DISPERSION ANALYSIS OF SQUARE PULSE WITH FINITE RISE TIME IN SINGLE, TAPERED AND COUPLED MICROSTRIP LINES

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ABSTRACT

Distortion of an electrical pulse, with finite rise time (quadratic-linear-quadratic transition) caused by dispersion as it propagates along a uniform microstrip, a tapered microstrip and a coupled pair of microstrips is investigated. Closed form analysis equations for single and coupled microstrips and an algorithm for numerical quadrature technique for evaluation of inverse Fourier transform have been used. The results will be useful in the time domain analysis of many circuit components where such microstrips are used.

INTRODUCTION

Microstrips are extensively used in modern fast computers, phased array antenna feeds and in planar distributed line filters. The knowledge of time domain analysis reveals many useful facts regarding their frequency domain behavior [1]. Also, the design of MICs and MMICs requires the knowledge of switching and transient signal behavior in microstrips and other planar transmission lines.

Dispersion of dc and RF pulses in waveguides and other transmission lines have been investigated [2]-[4]. Dispersion of an ideal square pulse and Gaussian pulse have been studied [5], [6]. However, the distortions of a square pulse with finite rise time, i.e., a non ideal square pulse in non-uniform and coupled microstrips have not been studied.

A square pulse consists of an infinite number of pure sinusoids with increasing frequencies and decreasing amplitudes. Since in a microstrip the phase velocity depends on frequency, different components of a square pulse propagate at different phase velocities. This results in the distortion of a square pulse as it propagates along a microstrip line.

This paper presents the results of an analysis of a square pulse, with finite rise time, as it propagates along an exponentially tapered and a pair of uniform coupled microstrip lines.

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THEORY

The time domain representation of a pulse at a point z=L along a tapered transmission line is given by:

$$V(t,L) = \frac{1}{2\pi}\int_{-a}^{+a} \left| T(w) \right| V(w, z=0)\, e^{j(wt - \theta(w))} dw \qquad (1)$$

where t is the time and

$$T(w) = \left| T(w) \right| e^{j\theta(w)} \qquad (2)$$

is the transfer function of the tapered line, and

$$\theta(w) = \int_{0}^{L} \beta(w,z)\, dz \qquad (3)$$

is the total phase shift along the line at a radian frequency ω, and $V(\omega, z=o)$ is the Fourier transform of the pulse. Obviously for a lossless uniform microstrip

$$\left| T(w) \right| = 1 \qquad (4)$$

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The time domain representation of a square pulse with finite rise time (square-linear-square transition), shown in Figure 1 is given by [7].

$$V(t, z=0) = \begin{cases} 1 & 0<t<T_1 \\ 1-a(t-T_1)^2 & T_1<t<T_1+q\tau_1 \\ bt+e, & T_1+q\tau_1<t<\tau-q\tau_1 \\ a(t-\tau)^2, & \tau-q\tau_1<t<\tau \\ 0 & t>\tau \end{cases} \quad (5)$$

$$a = \frac{-1}{2a(1-q)\tau_1^2}, b = \frac{-1}{(1-q)\tau_1}, e = \frac{2\tau - q\tau_1}{2(1-q)\tau_1}$$

$$V(w, z=0) = \frac{8}{q(1-q)\tau_1^2} \frac{sin\left[(\tau - \frac{\tau_1}{2})w\right] sin\left[\frac{q\tau_1 w}{2}\right] sin\left[\frac{(1-q)\tau_1 w}{2}\right]}{w^3} \quad (6)$$

The voltage transfer function of a tapered transmission line can be written as [8] (see Figure 2)

$$T(w) = \left[1 - \frac{1}{4}\left\{ln\frac{Z_L}{Z_a} F\left(\theta(w)\right)\right\}^2\right]^{\frac{1}{2}} e^{-j\theta(w)} \quad (7)$$

Where $F(\theta(\omega))$ depends upon the taper profile. As an example, for an exponential taper

$$F\left(\theta(w)\right) = \frac{Sin\left(\theta(w)\right)}{\theta(w)} \quad (8)$$

For a pair of microstrip lines, shown in Figure 3, the response to a single signal in line 1 and no excitation to line 2 is given by:

$$V_1(t,z) = \frac{1}{2}\left[V_e(t,z) + V_O(t,z)\right] \quad (9a)$$

$$V_2(t,z) = \frac{1}{2}\left[V_e(t,z) - V_O(t,z)\right] \quad (9b)$$

where $V_e(t,z)$ and $V_o(t,z)$, the even and the odd mode time domain excitations respectively, are obtained by the above method described for a single microstrip line.

