Imaging by 60GHz band Waveguide-type Microscopic Aperture Probe

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Abstract

For imaging of objects smaller than the wavelength, this paper presents a method of employing 60GHz band waveguide-type microscopic aperture probe and the measurement results in the transmission mode. The probe is made of WR-15 waveguide with one end shielded with metal plate, on which a 0.5mm-dia aperture is made. The experimental results to be reported are the spatial resolution measured over a tandem two-slit sample, the sensibility-in-depth measurement against grooves with various depth, and the scanned image of a leaf with parameters of frequency, amplitude and phase.

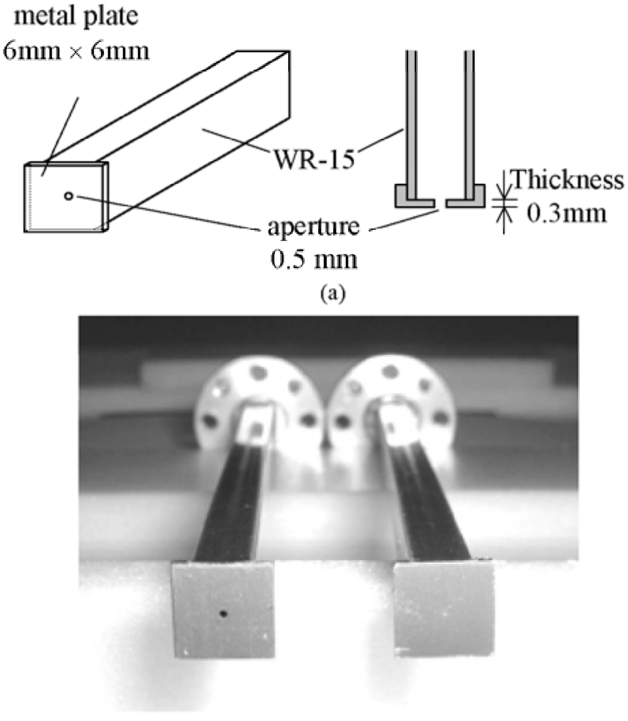
1. INTRODUCTION

Objects can be reproduced as images through transmission waves with smaller resolution than 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 [1][2]. It is also valuable to collect the phase information [3]. As embodiment of microscopic aperture, waveguide-type probes are employed in this research [4]. Employing the millimeter and submillimeter wavebands makes fabrication easier for aperture size smaller than the wavelength and use of vector measurement, while retaining moderate transmission depth and having expectancy of spectroscopic measurement.

This paper presents first the outline of fabricated microscopic aperture probe. Second, the spatial resolution measurement against a sample made of Teflon having two slits, each of 1mm width, arrayed at 1mm interval is presented. Third, the measurement of sensitivity in depth against the grooves engraved at the depth of 0.1mm, 0.5mm and 0.9mm in Teflon is presented. Finally, the scanned images of a leaf of cherry tree as a natural sample with the parameters of the frequency, amplitude and phase are presented.

2. WAVEGUIDE-TYPE MICROSCOPIC APERTURE PROBE

The waveguide-type microscopic aperture probe is made of WR-15 waveguide with one end shielded with metal plate of 0.3mm, on which a 0.5mm-dia aperture is made, as shown in Fig. 1. Throughout the current measurement, the microscopic aperture probe is used as a transmitter antenna and V-band corrugated horn antenna is used for receiver. The vector signal is measured by MVNA 8-350 (AB Millimeter, France).



(a)

(b)

Fig. 1: Waveguide-type microscopic aperture probe. (a) Outline. (b) Front view: the aperture size 0.5mm-dia (left) and 0.1mm-dia(right).

3. SPATIAL RESOLUTION MEASUREMENT

The spatial resolution of the fabricated microscopic aperture probe is evaluated by scanning the sample that has two slits, each with 1mm width, arrayed at 1mm interval in Teflon of thickness 1mm as shown in Fig. 2. The sample is moved at 0.05mm step. At each position the frequency is swept over 59.5GHz - 60.5GHz at 10MHz step. The result at 60GHz is shown in Fig. 3. Corresponding to the position of the slits, from 2 to 3mm and from 4 to 5mm, the probe can recognize each 1mm-slit, confirming the spatial resolution to be smaller than the wavelength.

