Dispersion Characteristics of Transient Signals in Microstrip Step Discontinuity

K. S. Chen*, G. W. Zheng* and S. T. Peng**

* Zheijiang University, Hangzhou, Zhijiang, China
** New York Institute of Technology, Old Westbury, New York

Abstract

We present an analysis of the transmission of electromagnetic pulse through a step discontinuity between two microstrip lines of different width. The step discontinuity is first characterized by a two-port network for which the frequency dependence of the scattering parameters are determined by the method of line. By means of the Fourier transform technique, transient responses of the step discontinuity to various pulses are then investigated for different ratios of strip widths and substrate materials. It is found that the distortion of pulses propagating through the step discontinuity can be quite substantial, particularly for the case of large width ratio and substrate of high dielectric constant. Thus, the results so obtained will provide valuable information for the design of microwave integrated circuits.

Introduction

The distortions of a pulse in transmission lines and material media have attracted considerable attention in the past; the distortion of transient signal in a uniform microstrip line has been investigated by Beghte an Balanis(1). In a microwave integrated circuit, there exist many junction discontinuities, such as an abrupt change in width at a junction between two unifrom microstrip lines, commonly known as a step discontinuity. The distortion of pulse caused by the step discontinuity has not been examined. A uniform microstrip line is a two-dimensional boundary value problem, whereas the step discontinuity is a three-dimensional one which is much more difficult to solve.

In this paper, we analyze the propagation of an electromagnetic pulse through a step discontinuity between two uniform microstrip lines, with particular attention directed toward the distortion of the pulse shape caused by the discontinuity. A step discontinuity may be represented by an equivalent network and the scattering parameters of the network may be obtained from the resonance technique developed by Jansen(2). In contrast, we employ here the method of line(3) for the computation of resonance frequency, rather than the spectral-domain method previously used, to obtain the frequency dependence of the network parameters. The method of inverse Fourier transform is then used to determine the time response of the discontinuity. The combination of these different methods makes the three-dimensional boundary value problem mathematically tractable.

Having the dispersion characteristics of the network parameters, the transient analysis of the microstrip step discontinuity is carried out first in the frequency domain. The results are then inverse-transformed back to the time domain to determine the change in pulse shapes during the transmission through the discontinuity. Two typical pulse shapes are considered: square and Gaussian pulses. Numerical results have been obtained for various ratios of the strip widths and substrae materials. It is found that the distortion of pulses propagating through the step discontinuity can be quite substantial, particularly for the case of large width ratio and substrate of high dielectric constant. Thus, the results so obtained will provide valuable information for the design of microwave integrated circuits.

Dispersion of Tansient Signal

Fig. 1, depicts a step discontinuity and its network representation. The junction discontinuity at x=0 is formed between two unfiorm microstrip lines of widths w_1 and w_2. The thickness of the substrate is d. The microstrip structure is shielded within a rectangular cavity, in order to perform a resonance analysis. For the dominant mode, the step junction can be described by a scattering matrix.

$$S = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} \quad (1)$$

Where the element s_{ij} $(i,j = 1,2)$ is generally a function of frequency. The determination of these elements will be discussed in the next section; we assume for a moment that they are known.

An electromagnetic pulse is incident from the left onto the step junction at z=0. The voltage or electric field at $z=0^-$ is represented by

$$v(t,0^-) = \begin{cases} p(t), & -T/2 < t < T/2 \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

0149-645X/88/0000-0631$01.00 © 1988 IEEE

where p is a function of t describing the pulse shape and T defines the pulse width. In the frequency domain, the spectrum of the signal can be determined from the Fourier transform:

$$V(\omega,0^-) = \int_{-T/2}^{T/2} v(t,0^-)\exp(j\omega t)dt \qquad (3)$$

Thus, $v(t,0^-)$ and $V(\omega,0^-)$ form the Fourier transform pair. For certain transient signal, such as a square pulse, the limits $-t/2 < t < t/2$ define the pulse width, and the signal is confined to a short time period. On the other hand, for a Gaussian pulse, the range of integration covers from negative to positive infinity, in order to characterize completely the response.

