan \delta$  are computed from equation (1) to (4). Q is calculated from the following relation

$$Q = f_0 / (f_2 - f_1)$$

Where  $f_0$  is the resonant frequency and  $f_2$  and  $f_1$  are frequencies at 3-dB points.

## III. DESIGN METHODOLOGY

The measurement system is as shown in fig.2 composed of the following:

- HP 8510C Network Analyzer
- LabVIEW Version 8.2
- Computer with GPIB card
- TE<sub>103</sub> cavity

The computer is interfaced with the network analyser through GPIB port. The cavity resonator is connected to the two ports of the HP 8510 s-parameter test set with standard waveguide to coax adaptors, the resonance properties Viz. resonant frequency and 3dB points are observed in VNA for both loaded and unloaded cavity. The program for the measurement of dielectric constant and loss tangent using VNA has been developed using LabVIEW which controls every stage of the measurement process. The program performs the tasks of instrument control, data acquisition and post processing of data. The computer plays the roles of talker (writes a control string to the instrument with the address), listener (receive data string from the instrument with the address) and controller (GPIB). The devised program has a simple and user friendly input panel where the details of the measurement set up like frequency range, number of points, dimensions of sample etc can be entered. The measured data and results are displayed in the Output panel. The program flowchart is shown in fig 3. In designing this measurement software, a modular approach has been chosen. In LabVIEW these modules are called

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Virtual Instruments (VIs) The main VI, ACP (automated cavity perturbation) measurements consists of various sub VIs which are designed for specific tasks as shown in fig.4. These sub VIs can be executed and debugged independently. The functions of various sub VI are as follows:

- (i) **Initilize.VI** : This VI initialises the system by taking information from the Input panel as start frequency, stop frequency, no. of points, parameter and scale .
- (ii) **-3 dB.VI** : This VI measures the resonance frequencies and -3 dB points on either side of the resonance curve, firstly for unloaded cavity as well as for the cavity loaded with the sample.
- (iii) **Cal.VI** : This VI calculates the dielectric parameters viz. dielectric constant ( $\epsilon_r'$ ) and loss tangent ( $\tan\delta$ ) from the recorded data using the general formalism of resonant cavity frequency shift theory of section 2.
- (iv) **Plot\_Gen.VI** : This VI presents the resonance curve for empty cavity and for the loaded cavity.
- (v) **Waveformgraph.VI** : This is used to present the waveform in desired format.
- (vi) **Sum2xcl.VI** : This saves and presents the results in EXCEL sheet.
- (vii) **Printgraph.VI** : This VI is used to print the graphs and to provide a hard copy of the data.

## IV. RESULTS

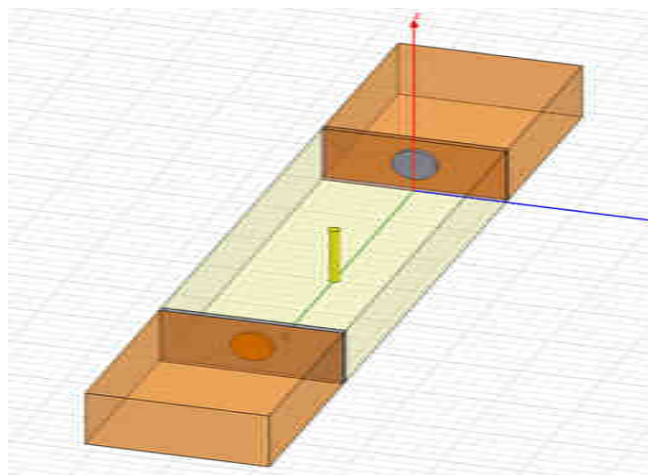
Figures fig.5(a) and (b) show the measured resonance curves for the unloaded cavity and the loaded cavity.

## V. CONCLUSION

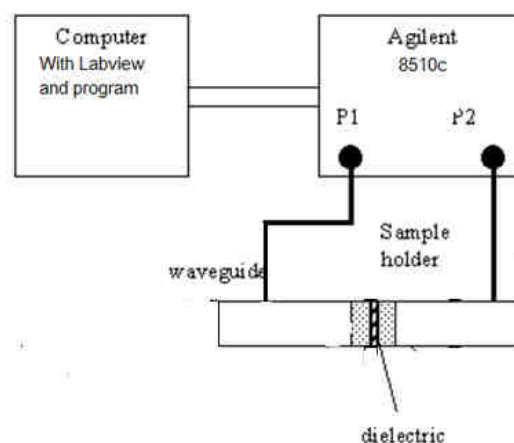
Software for automated measurement of dielectric constant and loss tangent of dielectric materials at X-band using VNA and LabVIEW has been successfully developed. The method is simple and flexible as the VIs can be adapted to meet changing requirements,if any, very quickly. The system is routinely used for our work on ceramic and ferrite.

