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BASIC MICROSTRIP JUNCTION ANALYSIS BY THE FINITE-DIFFERENCE TIME-DOMAIN METHOD

Репрезентовано результати аналізу методом скінчених різниць у часовій області таких базових з'єднань мікросмужкових ліній, як поворот лінії на 90 градусів, Т-з'єднання та хрестоподібне з'єднання. Для розрахунку характеристик цих з'єднань змодельовано розсіювання на відповідних мікросмужкових неоднорідностях гауссова імпульсу. Результати, що одержано у часовій області, наочно демонструють процес розсіювання у розвитку. За допомогою фур'є-перетворення даних із часової області у частотну визначено елементи матриці розсіювання.

Introduction. Microstrip junctions are most widely used building elements of microwave integrated circuits. Serve to connect microstrip devices, divide, or combine power, those elements represent simple microstrip discontinuities characterized by appropriate scattering matrices. Based on the knowledge of frequency-dependent parameters of circuit elements and junctions connecting these elements, large microwave devices can be easily analyzed by the circuit theory. That is why the accurate modeling basic microstrip junctions in terms of S matrix elements is a problem of great importance for modern microwave CAD.

Theory. Among various techniques used to solve electromagnetic problems, the finite-difference time-domain method (FDTD) can be distinguished due to its great flexibility in the analysis of a variety of microstrip configurations. Moreover, the ability of field simulation both in time and frequency domain allows us to get a deep insight into a time-dependent process of pulse scattering by circuit discontinuities and to obtain the frequency-dependent characteristics in terms of the S matrices.

The finite-difference method in time domain has been firstly introduced by K. S. Yee [1] to solve three-dimensional electromagnetic scattering problems and later applied to microstrip discontinuity analysis by many authors (for example [2], [3]). The method is based on dividing a limited computational domain with an analyzed structure inside into unit cubic cells and calculating field values at certain points of the space mesh at successive instants of time. An approximate solution of the electromagnetic problem can be obtained solving Maxwell's equations with appropriate initial, source and boundary conditions imposed on conductors, interface surfaces and the computational domain walls. The discretization of Maxwell's equations using the central-difference approximation leads to a set of algebraic equations providing an explicit computational algorithm for the simulation of electromagnetic field scattering.

Three basic microstrip junctions widely used in microwave integrated circuits, namely microstrip 90 degree bend, T-junction, and cross-junction, are considered inside their computational domains as shown in Fig.1 for the cross-junction. The domain of interest is divided into unit sells whose dimensions are Δx, Δy, Δz in x, y, and z directions, respectively.

The ground plane and the strips are assumed to be perfect electric conductors of zero thickness and involved in the analysis by setting the tangential electric field components on the conductors to zero. Field components on dielectric-air interface are

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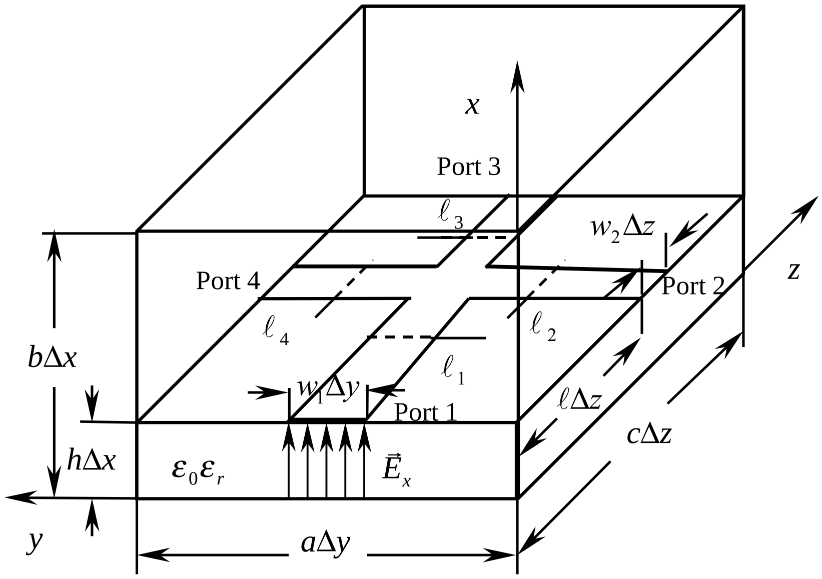

Fig. 1. Computational domain for microstrip cross-junction

calculated using the average permittivity $(\varepsilon_0 + \varepsilon_0\varepsilon_r)/2$. For tangential electric field components on the computational domain walls (except the ground plane) Mur's first-order approximate absorbing boundary conditions [4] are applied to simulate outgoing waves.

