HIGH SPATIAL RESOLUTION DIELECTRIC CONSTANT UNIFORMITY MEASUREMENTS USING MICROSTRIP RESONANT PROBES

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ABSTRACT

In this paper we present the use of evanescent fields of apertures in microstrip resonant probes for measuring dielectric constant uniformity with high spatial resolution. The accuracy we have achieved in dielectric constant measurement at 10 GHz is better than 2 % using apertures as small as 0.030" X 0.010" in size.

INTRODUCTION

Many different microwave techniques have been used in the past for determining the dielectric constant of materials [1-2]. One of the most common methods is to determine the resonant frequency of a cavity made of the dielectric material under test [3]. The disadvantage of this technique is that the spatial resolution is rather poor. A technique which has not been fully explored consists in using the evanescent fields of an aperture in a resonant cavity for probing the dielectric properties of materials [4]. The advantage of this technique is that the spatial resolution is determined by the aperture size. In this paper we show how we have used apertures in microstrip resonant probes for measuring dielectric constant with spatial resolution as small as 0.030" X 0.010" with an accuracy better than 2 % at 10 GHz. This represents an improvement of at least 3 orders of magnitude in spatial resolution over what is achieved using standard techniques.

MEASUREMENT PRINCIPLE

The principle of operation of the resonant probe is based on the fact that when a piece of dielectric material is brought in close proximity to an aperture in a microwave resonant cavity the resonant frequency of the cavity is perturbed by the presence of the material. The shift in the resonant frequency depends upon the cavity, its aperture and upon the dielectric properties of the material. If V_c represents the volume of the cavity and V_a the volume occupied by the evanescent fields at the aperture, the shift Δf_r in the resonant frequency f_r can be approximated by:

$$\frac{\Delta f_r}{f_r} \approx \frac{V_a\,(\varepsilon_a - 1)}{V_c\,\varepsilon_c} \qquad (1)$$

where ε_a and ε_c are the dielectric constant of the material in the aperture and in the cavity, respectively [5]. If the probe is properly calibrated the dielectric constant of a dielectric material or its spatial variation can be obtained by measuring the change in resonant frequency of the cavity as the aperture scans the dielectric material.

MICROSTRIP RESONATOR DESIGN AND FABRICATION

Figure 1 shows the top conductor of the inductively coupled microstrip resonator that we have used. It consists of the power feeding line L3, a three-quarter-wavelength long resonator L1 and two inductive stubs L2. The aperture in this resonant probe is the open end of the line L1. All the microstrip lines were designed to have a 50 Ω characteristic impedance. Resonant probes were designed for two different dielectric substrates Rogers RT/5880 and RT/6002 with two different thicknesses 0.010" and 0.005". The widths and lengths of the lines in the microstrip probes were determined with the aid of CAD programs Touchstone and LineCalc [6]. The simulated response using the design data showed that the resonant probes had a return loss larger than 30 dB at the resonant frequency of 10 GHz.

The probes were fabricated using photolithographic techniques and they were bonded onto 1/8 " thick copper plates to increase their mechanical rigidity. Figure 2 shows a schematic diagram of how the probes were assembled as well as the way in which SMA launchers were used to provide external connection to the measurement instruments. The probes were mounted inside a shielding box to eliminate any disturbance from the outside

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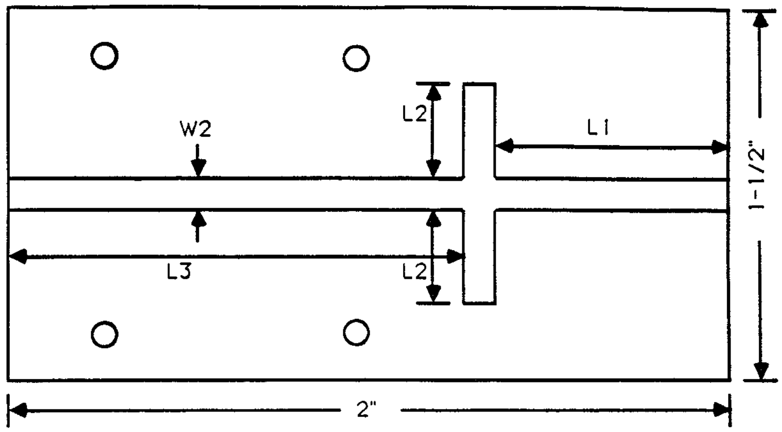

Fig.1 Layout of microstrip resonators with probing aperture on the right hand side of L1.

