Characterization of Picosecond Pulse Propagation in a Microstrip Line Divider

Yongxi Qian, *Student Member, IEEE*, Lei Zhu, *Student Member, IEEE*, and Eikichi Yamashita, *Fellow, IEEE*

Abstract— **Many extremely broad bandwidth circuit components have to be newly developed for practical applications of ultrashort electrical pulses. Theoretical and experimental investigation of the transmission property of picosecond pulses through a microstrip line divider are reported. Full-wave analysis results in the frequency domain are incorporated into a Fourier transform algorithm for computer simulations of pulse propagation through a 3-db microstrip line divider with curved-line branching circuit pattern. An excellent agreement has been found between our theoretical predications and the results of experimental measurements.**

I. Introduction

The generation and detection of ultrashort electrical pulses with femtosecond lasers have been a subject of great interest during the past few years, as they are offering unprecedented possibilities for studying ultrafast phenomena in materials [1] and characterizing the extremely broad bandwidth performance of MMIC's and other high-speed devices [2], [3]. Since pulses with a few picosecond durations have frequency bandwidth extending to several hundred gigahertz, one must pay particular attention when dealing with these ultrashort pulses. The propagation of picosecond electrical pulses along various types of transmission lines have been studied by a number of researchers in the past few years [4]–[7]. While only uniform transmission lines were considered in the above papers, most of the circuits actually designed will contain some kind of discontinuities, such as steps, bends, junctions and coupling lines. Very recently, Alexandrou *et al.* reported their experimental study of picosecond characteristics of bent coplanar waveguides [8]. Computer simulation of pulse propagation in a coplanar waveguide directional coupler has also been presented by Singkornrat *et al.* [9].

In this letter, we report the time-domain, picosecond characterization of a microstrip line divider. Computer simulations based on numerical analysis results are carried out to predict the pulse distortion after passing through the divider. A very good agreement has been found between the simulation result and that of experimental measurements with the fabrication divider. This proves the validity of our theoretical analysis, which can be extended to the characterization of a number of other devices and discontinuities.

Manuscript received December 17, 1991.
The authors are with the University of Electro-communications, Department of Electronic Engineering, Chofugaoka, Chofu-shi, Tokyo 182, Japan.
IEEE Log Number 9018195.

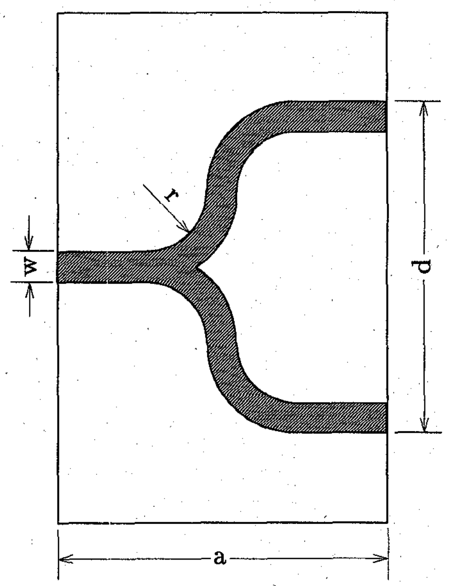

Fig. 1. Top view and dimensions of a microstrip line divider.

II. Simulations

Fig. 1 shows the top view and dimensions of a microstrip line divider with a curved-line branching circuit pattern. This structure has been analyzed by two of the authors recently [10]. The propagation constant and characteristic impedance at each point along the microstrip line are first calculated using the eigenfunction-weighted boundary integral equation method [11], and the general scattering parameters of the divider are estimated based on the transmission line network theory. The segmentation along the microstrip line was chosen to be small enough to ensure satisfactory convergence of the calculated results. Using the method we have obtained, the transmission parameter (S_{21}) of a 3-db microstrip line divider. Fig. 2 shows the numerical results of the amplitude $|S_{21}|$, as well as the phase delay, ϕ, of the divider.