The initial conditions force all field components to be zero at $t = 0$ throughout the computational domain. At $t = 1$, a Gaussian pulse is excited on the front wall with the vertical electric field component

$$E_x(t) = \exp\left[-\frac{(t-t_0)^2}{T^2}\right].$$

The remaining electric field components on the source wall of the computational domain are forced to be zero. To avoid undesired return wave reflection by the front wall, the electric source wall conditions should be switched on the absorbing boundary conditions when the Gaussian pulse reaches the discontinuity.

Numerical Results. All microstrip junctions considered are chosen with similar structural parameters: $\Delta x = \Delta y = \Delta z = \Delta h = 0.127$ mm, $\Delta t = k\Delta z / c$ sec, $a = c = 100$, $b = 40$, $l = 50$, $h = w_1 = w_2 = 10$, $\varepsilon_r = 8.875$, where k is the stability criterion constant ($k = 0.514$) and c is the velocity of light in air.

The field distribution of E_x component calculated for the microstrip 90 degree bend, T-junction, and cross-junction on the plane just underneath the strip surface at the moments $800\Delta t$ is shown in Figs. 2-4, respectively. The time-domain results explicitly illustrate Gaussian pulse scattering by the microstrip junctions. The figures allow us to observe Gaussian pulse splitting between ports of the microstrip discontinuities. In Fig.3 one can see a surface wave travelling from the discontinuity to the far end of the computational domain.

The frequency-dependent scattering matrix elements S_{ij} referred to the reflection and transition coefficients can be obtained from Fourier-transformed time-domain electric field values calculated at corresponding ports. The reflection and transition coefficients are determined as

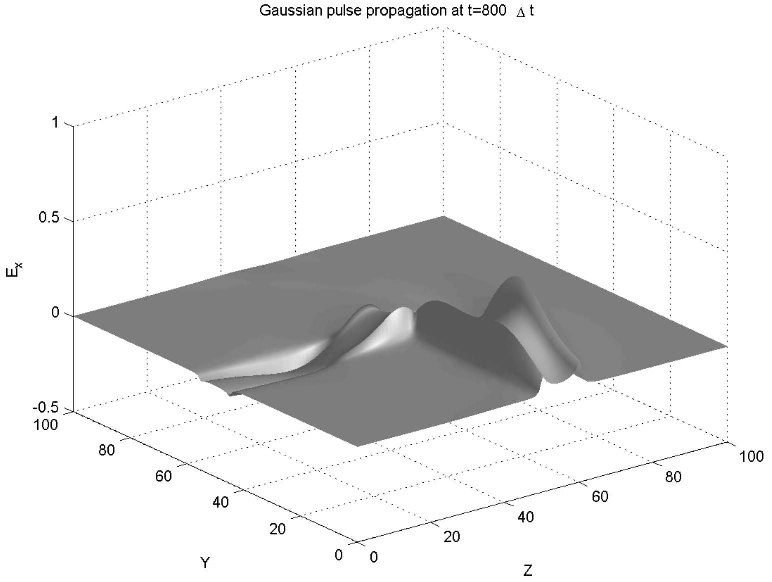

Fig. 2. E_x **component distribution for 90 degree microstrip bend at 800 time step**

$$S_{ii}(f)=\frac{\tilde{E}_x^{ref}(f,\ell_i)}{\tilde{E}_x^{inc}(f,\ell_i)}e^{2\gamma(f)l_i},$$

$$S_{ij}(f)=\frac{\tilde{E}_x^{tr}(f,\ell_i)}{\tilde{E}_x^{inc}(f,\ell_j)}e^{\gamma(f)(l_i+l_j)}$$

where $\tilde{E}_x^{ref}$ is the Fourier-transformed reflected electric field component calculated underneath of the strip at the reference plane $\ell_i\Delta h$ of the input port, $\tilde{E}_x^{inc}$ is the Fourier-transformed incident electric field component at the same point, and $\tilde{E}_x^{tr}$ is the Fourier-transformed transited electric field component at the corresponding reference planes. The incident field is obtained as a result of the FDTD modeling of a regular microstrip line [5] and the reflected field is obtained as a difference between the total scattered field in the input port and the incident field.