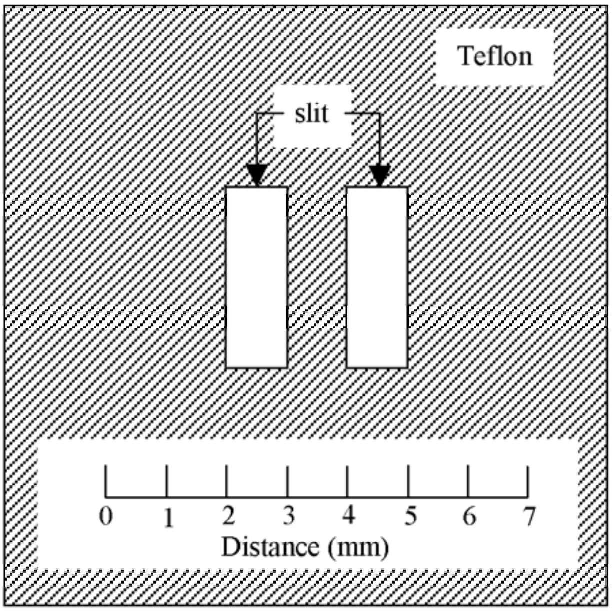


Fig. 2: Sample for spatial resolution.

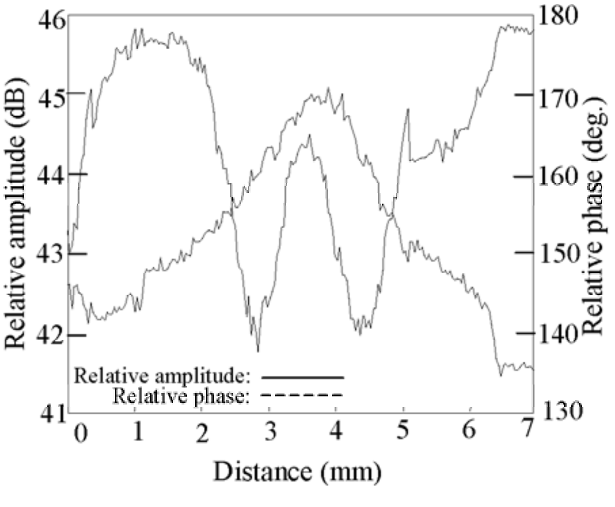


Fig. 3: Result of scanning two-slit measurement.

4. MEASUREMENT OF SENSIBILITY IN DEPTH

The sample has nine grooves, each with 1mm width engraved on Teflon plate of thickness 1mm, as shown in Fig. 4. The depth of each groove varies from 0.1mm to 0.9mm at 0.1mm step. The sample is moved at 0.05mm step. At each position the frequency is swept over 50-70GHz at 0.1GHz step. The results for 0.9mm, 0.5mm and 0.1mm in depth and at 60GHz are shown in Fig. 5. As seen from Fig. 5(a) and (b), the decrease of the amplitude is recognized corresponding to the depth. On the other hand, the change of the amplitude for 0.1mm-depth is not recognizable as shown in Fig. 5(c), so that the minimum sensibility in depth lies in the range between 0.1-0.5mm.

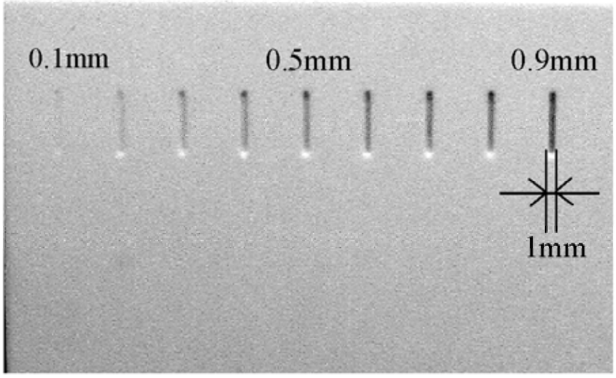
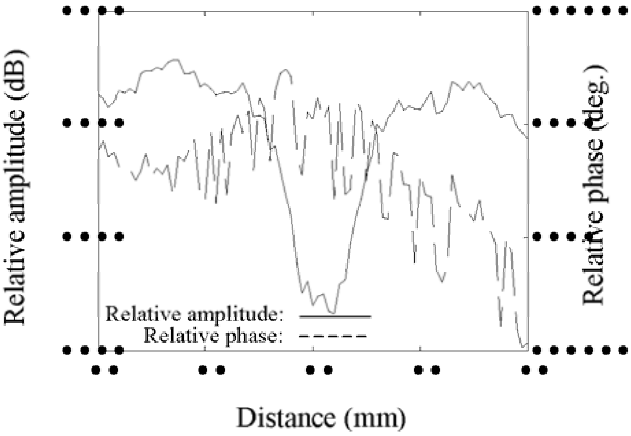