In the above equations, the propagation constants are computed by using the accurate closed-form equations [9], [10].

RESULTS

The distortion of a non ideal pulse of width 250 ps travelling a distance of L=25.4 mm along a tapered microstrip with =10.5, h=0.635 mm is shown in Figure 4 for various values of impedance transformation ratios. It is apparent that major distortion peaks along the leading and the trailing edges of the pulse have been created. Figure 4a effectively shows the results for a uniform microstrip line. Comparing the present results with those of zero rise time case in [5], it can be concluded that the amplitudes of the distortion peaks are dependent on the time lengths of the quadratic and the linear regions of the undistorted pulse.

Figure 5 shows the pulse response of a coupled pair of uniform microstrip lines. The even and the odd-mode pairs of pulses add constructively on the signal line and destructively on the sense line.

As signals first start out, the even and the odd pairs separate from each other due to their different phase velocities. What has been shown in Figure 5 is the difference of the separated signals in the sense line and the sum in the signal line.

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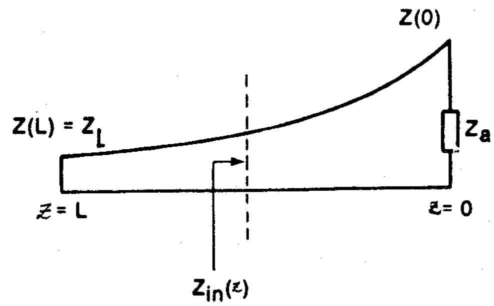

