Numerical and Experimental Near Field Distributions in High-Frequency Planar Circuits

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Abstract-A new test system for measuring electric field profile in planar circuits such as microstrip-line has been developed. In order to estimate the measured electric field profile, the 3D full-wave analysis is carried out by using a finite-difference time domain technique for planar printed circuits in high-frequency ranges. A test system proposed in this paper based on a small coaxial probe antenna and is not required complicated measurement system setup. The upper limit of the operating frequency and the spatial resolution for this measurement will be clarified.

Keywords: Leakage, Field distribution, Probe field mapping, FDTD method, Measurement, Microstrip line circuits

1.Introduction

In the last years, the popularization of mobile communications and rise in the operation clock frequencies of the computers, the rapid development of various electromagnetic (EM) circuits in high frequency ranges, has made the rigorous analysis of these circuits increasingly important[1]. Especially, the unwanted radiation problem from the high speed interconnects, high-frequency print circuits and other microwave structures is one of the troublesome problems, though simulation techniques have been developed and predicted various properties of EM circuits, high-speed interconnects and high frequency printed circuits. The 3D full-wave analysis for the EM circuits has been carried out by the FD-TD techniques. But, enormous computation time and large memory are required even for a simple model. Thus, it is considered that a detailed investigation of EM field distributions, in addition to the input/output frequency characteristics of EM circuits and high frequency printed circuits is useful not only for the optimization and adjustment of the EM circuits, but also for predictions in the theoretical analysis of more complicated discontinuity problems, for studies of electromagnetic coupling effects of EMI/EMC,etc. Recently, for measurement of two-dimensional field distributions in MMIC fabricated on substrates, a contactless test techniques using a small coaxial probe have been reported [2,3]. In this paper, we will show how to measure and compute the EM field distributions in microstrip-line circuits. The measurement technique itself is based on the small electric probe measurement system controlled by microcomputer and a complicated system is not required. The upper limit of the operating frequency and the resolution of the size for this measuring method will be clarified.

2. Basic relations with FDTD technique [5]

First, let us briefly explain the derivation of the basic relations for analyzing the microstrip-line circuits treated here. The FDTD method is a three dimensional central difference approximation for Maxwell's curl equations, both in space and time. The simulation region must be divided into "Yee Cells". In the Cartesian coordinate system, each "Yee Cells" contains six field components, Ex, Ey, Ez, Hx, Hy and Hz. These equations are expressed in a linearized form by means of central finite differentiation and are expressed as follows:

$$\mathbf{E}^{n} = \mathbf{E}^{n-1} + \frac{\Delta t}{\varepsilon} \nabla \times \mathbf{H}^{n-1/2} \quad (1)$$

$$\mathbf{H}^{n+1/2} = \mathbf{H}^{n-1} - \frac{\Delta t}{\mu} \nabla \times \mathbf{E}^{n} \quad (2)$$

where $\mathbf{E}^n$ and $\mathbf{H}^n$ are the electric and magnetic fields at the time step on n, and ε,μ and Δt are the permittivity, permeability, and time step, respectively. The following incident pulse wave is used:

(1) Gaussian pulse wave in the case of computing frequency characteristics:

$$p(t) = \begin{cases} \exp\left(-\dfrac{(n\Delta t - t_0)^2}{t_w^2}\right) & 0 \le t \le t_w \\ 0 & t \ge t_w \end{cases}$$

(2) Continuous wave in the case of computing frequency dependent EM field distributions:

$$p(t) = \begin{cases} \dfrac{1}{2}\left(1 - \cos\left(\dfrac{\pi f \cdot n\Delta t}{2}\right)\right) \times \sin(2\pi f \cdot n\Delta t) & 0 \le t \le t_f \\ \sin(2\pi f \cdot n\Delta t) & t \ge t_f \end{cases}$$

Continuous wave of the smooth build-up has been used. The excitation of the MS-line is established by the uniform electric field applied to right under the central conductor line.The absorbing boundary applied Mur-ABC (the secondary absorbing boundary) on cell size ($\Delta x \times \Delta y \times \Delta z$) using the standard and uniform cell.