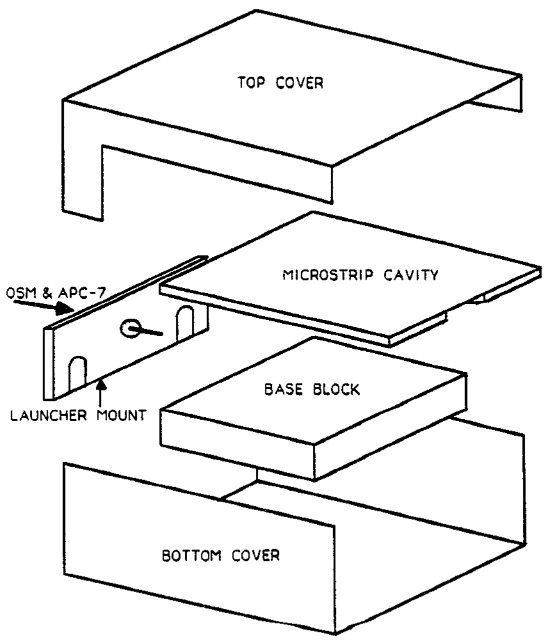

Fig.2 Assembly of microstrip resonator probes.

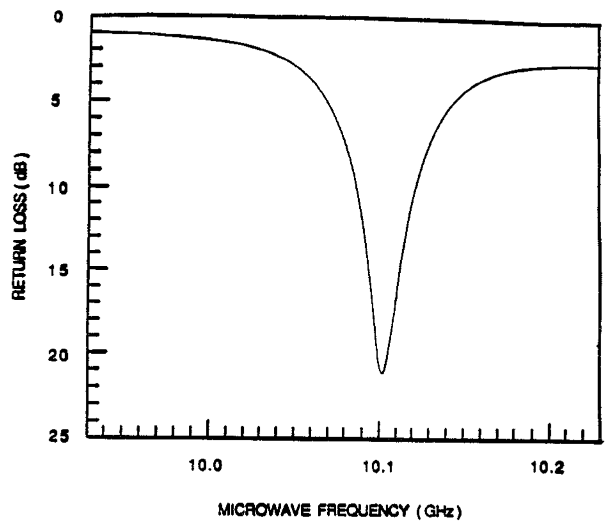

Fig.3 Measured return loss vs microwave frequency for the 0.010" thick probe.

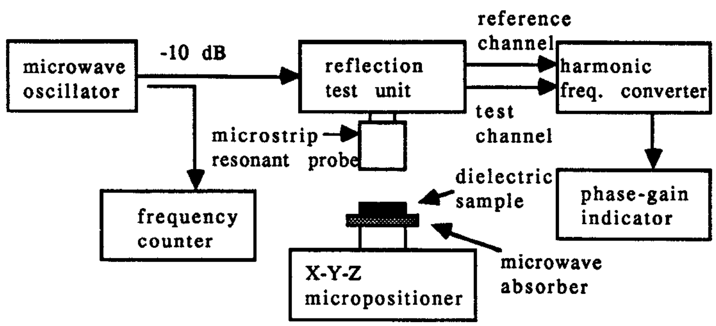

Fig.4 X-band microwave system for measuring the dielectric constant uniformity.

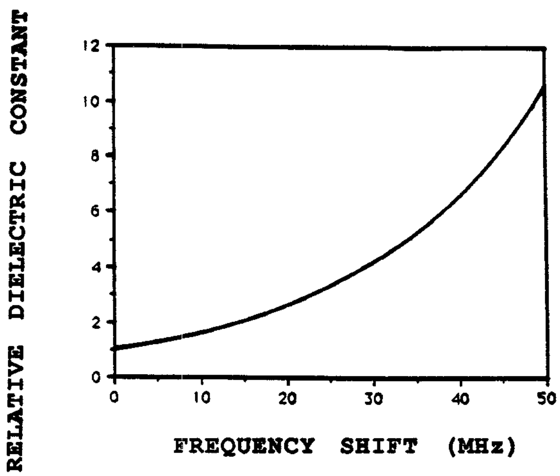

Fig.5 Calibration curve for the 0.010" thick probe.

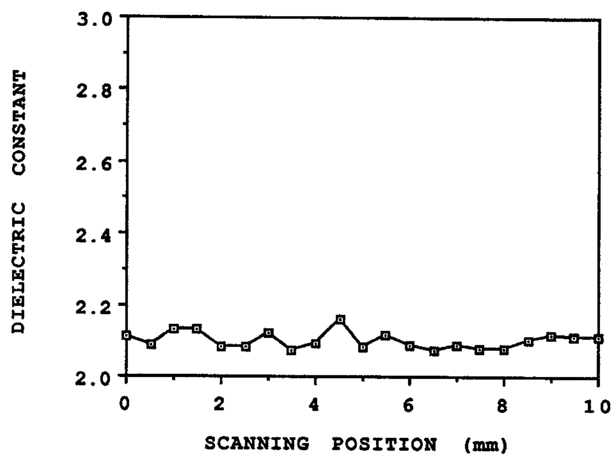

Fig.6 Measured spatial variation of dielectric constant of PTFE material.

