Theoretical and Experimental Evaluation of Picosecond Pulse Propagation in Suspended Coplanar Waveguides

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ABSTRACT

The propagation and dispersion characteristics of picosecond pulses in a suspended coplanar waveguide(SCPW) are presented. An evaluation based on numerical analysis shows that the SCPW can result in an improvement of about 5 times in pulse transmission capability than conventional CPWs. Pulse propagation along the SCPW is studied by both simulations and experiments, both showing a substantial suppression in pulse distortion.

INTRODUCTION

The continued progress in millimeter-wave integrated circuits and high-speed digital circuits has led to great advances in the field of ultrafast electronics[1]. Electrical pulses with picosecond durations are now routinely available, and can be accurately characterized with electro-optic (EO) or photoconductive (PC) sampling techniques[2]. On the other hand, however, the development of transmission structures capable of handling the extremely wide bandwidth of these pulses still remains an important issue, which requires a full understanding of the mechanisms of pulse distortion, including modal dispersion, conductor and dielectric losses, radiations, material resonances and some other factors. These problems have been studied extensively by a number of researchers during the recent years[3]-[6].

In a previous paper[7] we proposed the structural control of the dispersion characteristics of microstrip lines by adding parallel conductors on both sides of the strip conductor. Continued investigation into this dispersion control effect and the properties of pulse propagation in these dispersion-controlled transmission lines has been made. In particular, the modal dispersion of a suspended coplanar waveguide (SCPW) has been studied and turned out to have a much higher cutoff frequency compared with conventional coplanar waveguides(CPWs) fabricated on the same dielectric substrate[8]. In this paper we report for the first time the simulation and experimental results of pulse propagation along the SCPW. An evaluation based on numerical analysis is also presented, which shows an improvement of up to 5 times in the pulse propagation capability compared with conventional CPWs.

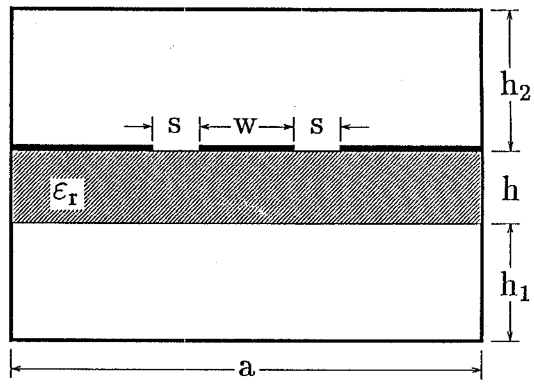

Fig. 1. Cross-sectional view and geometry of the suspended coplanar waveguide (SCPW).

DISPERSION CONTROL OF CPWs

The cross-sectional view of a suspended coplanar waveguide (SCPW) with a metallic shielding enclosure is shown in Fig. 1. The spectral domain approach(SDA)[9] has been used to obtain the dispersion characteristics of this structure. Figs. 2 and 3 show the numerical results of the dispersion characteristics of several coplanar waveguides with different geometries and dimensions. The curves, A_1 and A_2, in Fig. 2 show the propagation constant of two con-

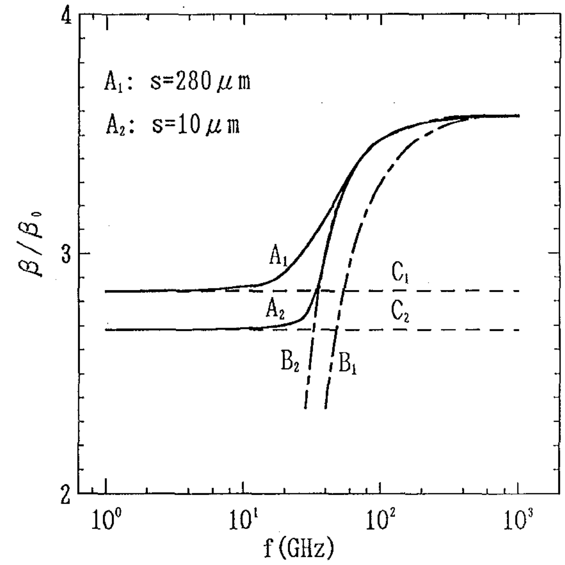

Fig. 2. Comparison of the dispersion properties of two shielded coplanar waveguides with different slot widths. (Other parameters: $w = 0.14mm, a = 2mm, h_1 = 0, h = 0.2mm, h_2 = 2mm, \varepsilon_r = 12.9$)