3. Measurement system using small coaxial probe antenna[2-4]

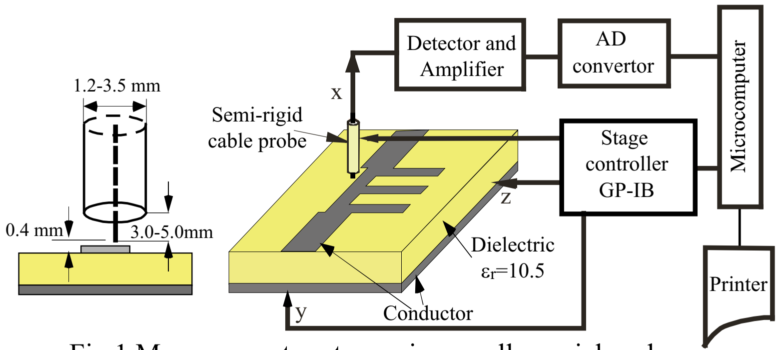

Fig.1 Measurement system using small coaxial probe.

Figure 1 shows a small electric field coaxial probe for measuring the EM field distributions in the microstrip-line circuits or high-frequency printed circuits. Since the normal component of electric field Ex(y,z) is vertical to dielectric sheet, we set a small coaxial probe upright over the dielectric sheet. The measurements are carried out by sliding the small coaxial probe antenna over the surface plane of the dielectric sheet, keeping it at a constant height. This small coaxial probe antenna is mounted on a movable rack mechanism that maintains a constant spacing between the probe tips and dielectric sheet even when the probe moves over the surface plane (constant height: 0.4[mm]). The computer-controlled stepping motor is used and the EM fields are sampled using A/D converter and stored in memory (Scanning minimum steps of 0.1-0.4 [mm] in the y- and z-directions were employed, and hence 8000-16000 field values were sampled in each measurement per cycle. Measurement-time is about 30 minute). Furthermore, the small probe-antenna is formed by protruding the center conductor of the semirigid cable into the enclosure and adjusting its length. The central conductor length is 3-5 mm and picks up as much as possible of the vertical electric component Ex(y,z). By adjusting the gain and sensitivity of the small probe antenna system, weak electromagnetic fields are also detected. The detector system including the small probe antenna is over a 12GHz band comparatively flat and only the vertical component of electric field is detectable. For reduction of the unwanted field disturbance caused by the electric probe, the probe of the detector can only be coupled weakly into the microstrip-line circuits. The matched load connected at the terminated end and periphery of the microstrip-line is terminated by a lossy material absorber so as to avoid reflection. However, due to the imperfection of the matched load, a small amount of frequency dependent reflection occurs and this mismatched termination affects the accuracy of the measurement

4. Numerical and Experimental Results

In order to confirm the validity of our simulation and measurement system, we simulated and measured the straight microstrip line for which other numerical solutions using Moment method are obtained. Based on the many measurements, the limit of application for this measuring method is clarified (that is, the minimum spatial resolution and the upper limit of the measurement frequency).

(1) EM Field Distributions of straight MS-line

In the first example, EM field distribution in straight MS line is calculated by FDTD method. We simulated benchmark test for which exact or other numerical solutions are obtained. The numerical result is compared with the exact solution obtained by the Moment method. Figure 2 shows the steady-state field Ex component for the straight MS-line at 2.79GHz. The cell-size is Δx=0.4, Δy=0.45, Δz=0.5[mm], and the time step is Δt=0.6[ps]. The results are in good agreement with each other. Very good agreement has been obtained between FD-TD, Moment method and measured results. The agreement has been obtained between FD-TD, Moment method and measured result.

