Characterization of the Perturbation Effect of A Probe Head Using the FD-TD Method

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Abstract— **The perturbation effect of a probe head in microwave measurement is investigated by using the FD-TD method. A two-simulation approach with improved accuracy is employed to predict the insertion loss caused by the probe head. Depending on the diameter and reclining angle of the probe head, a maximum insertion loss of up to 0.8 dB has been calculated for an example structure. This work provides a rigorous and quantitative estimation of the probe effect. The analysis results may also serve as a guidance for optimal designing and positioning of probe heads so that a minimum field perturbation during measurement can be expected.**

I. Introduction

To offer direct probings of high-frequency signals in microwave devices, various types of probes have been developed, with typical insertion loss of 1~2 dB in the frequency range from DC to 26 GHz [1], [2]. This insertion loss is believed to be mainly due to the field perturbation effect of the probe head on the circuit under test. An accurate evaluation of this probe effect, to the authors' knowledge, has so far been obtained only through experimental measurements.

In this work, we have tried to offer a quantitative estimation of the field perturbation effect of the probe head by applying a FD-TD algorithm developed for three-dimensional microwave circuit analysis and simulation [3]. The insertion loss introduced by the probe has been obtained by comparing the signal intensities with and without the probe head, which efficiently cancels the numerical errors. For the example structure, the insertion loss is found to have a maximum value of 0.6~0.8 dB near 5 GHz, depending on the size and reclining angle of the probe head. Although other factors such as conductor loss of the probe head have been neglected in the present FD-TD analysis, the results of this work should be useful for optimal designing of the probe head so that a minimum invasiveness can be expected in microwave measurements.

II. Analysis Procedures

The structure under investigation is shown in Fig. 1, where a metallic probe head is put in direct contact with the microstrip line. For a rigorous analysis of such three-dimensional structures, the FD-TD is probably the most suitable method [4], although other approaches such as the method of moments have also been employed in analyzing a similar wire-to-plate junction [5]. The first step of FD-TD analysis is to define a problem space of reasonable dimensions for computation. Here, we analyzed a probe head in contact with a 50-Ω microstrip line on alumina substrate ($\varepsilon_r = 9.6$) with the following dimensions: $w = d =$ 0.6 mm, h =3.4 mm, a =7.6 mm, and b =13.0 mm. The fineness of the Yee's mesh is 0.1 mm, while the time step for iteration is chosen to be 0.171 ps to satisfy the stability criterion. This results in a structure with 40×76×130 meshes. The probe is supposed to be of uniform, cylindrical geometry, with a diameter of S and a bending angle of 135 degrees at the head.

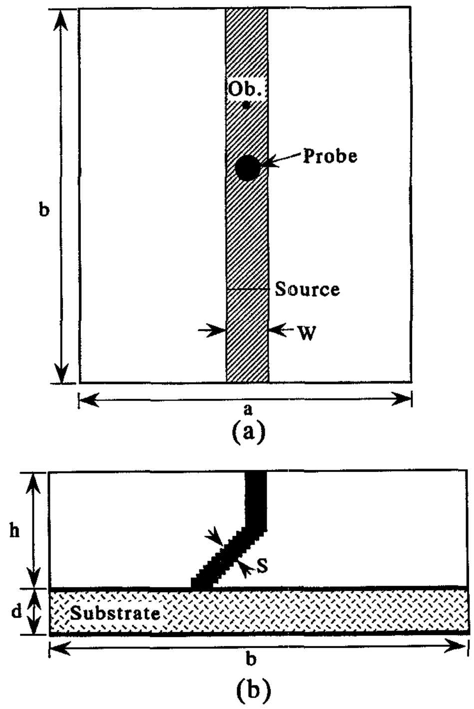

Fig. 1. (a) Top view and (b) side view of a microwave probe head in a microstrip line structure.

Mur's absorbing boundary conditions [6] are applied on the boundaries of the problem space. A Gaussian pulse of 40 ps (FWHM) is used as the source. Two simulations of pulse propagation along the microstrip line are made, one with the probe head in contact with the line and the other without the probe head. The voltages at the observation point, which is located slightly behind the probe head, are obtained by numerically integrating the vertical electric field component between the microstrip and ground conductor. A FFT algorithm is then used to convert the time domain signals into the Fourier spectral domain, from which the insertion loss

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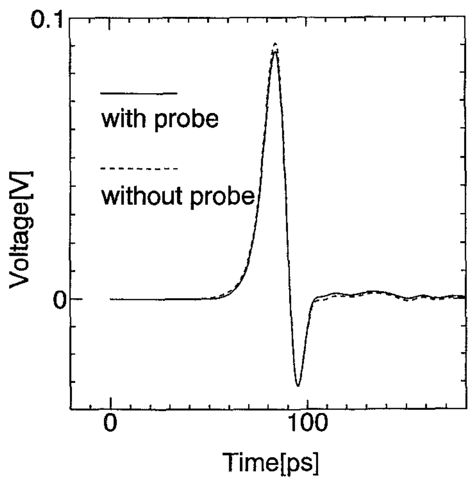

Fig. 2. Simulation results of the voltage waveforms at the observation point with and without the probe head.