After transmission through the step discontinuity, the signal at $z = 0^+$ in the frequency domain can be written as

$$V(\omega,0^+) = V(\omega,0^-)s_{12}(\omega) \qquad (4)$$

where s_{12} is the transmission coefficient as indicated in (1). Taking the inverse transform of (4), we obtain the time-domain representation of the pulse at $z = 0^+$.

$$v(t,0^+) = \frac{1}{2\pi}\int_{-\infty}^{\infty} V(\omega,0^-)s_{12}(\omega)\exp(j\omega t)d\omega \quad (5)$$

For a given initial pulse of known shape, such as: square, Gaussian, triangular DC or RF pulse, its Fourier transform, $V(\omega,0^-)$, is assumed known. Thus, the transient response of a step discontinuity to any initial pulse can then be analyzed by evaluating the integral above.

Evaluation of Scattering Parameters

It is evident from the preceding section that the determination of the frequency dependence of the transmission coefficient, s_{12}, is a crucial step in the analysis of the transient response of the junction discontinuity. The scattering parameters of the microstrip step discontinuity can be derived from the resonance technique developed by Jansen(2). The main idea of this technique consists of essentially numerical simulation of the microstrip discontinuity, which is characterized by a two-port network, embedded in a configuration of ideally short-circuited microstrip line, such that a resonance structure results. The resonance condition is formulated in terms of strip lengths for a fixed operating frequency. Several different resonance situations must then be simulated to allow a determination of the scattering parameters for the equivalent two-port network. Here, we employ the method of line(3) for the investigate the resonance behavior of the shielded microstrip structure, instead of the spectral-domain method as commonly used. One of the advantages of the method of line is that it is generally applicable to discontinuity of arbitrary shape. In addition, it exhibits a relatively low numerical expense for the generation of the elements of the final matrix equation.

The method of line reduces the original Helmholtz equation to a system of ordinary differential equation. In contrast to the spectral-domain approach, the reduction in complexity and presumption for further analytical processing is achieved by discretization of the helmholtz operator; a typical equation is shown as follows:

$$\left(\frac{d^2}{dy^2} + k^2\right)f_{mn} + \frac{f_{m-1,n} - 2f_{mn} + f_{m+1,n}}{h_x^2} + \frac{f_{m-1,n} - 2f_{mn} + f_{m+1,n}}{h_z^2} = 0 \qquad (6)$$

This implies a two-dimensional finite-difference representation of the field for each plane at a constant y. It is recognized as a coupled tridiagonal matrix system of equations, which can be easily diagonalized. Thus, the y-dependence of the layered structure can be described in analytical form, including the boundary conditions at the ground and top planes. For the relevant tangential electric field and current density in the plane of the strip, the boundary conditions are formulated pointwise. This can not be performed in terms of the transformed quantities, and requires an inverse transform back to the time domain. As in the spectral domain approach, the last step in the method of line is the solution of a determinantal equation from which the eigen values are evaluated for the boundary-value problem under consideration.

Results and Discussion

Two widely used substrate materials for the microstrip line are considered in the computation. The first one has a low relative dielectric constatn $\epsilon_r = 2.32$ and the other has $\epsilon_r = 10.2$. The thickness of the substrate is: $d = 0.762$ mm, for both materials.

The scattering parameters for the step discontinuity between two uniform microstrip lines of different widths are analyzed for the two width ratios: $w_2/w_1 = 1.57$ and 2.71. Fig. 2 shows the frequency dependence of the transmission coefficient, including amplitude and phase, for the case of low dielectric constant of $\epsilon_r = 2.32$. In order to establish the accuracy of our computations, we have carried out an analysis for the structure of Koster, et al(4); our results agree well with the published data up to 12 GHz. For the transient analysis here, a much wider frequency range is needed, and we have extended it to 50 GHz. With the transmission characteristics shown, the step discontinuity behaves like a low-pass filter. The bandwidth is wider for the small ratio of the strip widths than that for the larger ratio. Therefore, it is anticipated that the larger the width ratio, the more distortion a pulse will experience while propagating through the step discontinuity.

Having the dispersion characteristics of the transmission coefficient for the step discontinuity, we then performed the inverse Fourier tranform to determine the pulse shape after transmission through the discontinuity. We consider two different pulse shapes: DC Gaussian pulse of width T = 25 ps and DC square pulse of width T = 1.25 ns. Fig. 3 shows the distortions of a Gaussian pulse for two different width ratios for the case of low dielectric constant, that is, $\epsilon_r = 2.32$, while Fig. 4 shows those for a square pulse. Evidently, the distortion is quite pronounced, when the width ratio becomes large, as anticipated.