(2) Frequency dependent EM Field Distributions of L-type stub circuit

Figure 3 shows calculated and measured frequency characteristics of L-type bias stub circuit. The measurement results of frequency-dependent electric field distributions are compared with the numerical results based on the FD-TD method. The calculated and measured results show the same frequency dependent field Ex(y,z) distributions. The dimensions of the structure used here are microstrip line-width W=0.56 mm, dielectric sheet thickness d=0.635 mm, and relative dielectric constant ε_s=10.5. As shown in Fig.3(a), analysis space in the FDTD is $3.50 \times 17.92 \times 17.92$ mm three dimensional space (the grid is $50 \times 256 \times 256$). The cell size in the space is Δx=Δy=Δz=0.07[mm], the time step is Δt=0.1[ps]. The measured step-size for this structure is chosen as follows: Δy=0.2, Δz=0.2[mm] and height position from dielectric sheet Δx=0.4[mm]. In the case of calculating in 3D field distributions, the CW wave was used for source excitation. The computed and measured frequency characteristics in L-type stub circuit are shown in Fig. 3(b). Fig. 3(c) and (d) show the frequency dependent field distributions Ex(y,z) obtained with the circuit pattern of Fig. 3(a). This circuit reveals the stop band at the frequency range of f=4 GHz and pass band at the other frequency band. Thus, a physical understanding of operating property in the L-type bandstop circuit is given by the 3D display of electric field distributions. Good agreement has been obtained between FDTD analysis and measured results.

(3) 3D display of electric field distributions of straight microstrip-line resonator circuit

Figure 4 shows the frequency dependent field distributions Ex(y,z) obtained by measurement of resonant modes of the microstrip-line rectangular resonator. This resonator has the resonance characteristics at the frequency of f=3.55, f=7.0 and f=10.35GHz. Good agreement has been obtained between FDTD analyzed and measured results except the field distributions of resonant modes. But it is included the essential problem that the radiation phenomenon based on the electromagnetic coupling virtually disappear from the simulation using a conventional FD-TD method.

We also measured the electric field distributions for the 3-stub low pass filter and 3-section side coupled bandpass filter, and large number of microstrip-line circuits. Figure 5 shows measured frequency dependent3-section side coupled band pass filter. As a result, the minimum spatial resolution of measurement system is 0.1[mm] and the upper limit of the operating frequency is over 12 [GHz].

5. Conclusion

A method for calculating and measuring the EM field distributions in microstrip-line circuits was given by using FDTD method and electromagnetic measurement system. It is considered that the leakage phenomenon is caused by the electromagnetic coupling effects between the resonant mode of microstrip resonator and the surface wave TM_0 mode of covered dielectric slab that propagates from DC. But the leakage phenomenon such as electromagnetic coupling effects can never obtained by a simulation using a conventional FD-TD method. Thus, our proposed measurement system offers a valid means for predictions in the theoretical analysis of microstrip-line type arbitrary-shaped planar circuits and complicated measurement system is not required.

In the future, the method of analysis and measurement proposed here will be also applied to VLSI, MMICs, various electromagnetic circuit structures, and the electromagnetic coupling problems for EMI/EMC etc.