FIGURE 2: Tapered Transmission Line

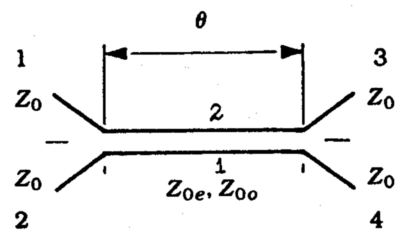

FIGURE 3: Coupled Lines

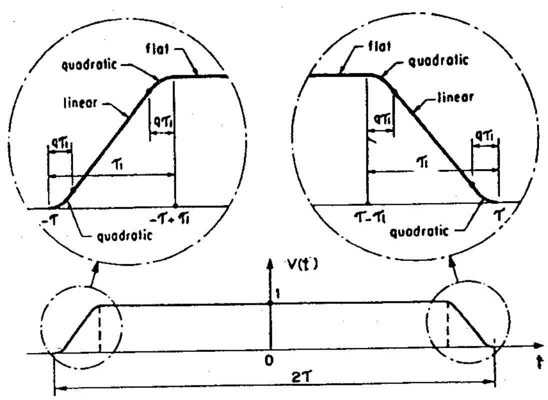

FIGURE 1: Square Pulse with Finite Rise Time

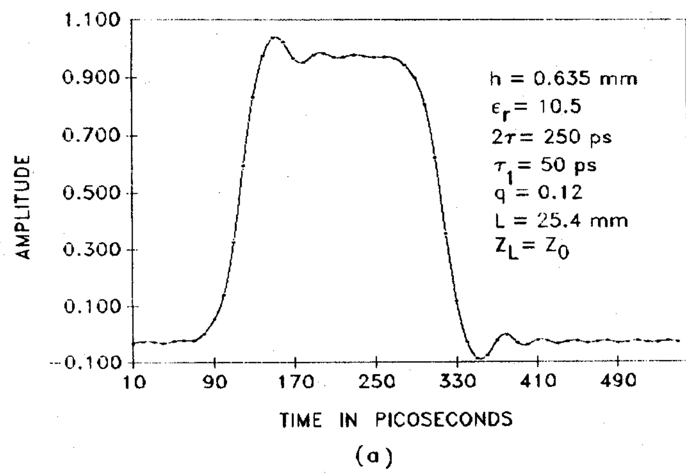

FIGURE 4. Response of tapered microstrips

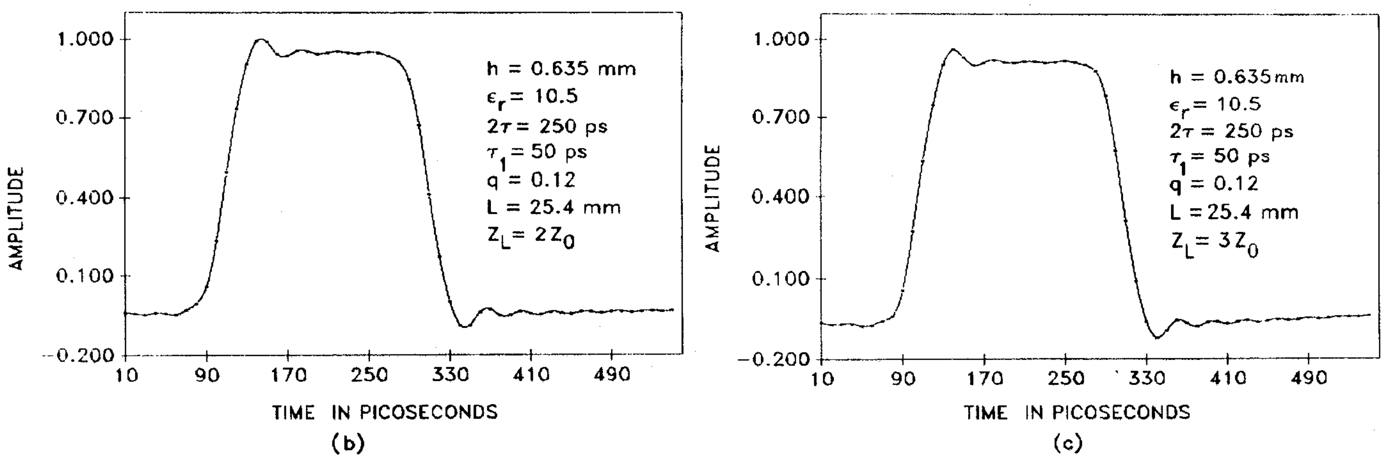

FIGURE 4. Response of tapered microstrips

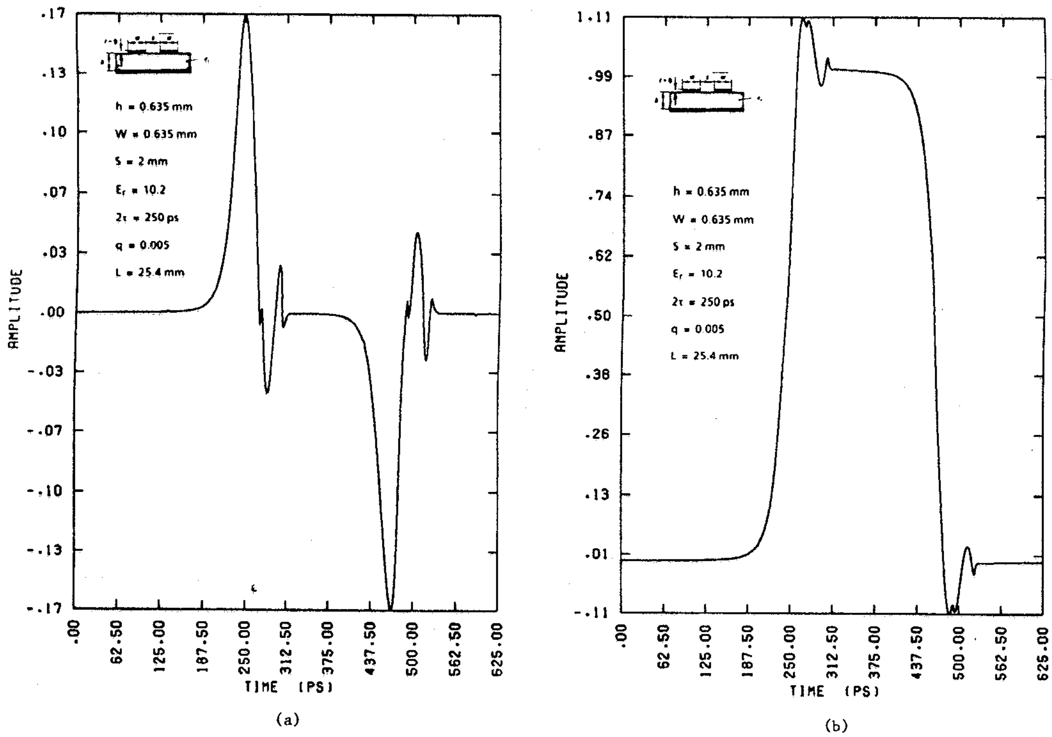

Figure 5: Response of Coupled Microstrip - (a) Difference (b) Sum