ventional CPWs($h_1 = 0$) with different slot widths, $s = 280\mu m$ and $s = 10\mu m$, respectively. When the slot width is very small, the field energy is highly concentrated in the two gap regions, and the field patterns corresponding to the quasi-TEM mode(curve C_2) and the dominant slotline mode(curve B_2) are almost orthogonal to each other. As a result, the transmission line is less dispersion at lower frequencies and experiences an abrupt rising in the propagation constant when reaching a certain frequency.

In order to make the transmission line free of dispersion in a wider range of frequencies, we add an air layer beneath the dielectric substrate to form a suspended coplanar waveguide(SCPW). The advantage of making the CPW suspended is that the corresponding finline structure has a relatively wide single-mode bandwidth as it resembles the ridged waveguide. Fig. 3 shows a comparison of the dispersion properties of a conventional CPW (A_1) and a SCPW (A_2). Assuming the same dielectric substrate($200\mu m$ GaAs), center strip width($140\mu m$) and slot width($10\mu m$), we find that the SCPW can be used in a frequency range near to 100GHz, which is several times broader than that of the conventional CPW.

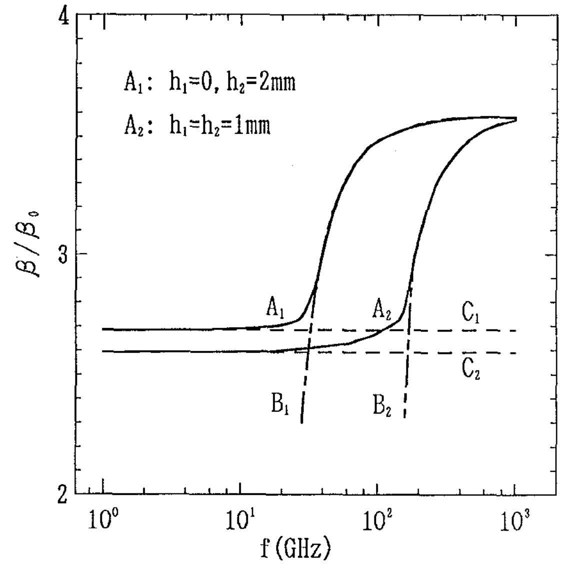

Fig. 3. Comparison of the dispersion properties of a conventional CPW (A_1) and a SCPW (A_2) . (Other parameters: $w = 0.14mm, a = 2mm, h = 0.2mm, s = 10\mu m, \varepsilon_r = 12.9$)

SIMULATIONS OF PULSE PROPAGATION

Fig. 4 shows computer simulation results of the propagation of a Gaussian pulse along the three coplanar waveguides described above. The algorithm is the same as that described in a previous paper[10]. In Fig. 4(a) and (b), both pulses are strongly distorted after a propagation distance of several millimeters. More oscillation ringings are observed in Fig. 4(b), which is due to the abrupt dispersion of the CPW with narrow slot width($s = 10\mu m$). On the other hand, the SCPW structure is almost dispersion-free up to about 100GHz. As a result, the 10ps input pulse is only slightly distorted even after a propagation distance of 10mm(Fig. 4(c)).