References

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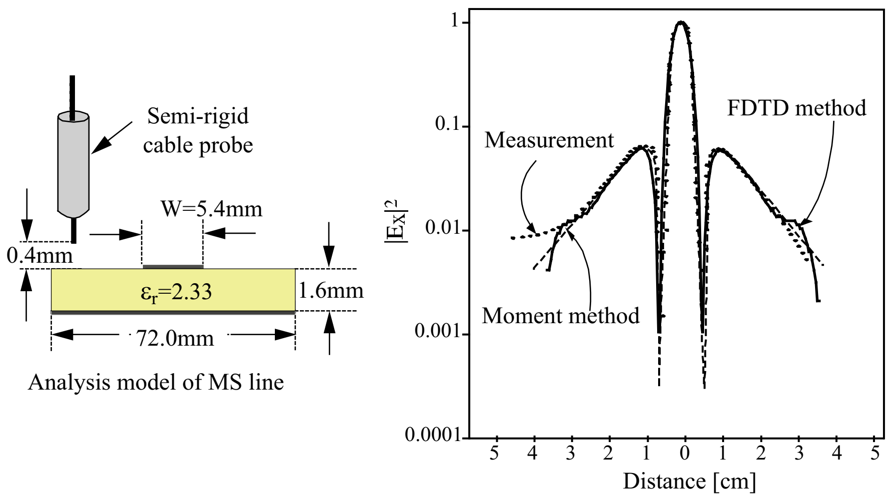
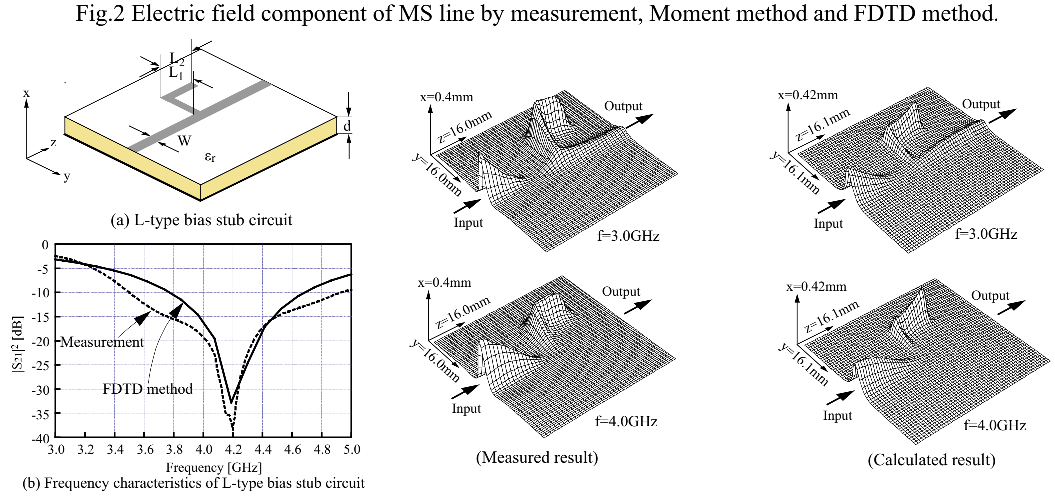
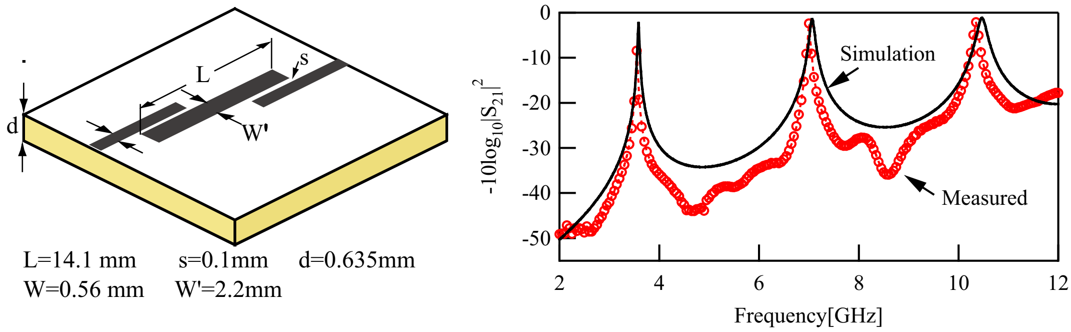


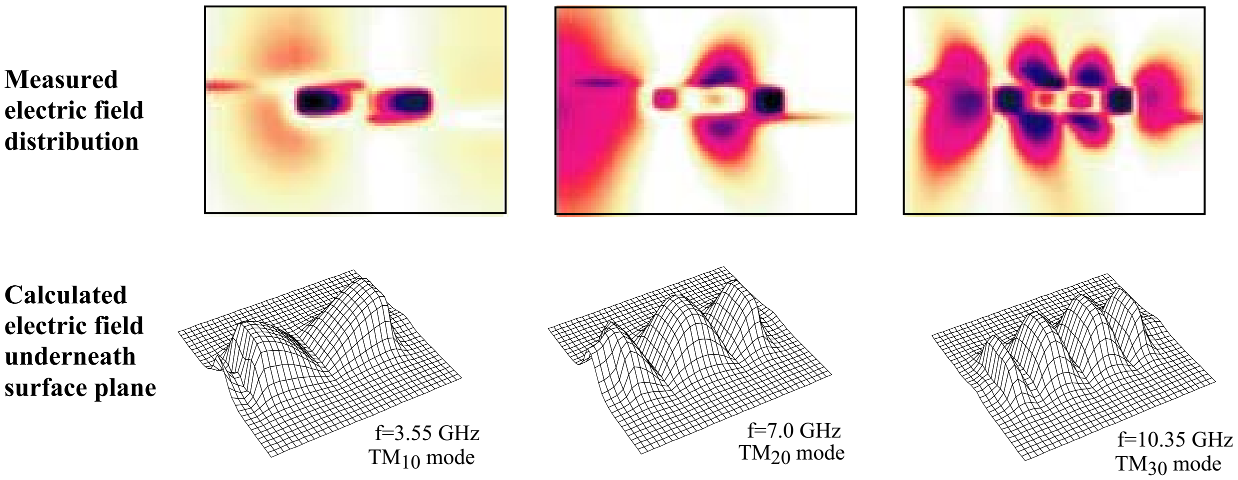
Fig.2 Electric field component of MS line by measurement, Moment method and FDTD method.