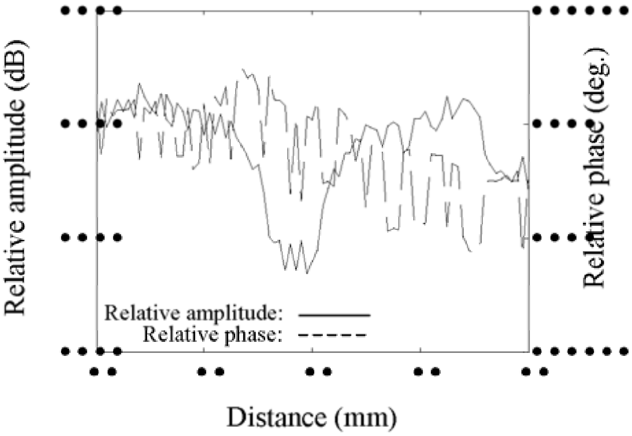
Fig. 4: Sample for sensibility-in-depth measurement.

5. IMAGING OF CHERRY LEAF

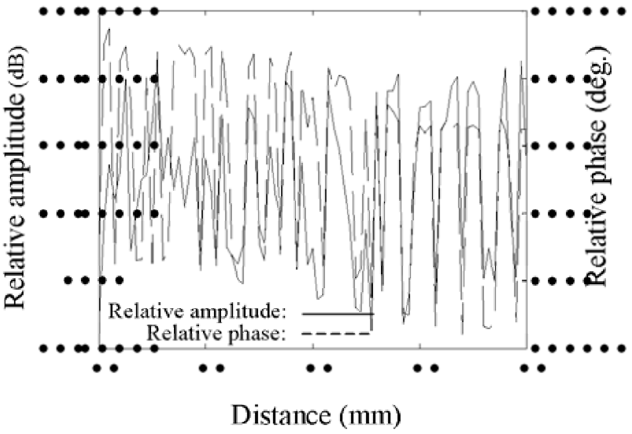
Using the microscopic aperture probe, two-dimensional images of a leaf are obtained. A leaf of Prunus × yedoensis (Japanese cherry) is used as a sample as shown in Fig. 6(a). Prior to the measurement the sample is flattened as much as possible by pressing it onto an acrylic board. During the measurement the leaf is kept under tension in much the way as the surface evenness is maintained in general except the area adjacent to the vein, at where the topographical change takes place. The probe tip is covered with a thin film of chloroethylene with approximate thickness 8μm. The distance between the probe and the leaf is kept in close touch during the scan. The scanned area is 4mm by 4mm as designated in Fig. 6 (a). The probe, when placed on the position (2mm, 2mm), aims at the vein's branch point, where a branch extends toward upper right. The frequency is swept over 55-65GHz at 500MHz step.