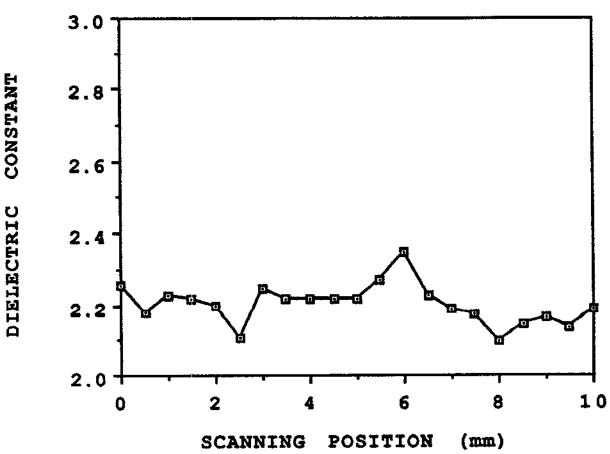

Fig.7 Measured spatial variation of dielectric constant of RT/5880 material.

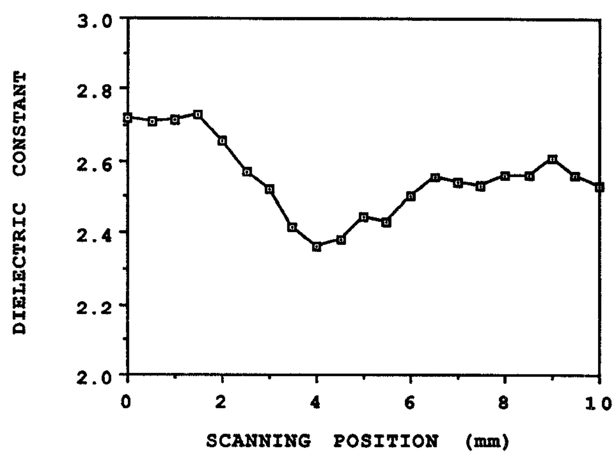

Fig.8 Measured spatial variation of dielectric constant of ULTRALAM material.

during measurements. Figure 3 shows the measured return loss as a function of frequency for one of the 0.010" thick probes. A very good agreement was found between the designed and measured values of the resonant frequency and of the Q-factors.

MICROWAVE MEASUREMENT SETUP

Figure 4 shows the X-band measurement system used for determining the resonant frequency of the microstrip probes. The dielectric test sample is placed in contact with the resonator aperture on an X-Y-Z stage with a microwave absorber underneath to eliminate any spurious microwave signal reflected from the stage. The source oscillator frequency is tuned manually to obtain a maximum return loss and the microwave frequency is read from a frequency counter. The maximum return loss is determined by observing the gain dial of the phase-gain indicator unit. The system was found to have a reproducibility in measuring the resonant frequency of ±0.25 MHz at 10 GHz and the stability of the resonant frequency of the microstrip probe was better than ±0.25 MHz in a time span of 1 hour.

DIELECTRIC CONSTANT UNIFORMITY MEASUREMENT

The resonant probes were calibrated using thick samples of dielectric materials of known dielectric constant. Figure 5 shows the calibration curve, i.e. dielectric constant versus resonant frequency shift, obtained for a 0.010" thick probe. From this figure and the accuracy with which the resonant frequency can be measured we determine that the dielectric constant can be measured with an accuracy better than 2 %. The aperture of the 0.010" probe has an area of 0.030" X 0.010" and we estimate this to be the area in which the dielectric constant is measured. The penetration depth of the evanescent fields has been experimentally determined to be of the order of 0.010". The measurements of dielectric constant uniformity were carried out by scanning the probe over dielectric materials along 1 cm long straight line and taking data for every 0.5 mm. Figure 6 shows the spatial variation of the dielectric constant of PTFE using this probe and it shows that the material is very uniform as expected. The same result was obtained for Rogers RT/5880 and is shown in figure 7 where it is seen that this material is as uniform as PTFE. However, figure 8 which is obtained for Rogers ULTRALAM material shows more spatial variation in the dielectric constant which has a standard deviation of more than 4%.

SUMMARY

In summary we have developed microstrip resonant probes which can measure dielectric constant uniformity with spatial resolution of 0.030" X 0.010" and accuracy better than 2 % at 10 GHz. The accuracy of the measurement can be improved to be better than 1% by using a closed-loop frequency discriminator to automatically measure the frequency shift. Dielectric constant measurements using this system as well as smaller aperture probes fabricated on 5 mil thick substrates are in progress and will be reported shortly.

ACKNOWLEDGMENT

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