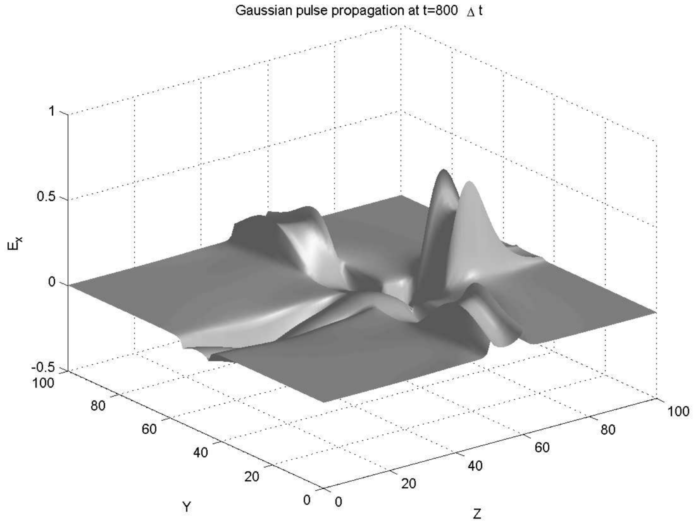

Fig. 3. E_x **component distribution for microstrip T-junction at 800 time step**

Figs.6, 7 represent scattering matrix element behavior for microstrip T-junction (symmetrical excitation) and microstrip cross-junction, respectively. For T-junction, port 3 corresponds to the port designed as forth port in Figs.1. Parameters S_{21}, S_{31} for T-junction, and S_{41}, S_{21} for cross-junction are referred to the same curve due to the symmetry of the corresponding structures. From Fig. 7 it can be seen that at low frequencies all S parameters tend to the value 0.5 indicating that the total field energy is equally divided between four ports of the microstrip cross-junction.

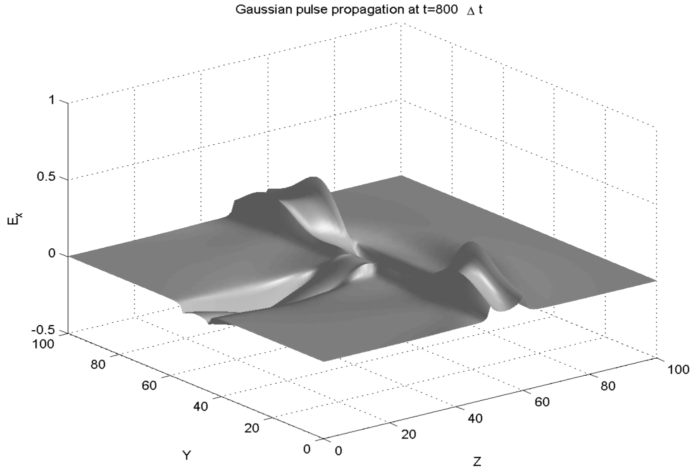

Fig. 4 E_x **component distribution for microstrip cross-junction at 800 time step**