(a) Depth 0.9mm

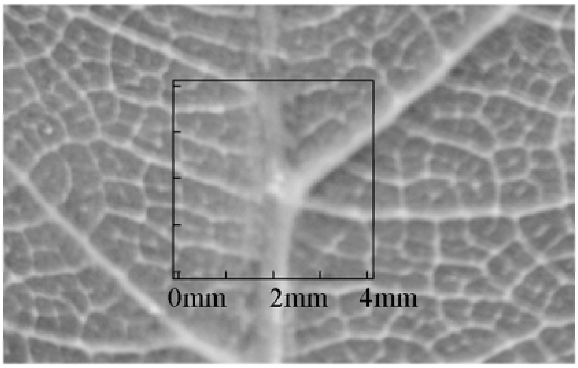


(b) Depth 0.5mm

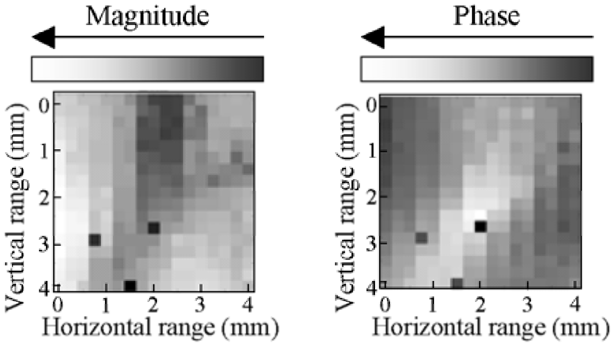


(c) Dept 0.1mm

Fig. 5: Result of sensibility-in-depth measurement.

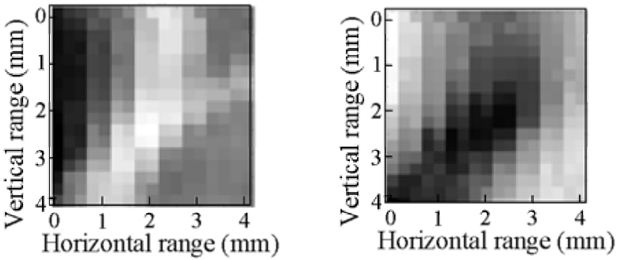


(a) Leaf of Prunus × yedoensis (Japanese cherry)



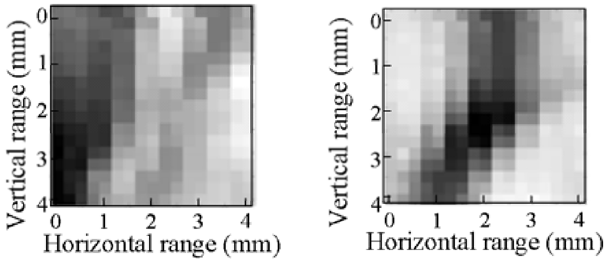
(b) 55GHz; amplitude

(c) 55GHz; phase



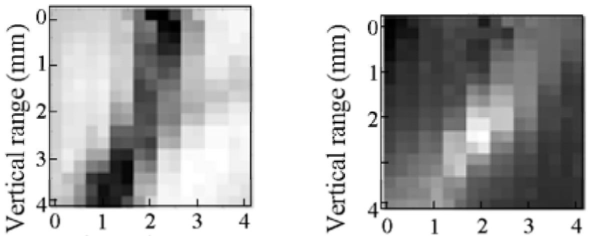
(d) 57.5GHz; amplitude

(e) 57.5GHz; phase



(f) 60GHz; amplitude

(g) 60GHz; phase



(h) 62.5GHz; amplitude

(i) 62.5GHz; phase

Fig. 6: Images by microscopic aperture probe.

The images at 55GHz, 57.5GHz, 60GHz and 62.5GHz and in terms of amplitude and phase are shown in Fig. 6 (b)-(i). Each image shows the contrast of the vein verse mesophyll. The amplitude of the vein increases at 57.5 and 60GHz, and decreases at 55 and 62.5GHz. The phase of the vein leads at 57.5 and 60GHz, and lags at 55 and 62.5GHz. The reverse of the contrast in amplitude between 55GHz and 60GHz, and between 57.5GHz and 62.5GHz are due to the interference between the direct transmitted and internal reflected waves in the vein or mesophyll. These images seem to change periodically by frequency. These results imply the possibility of topographical and dielectric structure reconstruction.

6. CONCLUSION

On the prototype 60GHz band waveguide type probe having a 0.5mm-dia aperture, it is experimentally confirmed that the spatial resolution has an order of 1mm, a fraction compared to the wavelength, and the sensibility in depth responds to a minimum between 0.1-0.5mm. Images of a leaf exhibit the dependency on the frequency and the received signal's amplitude and phase due to the interference between the direct transmitted and internal reflected waves. By exploiting these dependencies, it is possible to reconstruct the dielectric distribution and topographical variation of biological objects.

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