To offer a further comparison of the pulse propagation capability of the abovementioned coplanar waveguides, we make an approximate evaluation of the minimum pulsewidth which can be supported on these transmission lines. For a Gaussian pulse with FWHM of τ, if we define $f_{0.1}$ as the frequency where the amplitude of its Fourier spectral component is 10 percent of the peak value, we obtain

$$f_{0.1} = \frac{2\sqrt{\ln 2 \cdot \ln 10}}{\pi \tau} \quad (1)$$

We further define f_{TEM} as the frequency where the propagation constant, β, is 3 percent larger than β_{TEM}, which

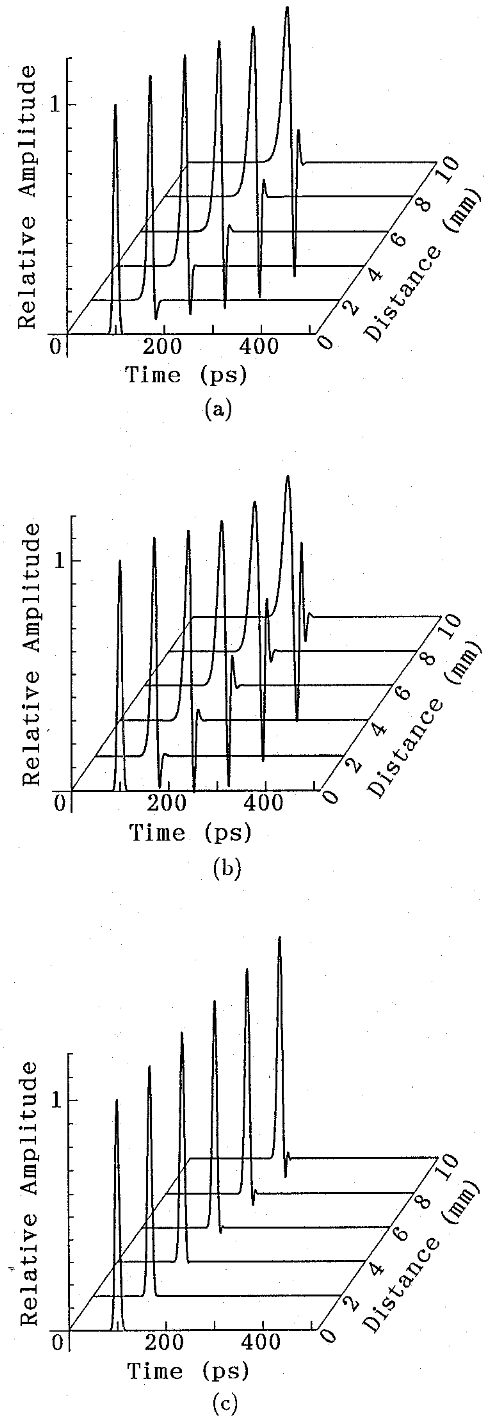

Fig. 4. Computer simulation results of the propagation of a 10 ps Gaussian pulse along three types of transmission lines: (a) a CPW with $s = 280\mu m$, (b) a CPW with $s = 10\mu m$ and (c) a SCPW with $h_1 = h_2 = 1mm$ and $s = 10\mu m$. (Other parameters: $w = 0.14mm, a = 2mm, h = 0.2mm, \varepsilon_r = 12.9$)

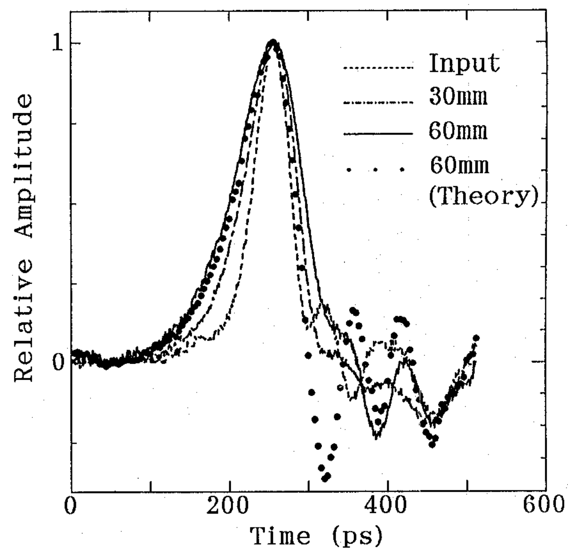

Fig. 5. Experimental(lines) and simulation(dots) results of pulse propagation along a conventional CPW($w = 1.2mm, s = 2mm, a = 20mm, h_1 = 0, h = 1.27mm, h_2 = 5.4mm, \varepsilon_r = 10.5$)