We have also carried out the same calculations for the substrate of high dielectric constant $e_r = 10.2$. For comparison purpose, Fig. 5 shows the changes in the shape of a Gaussian pulse after the transmission through a step discontinuity of the width ratio: $w_2/w_1 = 2.71$, for two substrate materials of low and high dielectric constants. Fig. 6 shows those for a square pulse. From these results, it is seen that in the case of substrate with a high dielectric constant, the pulse shape is substantially distorted by a single step discontinuity. Therefore, in the design of an integrated circuit where many discontinuities are expected, it will be very important to take into consideration the effect of pulse distortion due to each discontinuity, as shown here.

Reference

(1) R.L. Veghte and C.A. Balanis, "Dispersion of Transient Signals in Microstrip Transmission Lines," IEEE Trans. Microwave Theory and Tech., Vol.MTT-34, pp.1427-37, 1986.

(2) R.H. Jansen, "Hybrid Mode Analysis of End Effects of Planar Microwave and Millimeterwave Transmission Lines," Proc. Inst. Elec. Eng., pt.H. Vol.128, pp.77-86, 1981.

(3) S.B. Worm and R. Pregla, "Hybrid-Mode Analysis of Arbitrarily Shaped Planar Microwave Structure by the Method od Lines," IEEE Trans. Microwave Theory and Tech., Vol.MTT-32, pp.191-196, 1984.

(4) N.H.L. Koster and R.H. Jansen, "The Microstrip Step Discontinuity: A Revised Descritipn," IEEE Trans. Microwave Theory and Tech., Vol.MTT-34, pp.213-223, 1986.

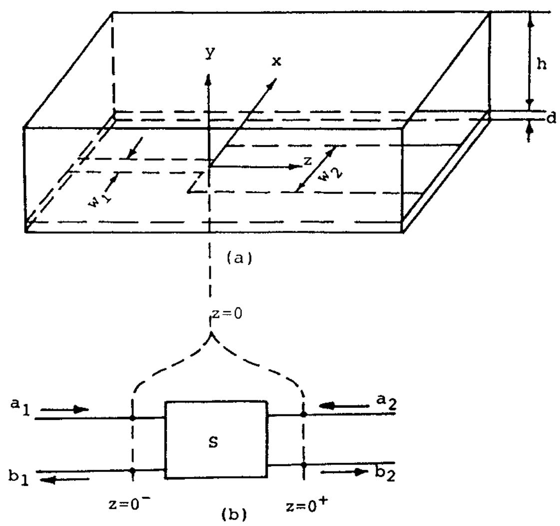

Fig. 1 Structure configuration

(a) Shielded microstrip step discontinuity

(b) Equivalent network representation

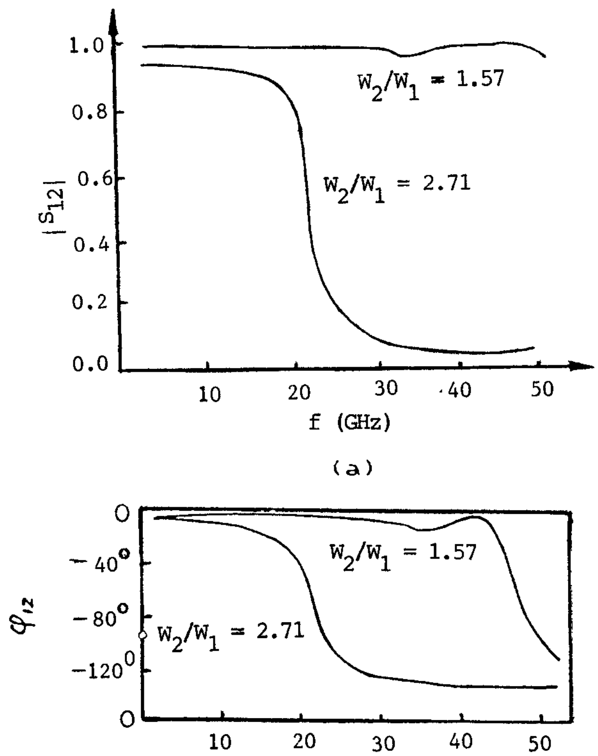

Fig. 2 Frequency dependence of S_{12} for different ratios of strip widths

($\epsilon_r = 2.32$)