## REFERENCE

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**Fig. 1: Cavity resonator**



**Fig 2 : Block diagram of the test set up**

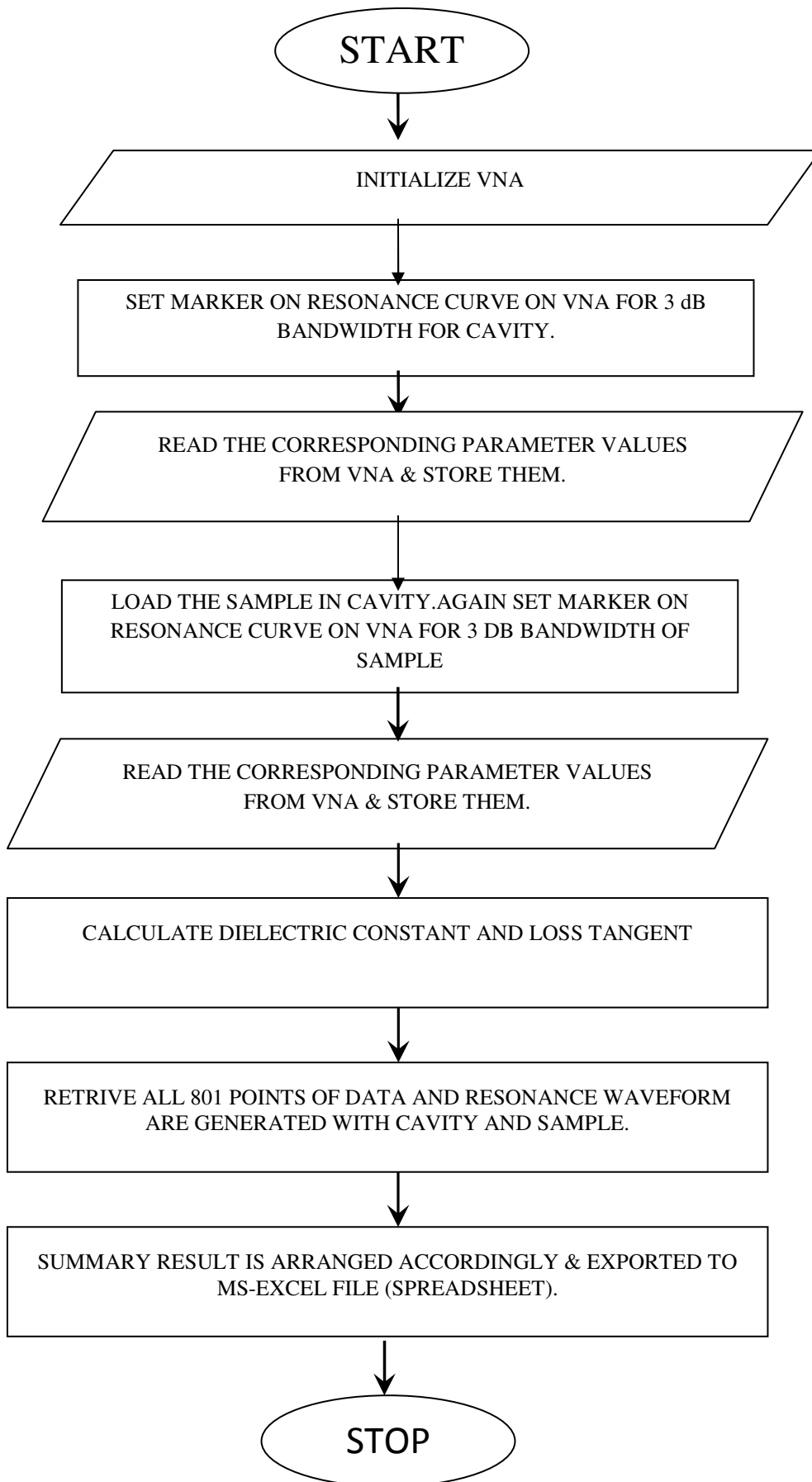


Fig. 3: Flow chart of the software

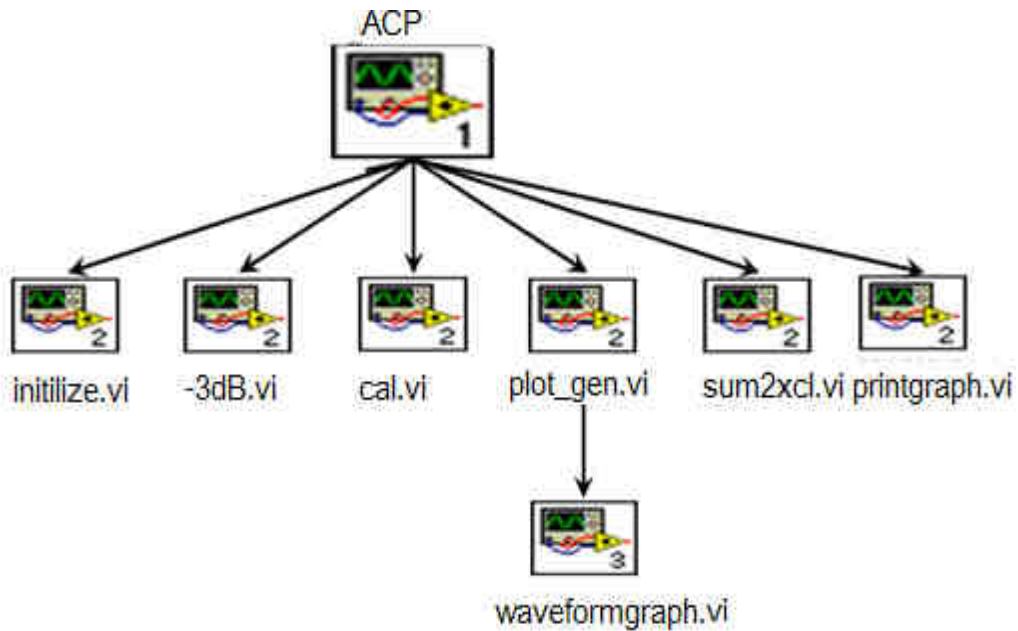