(c) Left : Measured results by coaxial probe antenna and (d) Right : Calculated results by FDTD method
Fig.3 Frequency characteristics and 3D display of electric field distributions in L-type bias stub filter circuit.



(a) Experimental model and Frequency characteristics of half-wave long microstrip resonator



(b) Electric field of TM_{10} mode Electric field of TM_{20} mode Electric field of TM_{30} mode

Fig.4 Measured and calculated results of electric field distribution of half-wave long microstrip resonator.

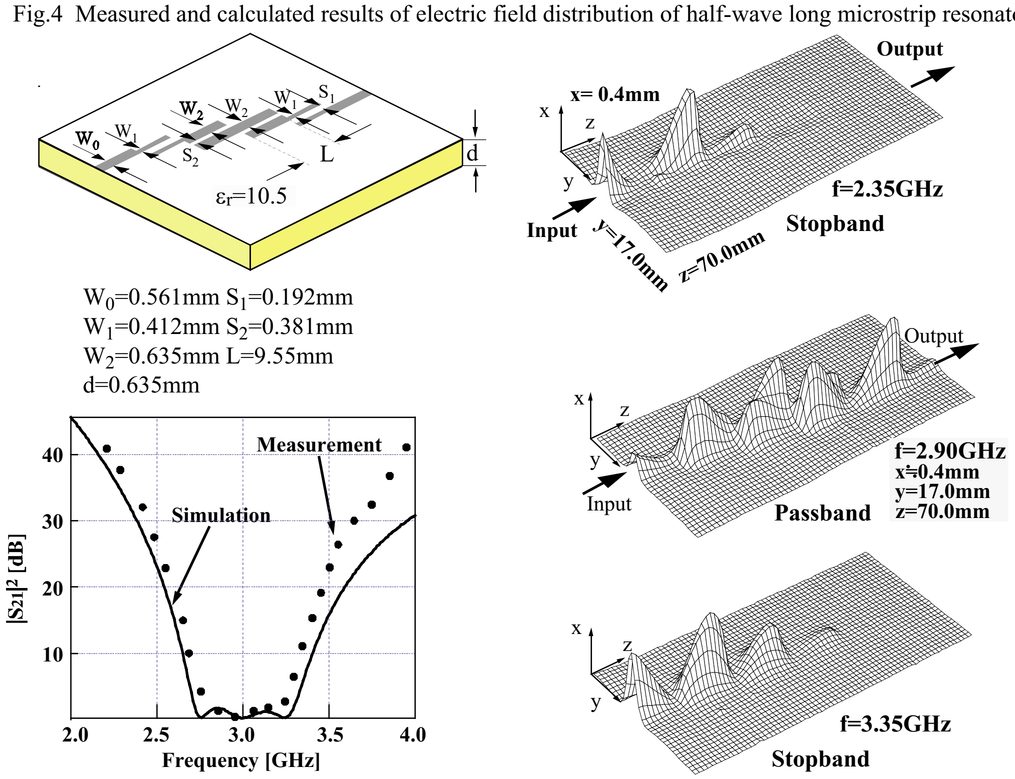


Fig.5 3D display of electric field distributions in 3-section side coupled band pass filter.