(a) Amplitude (b) Phase

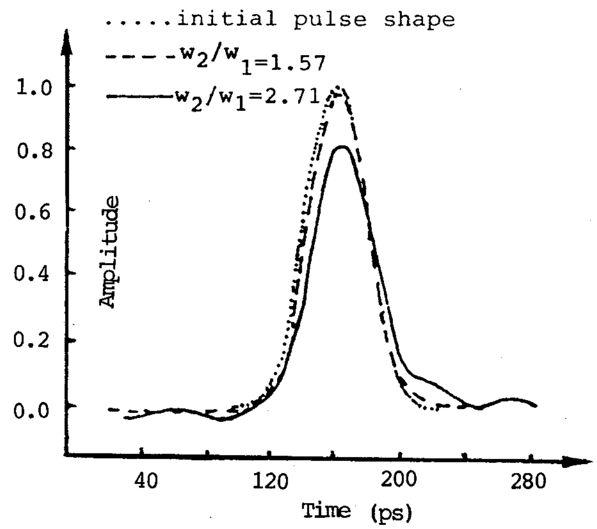

Fig. 3 Distortion of Gaussian DC pulse for different ratios of strip widths. (ϵ_r = 2.32)

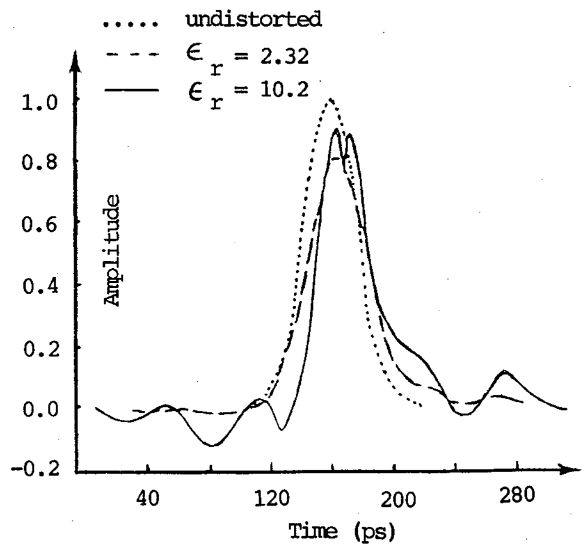

Fig. 5 Distortion of Gaussian DC pulse for different dilectric constants. (W_2/W_1 = 2.71)

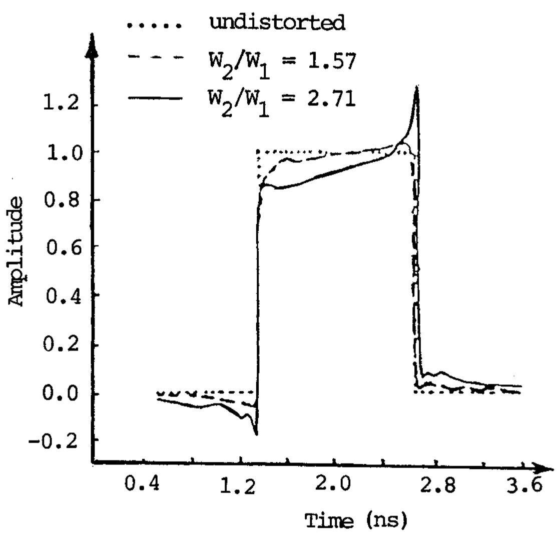

Fig. 4 Distortion of square DC pulse for different ratios of strip widths. (ϵ_r = 2.32)

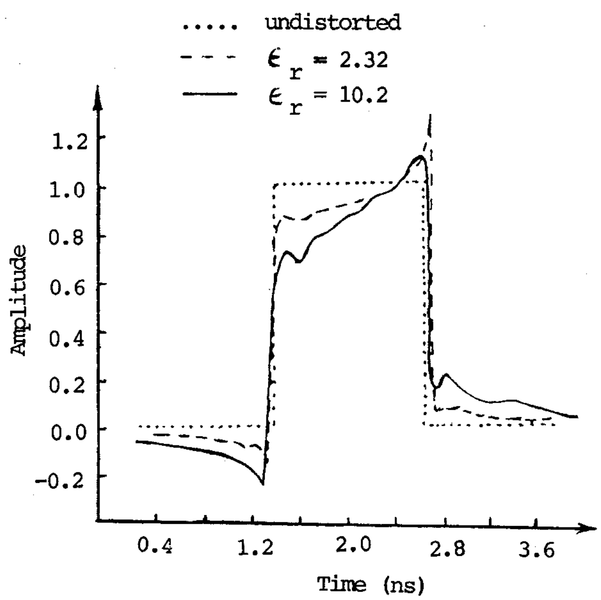

Fig. 6 Distortion of square DC pulse for different dielectric constants. (W_2/W_1 = 2.71)