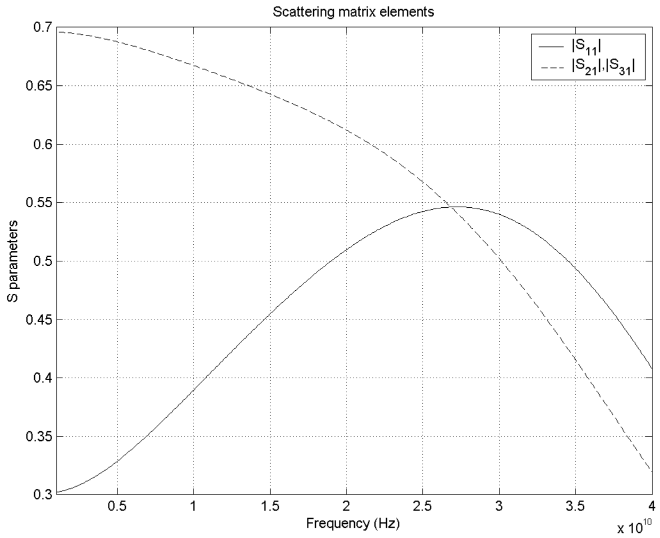

Fig. 5. Frequency-dependent scattering parameters for 90 degree microstrip bend

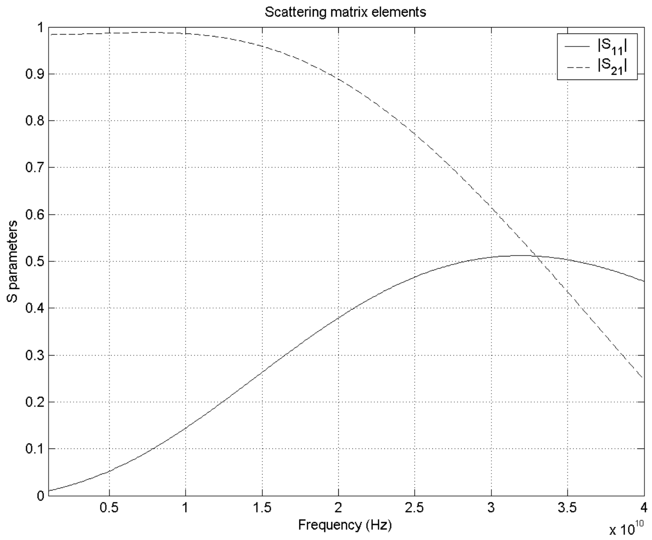

Fig. 6. Frequency-dependent scattering parameters for microstrip T-junction

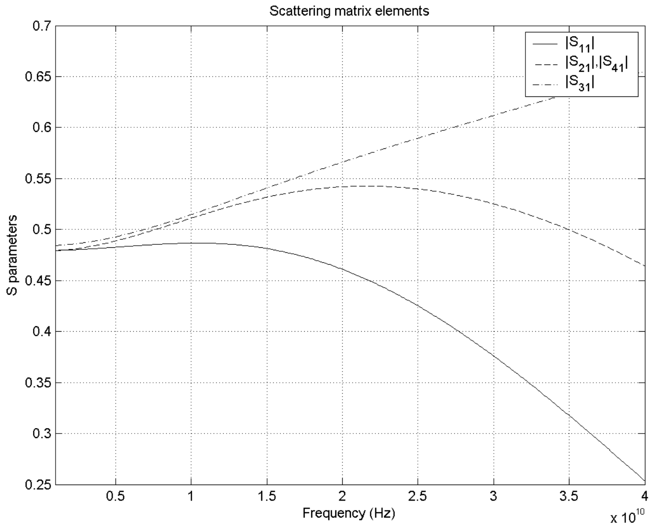

Fig. 7. Frequency-dependent scattering parameters for microstrip cross-junction

Conclusions. The finite-difference time-domain method has been applied to the analysis of basic microstrip line junctions, such as rectangular bend, T-junction, and cross-junction. Numerical results have been obtained in time and frequency domains to illustrate pulse signal propagation and scattering process, and to characterize microstrip junctions in terms of scattering matrix elements.

Представлены результаты анализа методом конечных разностей во временной области таких базовых соединений микрополосковых линий, как поворот линии на 90 градусов, Т-образное и крестообразное разветвление. Для расчета характеристик данных соединений смоделировано рассеяние на микрополосковых неоднородностях гауссова импульса. Результаты, полученные во временной области, наглядно показывают процесс рассеяния в динамике. При помощи фурье-преобразования данных из временной в частотную область определены элементы матрицы рассеяния.

Basic junctions of microstrip lines, such as rectangular bend, T-junction, and cross-junction, are analyzed using the finite-difference time-domain method. Gaussian pulse scattering is simulated to achieve time- and frequency-dependent characteristics of the microstrip junctions. Time-domain results are obtained to explicitly demonstrate scattering process evolution. Scattering matrix elements are calculated in frequency-domain from the time-domain data using the Fourier transform.

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