Local Dielectric Measurement by Waveguide-type Microscopic Aperture Probe

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Abstract—For dielectric constant measurement of areas smaller than the wavelength, this paper proposes a method of employing waveguide-type microscopic aperture probe. The probe is made of WR-15 waveguide with one end shielded with metal plate of 0.3 mm, on which a 0.5 mm-dia or a 0.1 mm-dia aperture is made. The dielectric constant is derived from the slope of phase difference swept over 50–70 GHz between the cases of free-space transmission with and without the dielectrics. In order to evaluate the system, the dielectric constant of Teflon has been measured by three cases of using the probes of 0.5 mm-dia and 0.1 mm-dia, and two V-band corrugated horns. The results show good agreement.

1. Introduction

One of the well-established dielectric measurement methods in millimeter and submillimeter wave bands is the free-space transmission method using two horns[1]. That is sufficient for large objects compared to the wavelength. For the measurement of microscopic regional dielectric distribution of heterogeneous dielectric materials and cellular tissues, the aperture must be downsized so as the spatial resolution to be smaller than the wavelength [2].

As the embodiment of small aperture, waveguide-type probes are employed in this research. The probe is made of WR-15 waveguide with one end shielded with metal plate of 0.3 mm, on which a 0.5 mm-dia or a 0.1 mm-dia aperture is made. Figure 1 shows the outline. The probe replaces one horn at the transmission side in the free-space transmission measurement.

A microscopic aperture illuminates the region comparable to the aperture size, so that it realizes high spatial resolution of scanning microscopy for surface topography. Furthermore, employing the millimeter and submillimeter wavebands enables spectroscopic analysis, for example, oxygen content analysis by 60 GHz band as envisioned. On the other hand, it must be experimentally investigated to evaluate the decrease of the signal-to-noise ratio.

In order to evaluate the system, the dielectric constant of Teflon has been measured both by the proposed system and the free-space transmission method using two V-band corrugated horns with the aperture diameter 31 mm.

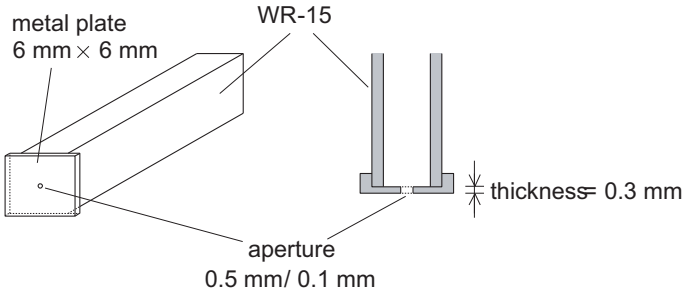


Figure 1: Waveguide-type probe.

2. Measurement

The dielectric constants is obtained from the slope of phase difference between the case of free-space transmission with and without the dielectrics. Relative dielectric constant ε_r is derived by

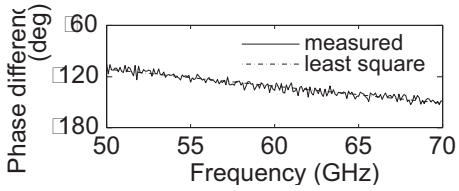
$$\varepsilon_r = (\frac{300\Delta\phi}{360d} + 1)^{\frac{1}{2}} \tag{1}$$

where $\Delta\phi$ (degree/GHz) is the slope of the phase difference, and d (mm) is the sample thickness. As a dielectric sample, a Teflon plate 100 mm × 100 mm × 4.1 mm (thickness) is used. The Teflon plate is contacted with the transmission side horn or the probe.

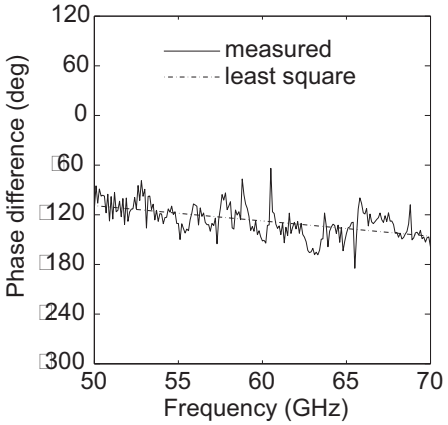
The phase difference is measured by using the vector network analyzer MVNA 8-350 (AB Millimeter, France). The lower frequency limit of the probe is determined by the cutoff frequency 40 GHz for the TE10 mode of WR-15. The frequency is swept over 50–70 GHz at 0.1 GHz step.

3. Result

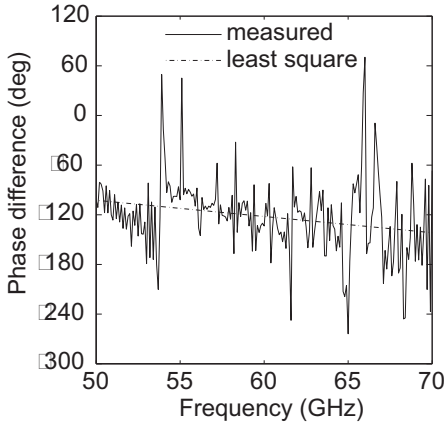
The measurement of phase difference is made three times to obtain the average ε_r. One result by each system is shown in Figure 2. The solid line shows the measured phase difference, and the dotted line is derived by the least square method. As the aperture is smaller, the phase variance is increasing. The two-horn system gives $\varepsilon_r = 1.99$ and the proposed system gives $\varepsilon_r = 1.89$ with 0.5 mm aperture and $\varepsilon_r = 1.93$ with 0.1 mm aperture. They show good agreement, although the proposed systems have larger variance of phase difference.



(a) Two-horn system.



(b) Probe with 0.5 mm-dia aperture.



(c) Probe with 0.1 mm-dia aperture.

Figure 2: The phase difference and the slope measured by the two-horn free-space transmission method (a) and the proposed probes (b) and (c).

4. Conclusion

The dielectric constant has been measured by the waveguide-type microscopic aperture probes with 0.5 mm and 0.1 mm-dia, and the standard two-horn free-space transmission method as a reference. There is a good agreement between three results, while they show slightly small values compared to the nominal value of Teflon 2.1. The next step is the measurement by scanning with improved accuracy.

REFERENCES

1. Goy, P., and M. Gross, "Free-space vector transmission-reflection from 18 to 760 GHz," *24th European Microwave Conference*, Communication C10.5, France, September 1994.
2. Schade, U., K. Holldack, P. Kuske, and G. Wustefeld, "THz near-field imaging employing synchrotron radiation," *Applied Physics Letters*, Vol. 84, No. 8, 1422–1424, 2004.