The algorithm of computer simulations of pulse propagation through the divider is similar to that described in a previous paper [12]. The input signal, $V_{\text{in}}(t)$, is first Fourier transformed into its frequency spectrum, $\Im[V_{\text{in}}(t)]$. Multiplying this by the transmission parameters and taking an inverse Fourier transform, we obtain the pulse waveform, $V_{\text{out}}(t)$, at the output port of the divider. This procedure is expressed as follows:

$$V_{\text{out}}(t) = \Im^{-1}\left\{|S_{21}| \cdot \Im[V_{\text{in}}(t)] \cdot e^{\phi(f)}\right\}. \tag{1}$$

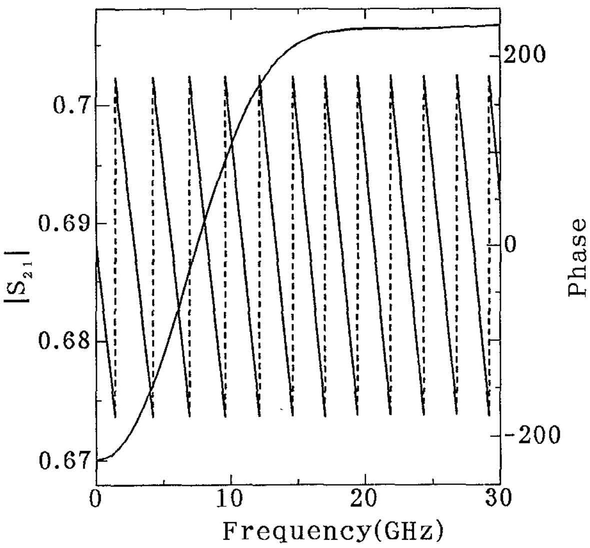

Fig. 2. Numerical results of the scattering parameters (S_{21}) of the microstrip line divider. (Dimensions: w = 1.2 mm, r = 4.8 mm, a = 32 mm, d = 25 mm. Substrate: ϵ_r = 10.5 mm, h = 1.27 mm.)

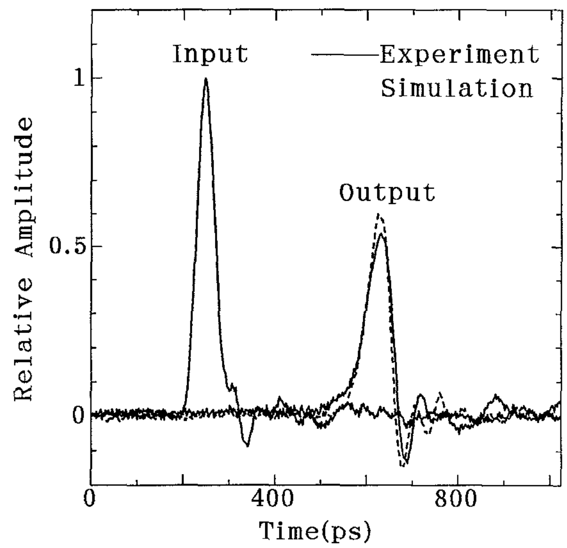

Fig. 3. Comparison of experimental and simulation results of pulse propagation through the microstrip line divider.

In simulations of pulse propagation, the input signal, $V_{\text{in}}(t)$, can either be expressed with a closed formula, such as a Gaussian pulse, or be described by a discrete series of experimental data obtained from a digital sampling oscilloscope.

III. Experiments

The microstrip line divider for experimental measurements was fabricated on the DI-CLAD 810 substrate produced by Arlon, which is 1.27-mm thick and has a dielectric constant of 10.5. All metal lines were 1.2 mm wide to obtain a matched impedance of 50 Ω. Other dimensions of the divider are same as explained in Fig. 2. The input pulse, as shown in Fig. 3, was obtained from a 22-ps rising step using a pulse-forming network [13]. The experimental system, which is similar to that described in a previous paper [12], includes a sampling oscilloscope (Textronix 11802) controlled via GPIB by a personal computer (NEC PC-9801) for data transference and processing. The sampling head (SD-30) of the oscilloscope has a frequency bandwidth of 40 GHz, which corresponds to a time resolution of 8.8 ps.

In the experiment, one of the two output ports of the divider was terminated by a 50-Ω load and the other connected to the sampling head. The measured pulse is shown in Fig. 3. Compared to the input pulse, which has a 10–90 percent risetime of 32 ps and FWHM (full width at half maximum) of 46 ps, the output pulse is expanded to have a FWHM of 58 ps and its risetime is 62 ps, nearly double that of the original pulse at the input. Computer simulation results using the same input pulse have been plotted on the same figure, and are found to be in very close agreement with the measurement results in both pulse waveform and time delay. The slight difference between the peak value of the two pulses is mainly caused by signal reflections at the two connections between microstrip lines and coaxial cables, as well as the negligence of propagation losses in the numerical analysis.