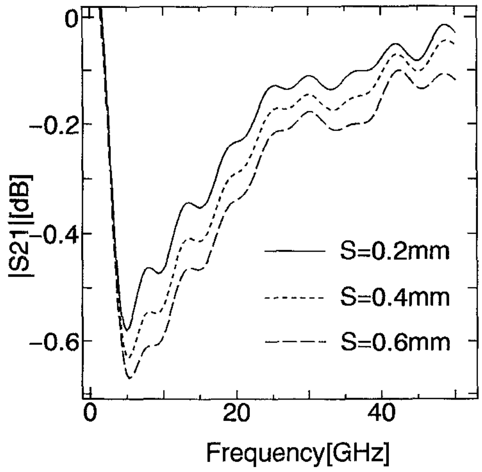

Fig. 3. Calculated results of the insertion loss with respect to different sizes of the probe head.

is obtained. Typical CPU time for one simulation is 90 minutes on a Hitachi S3800 super computer.

III. Numerical Results

Fig. 2 shows the voltage waveform at the observation point with and without the probe head. The existence of the probe head, as can be seen, results in a slight decrease in the peak value of the voltage, while the waveform remains unchanged as a whole. Although in theory the insertion loss can be derived by directly comparing the signal intensities before and behind the probe head, numerical accuracy will be a serious problem since the perturbation effect of the probe head is only of a second order. The two-simulation approach introduced here enables us to cancel the numerical errors in an extremely efficient manner, since the two simulations are carried out under identical conditions except the existence/absence of the probe head.

Fig. 3 plots the insertion loss due to the probe head, which has been calculated by a Fourier transform of the time-domain waveforms of Fig. 2. The change of the insertion loss with different diameters of the probe head, S, is also shown. It is found that the insertion loss increases almost linearly at the lower frequency end, where a maximum is reached near 5 GHz for the present structure. The peak value is dependent on the probe size and decreases slightly when the diameter of the probe head is reduced from 0.6 to 0.2 mm. When the frequency is further increased, the field becomes concentrated in the dielectric substrate under the strip conductor and less current flows into the probe head. This explains the gradual decrease of the insertion loss at higher frequencies.

We have also investigated the change of insertion loss caused by different arrangements of the probe head. Fig. 4 shows the numerical results for various positionings of the probe head. It is found that the insertion loss changes only slightly with different reclining angles as long as the probe head is located in a plane parallel to the microstrip line. On the other hand, when the probe head is reclined in a plane perpendicular to the strip line, a relatively large insertion loss

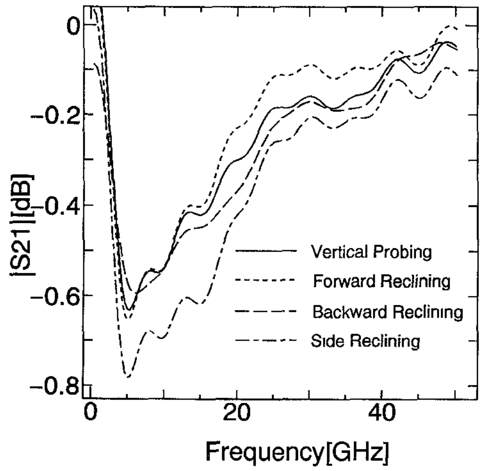

Fig. 4. Calculated results of the insertion loss with respect to different reclining angles of the probe head.

is observed, which can be interpreted as the result of stronger perturbation of the wave propagation along the transmission line by the probe head.

IV. Conclusions

The insertion loss caused by the contact of a probe head to microstrip lines is calculated by using the FD-TD method. Several factors affecting the magnitude of the insertion loss, such as the probe diameter and positioning of the probe head, have been investigated. A frequency-dependent behavior of the insertion loss has also been revealed. Based on these numerical results, microwave probe heads with optimal dimensions and positionings can be designed and a minimum field perturbation during measurement can be expected.

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