Fig. 4. Main VI and Sub VI

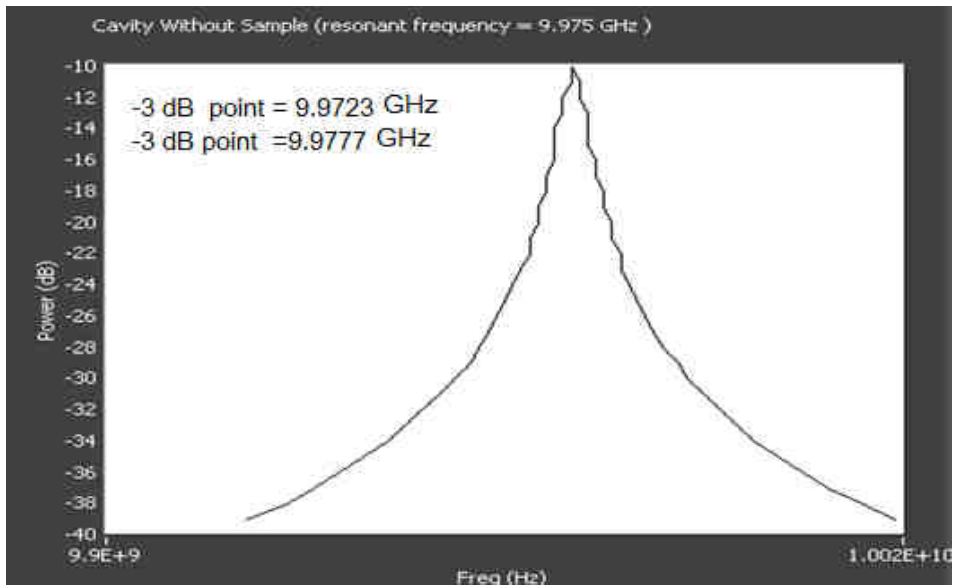


Fig. 5(a): Resonant frequency curves for unloaded cavity

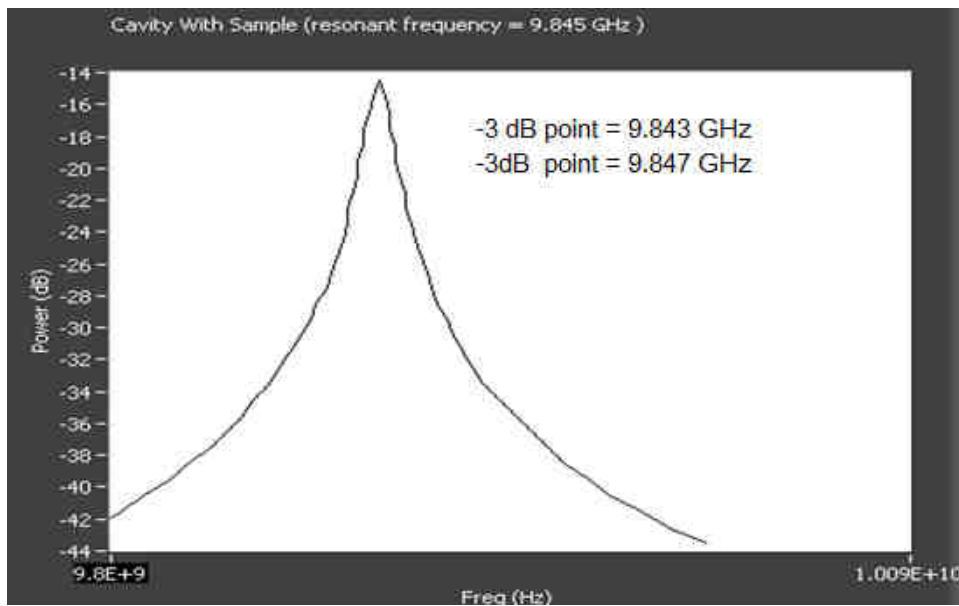


Fig. 5(b): Resonant frequency curves for loaded cavity