IV. Conclusion

The picosecond pulse propagation characteristics of microstrip line divider has been investigated. It is demonstrated by both computer simulations and experimental measurements that serious pulse distortion may occur after passing through a divider if it is designed without considering the extremely wide bandwidth of these ultrashort pulses. Since our theoretical analysis of pulse propagation has been proved to be quite accurate, we believe it can also be used for optimum designing of dividers with broadband performances, as well as some other components for MMIC's and high-speed devices. It should also be noted here that time-domain measurement method with ultrashort electrical pulses is very useful for testing broad bandwidth circuits and can become one of the standard measurement methods in the future.

Acknowledgment

The authors would like to thank Mr. F. Takeda and Mr. T. Takagi of Mistubishi Electric Corp. for their assistance in fabricating the microstrip line divider for experiments.

References

[1] D. H. Auston, "Probing semiconductors with femtosecond pulses," *Phys. Today*, pp. 46–54, Feb. 1990.

[2] C. H. Lee, "Picosecond optics and microwave technology," *IEEE Trans. Microwave Theory Tech.*, vol. 38, pp. 596–607, May 1990.

[3] M. Matloubian, H. Fetterman, M. Kim, A. Oki, J. Camou, S. Moss, and D. Smith, "Picosecond optoelectronic measurement of S-parameters and optical response of AlGaAs–GaAs HBT, *IEEE Trans. Microwave Theory Tech.*, vol. 38, pp. 683–686, May 1990.

[4] J. F. Whitaker, R. Sobolewski, D. K. Dykaar, T. Y. Hsiang, and G.A. Morou, "Propagation model for ultrafast signals on superconducting dispersive striplines," *IEEE Trans. Microwave Theory Tech.*, vol. 36, pp. 275–385, Feb. 1988.

[5] E. B. Ekholm and S. W. Mcknight, "Attenuation and dispersion for high-T_c superconducting microstrip lines, *IEEE Trans. Microwave Theory Tech.*, vol. 38, pp. 387–395, Apr. 1990.
[6] D. S. Phatak and A. P. Defonzo, "Dispersion characteristics of optically excited coplanar striplines: Pulse propagation," *IEEE Tran. Microwave Theory Tech.*, vol. 38, pp. 654–662, May 1990.
[7] C. Shu, X. Wu, E. S. Yang, X.-C. Zhang, and D. H. Auston, "Propagation characteristics of picosecond pulses on a periodically loaded coplanar waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 930–935, June 1991.
[8] S. Alexandrou, R. Sovolewski, H. Nakano, B. C. Tousley, and T. Y. Hsiange, "Picosecond characterization of bent coplanar waveguides," *IEEE Microwave Guided Wave Lett.*, vol. 1. pp. 236–238, Sept. 1991.
[9] P. Singkornrat and J. A. Buck, "Picosecond pulse propagation in coplanar waveguide forward directional couplers," *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 1025–1028, June 1991.
[10] L. Zhu and E. Yamashita, "Analysis method for microstrip line power dividers with arbitrary branching circuit pattern," to be presented at *IEEE MTT-S Int. Microwave Symp.*, Albuquerque, NM, June 1–5, 1992.
[11] L. Zhu and E. Yamashita, "New method for the analysis of dispersion characteristics of various planar transmission lines with finite metallization thickness," *IEEE Microwave Guided Wave Lett.*, vol. 1, pp. 164–166, July 1991.
[12] Y. X. Qian and E. Yamashita, "Phase compensation and waveform reshaping of picosecond electrical pulses using dispersive microwave transmission lines," *IEEE Tran. Microwave Theory Tech.*, vol. 39, pp. 924–929, June 1991.
[13] M. Y. Frankel, S. Gupta, J. A. Valdmanis, and G. A. Mourou, "Picosecond pulse formation by transmission line discontinuities," *Electron. Lett.*, vol. 25, pp. 1363–1365, Sept. 1989.