can be derived as follows[10]

$$f_{TEM} = \left(\frac{\sqrt{\varepsilon_r} - 1.03\beta_{TEM}/\beta_0}{0.03a\beta_{TEM}/\beta_0}\right)^{-1/b} f_{TE} \quad (2)$$

where a and b are coefficients obtained by curve-fitting the dispersion data calculated with the numerical method. Since 99 percent of the pulse energy is contained in frequencies less than $f_{0.1}$, we may regard that the pulse will propagate with negligible dispersion if $f_{0.1}$ does not exceed f_{TEM}. We thus obtain the minimum FWHM of the pulse as follows

$$\tau_{min} = \frac{2\sqrt{\ln 2 \cdot \ln 10}}{\pi f_{TEM}} \quad . (3)$$

For the CPW with $s = 280\mu m$ in Fig. 2 and the SCPW in Fig. 3, the minimum pulsewidth, τ_{min}, is calculated to be 49.3ps and 10.6ps, respectively, which shows an improvement of near to 5 times in the pulse propagation capability of the transmission line.

EXPERIMENTAL RESULTS

Figs. 5 and 6 present some experimental results of the propagation of a Gaussian-like pulse along a conventional CPW and a SCPW we fabricated and measured on a digital

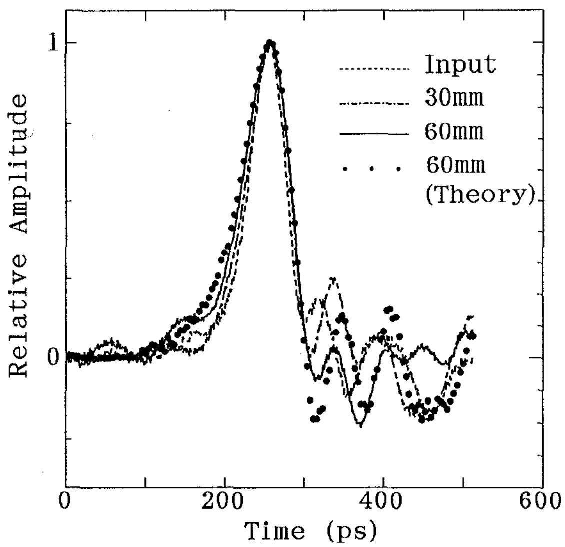

Fig. 6. Experimental(lines) and simulation(dots) results of pulse propagation along a SCPW($w = 1.2mm, s = 0.5mm, a = 20mm, h = 1.27mm, h_1 = h_2 = 2.7mm, \varepsilon_r = 10.5$)

sampling oscilloscope (Tektronix 11802). The input pulse has a rise time of 58ps and FWHM of 52ps. The time delay and amplitude of the signals have been normalized for easy comparison of the waveforms. Since the CPW structure is strongly dispersive in the frequency bandwidth of the input signal, a considerable distortion in the pulse waveform is observed in Fig. 5 as it travels along the line. At a distance of 60mm, the pulse has a rise time of 113ps and FWHM of 96ps. For the case of the SCPW(Fig. 6), however, the rising edge of the pulse remains almost unchanged throughout the distance of propagation, and the FWHM of the pulse is slightly expanded(65ps) after a propagation distance of 60mm. Computer simulation results of the pulse waveform are also plotted for comparison. Although some discrepancies exist due to signal reflections at the connectors and from the bottom side of the SCPW, the measured pulses are in reasonable agreement with theoretical predictions, and an appreciable suppression effect of pulse distortion with the SCPW has been confirmed.

CONCLUSIONS

In this paper we have investigated the propagation and dispersion of picosecond pulses along suspended coplanar waveguides(SCPWs) by simulations as well as experiments, both revealing a substantial improvement in the pulse propagation capability. We conclude that the SCPW should be a very promising transmission structure for ultrashort pulses with picosecond and subpicosecond durations.

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