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THE FEATURE OF THE NARROW-PULSE TRANSMISSION ON CONVENTIONAL COPLANAR WAVEGUIDES WHEN POWER LEAKAGE IS PRESENT

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Abstract

We investigate the feature of the wave-form deformation and the unexpected cross talk caused by the effect of the dominant-mode power leakage that most of printed-circuit waveguides reveal, when narrow pulse is transmitted. Numerical examples for conventional coplanar waveguides prove that such a feature has serious influence on high-speed circuit design.

I. INTRODUCTION

We report here a new feature of the wave-form deformation and the unexpected cross talk when a narrow pulse is transmitted on the conventional coplanar wave-guides (CPW). The causes of such a new feature are that the standard, well-known dominant mode on conventional CPW becomes leaky above a certain critical frequency and also that CPW possesses another type of dominant mode below that frequency. Especially, the leakage effect appears on most of printed-circuit waveguides at higher frequencies, so that the investigations on such a new feature of the narrow-pulse transmission are important when millimeter-wave integrated circuits and high-speed circuits are designed.

It was not generally known until our recent work[1-2] that above a certain critical frequency the dominant mode on printed-circuit waveguides (of which a conventional CPW shown in Fig.1 is one example) leaks power into a surface wave on the outer portions of the waveguide or the support structure. Away from the central region of the CPW of Fig.1 we have a grounded dielectric layer of height equal to that of the substrate, on which the lowest surface wave is the TM_0 mode. Leakage then occurs above the frequency at which the dispersion curve for the standard CPW dominant mode touches that of the TM_0 surface wave, and the power leaks at an angle to the guide axis in the form of the TM_0 surface wave. In an integrated circuit context, this leakage can result in a serious pulse-waveform deformation and also a significant cross talk with neighboring circuits. Of course, the power leakage reflects to the transmission loss of the CPW itself.

The CPW of Fig.1 consists of three conductors, so that it possesses two dominant modes of open-circuit-bisection symmetry. One of them is the standard CPW dominant mode, of course. The second dominant mode is new in the sense that it has recently been identified by us[3] for the first time. This new mode that we were calling it the "CPW surface-wave-like (SWL) mode" is a type of bound surface wave on a structure composed of a dielectric layer on which the ground plane is of infinite width, and has gaps in the metal. The conventional CPW supports this CPW-SWL mode as a bound mode below the critical frequency of leakage[3].

It becomes now clear that the conventional CPW supports essentially two dominant modes below a critical frequency and also a leaky mode above that frequency. (The analytical continuity of solutions in the mode-transition region and associated problems are discussed in detail in [3] and also an accompanied paper[4] to be presented at this symposium.) Therefore, when a narrow pulse, already now in subpicosecond range, thus spreading very widely in the frequency spectrum, is launched to a uniform length of such a CPW or its circuits including junctions and discontinuities, the low-frequency spectral part of the pulse will be affected complicatedly by the mutual interaction between two dominant modes, while the high-frequency spectral part suffers the power-leakage effect, as the pulse travels. Then we can expect that these effects cause some inevitable deformation on the narrow-pulse shape. In addition, the leaky field in the high-frequency spectral part, which spreads out on the surrounding dielectric substrate, produces a serious dynamic coupling or cross talk with neighboring lines or circuits. This paper discusses for the first time such possible problems associated with the narrow-pulse transmission on the conventional CPW.

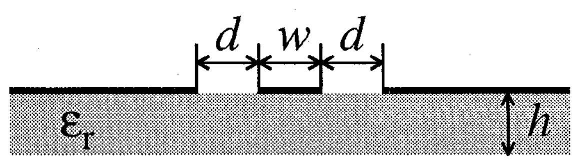


Fig.1. Cross-section view of conventional coplanar waveguide of infinite width.

We have made calculations of the properties associated with the narrow-pulse transmission, for several different structures, by means of the finite-difference time-domain (FD-TD) method. However, the conventional excitation used in this method always accompanies unwanted radiation fields in the form of the TM_0 surface wave. This unwanted wave has the same nature with that of the leaky wave. Therefore, we must devise a special scheme for the mode launching when this method is applied to leaky waveguides. This new scheme is not explained here due to space limitations and will be presented in the session. The next section contains some examples from those calculations.

II. TYPICAL RESULTS

A. Field Distributions Peculiar to The Narrow-Pulse Transmission

As mentioned above, the conventional CPW is characterized by the two dominant-mode operation at low frequencies and also by the power leakage at high frequencies. An example of such a complicated dispersion behavior is shown in Fig.2, which is calculated by the modified spectral-domain method when h=1.6 mm. For that guiding structure, we launch here two kinds of the Gaussian pulse at one end of the CPW (z=0); this point is 4 mm away from the launching end. The electric field is applied horizontally only between edge points of the center conductor and the outer infinite plates, but oppositely in the direction in both slits, to excite predominantly the standard CPW dominant mode. The special launching scheme in calculations is, of course, applied. Fig.3(a) shows the field plot of the E_y component just on the xz plane at y=0 after traveling 20 mm in length, when a wide Gaussian pulse (with the half-power width of 16.4 *psec*) is launched; its spectral intensity spreads in the narrow half-power range from 0 to 13.4 GHz. This frequency range corresponds to the normalized frequency range given by $0<h/\lambda_0<0.07$ in Fig.2. The CPW structure under consideration exhibits the leakage effect above the critical frequency 49.2 GHz (h/λ_0=0.26). Therefore, we can expect that this wide pulse suffers from negligible leakage effect. Indeed, the field of the launched pulse travels the distance 20 mm, being bound to the waveguide, as it is ordinarily believed.

On the other hand, when we launch a narrow Gaussian pulse with the half-power width of 3.6 *psec*, of which spectral intensity spreads from 0 to 62 GHz ($0<h/\lambda_0<0.33$) in the half-power range, a part of the power carried by the high frequency spectra leaks into the outer substrate region in the form of the TM_0 surface wave as mentioned above, accompanying the unbound field peculiar to the leaky wave on the substrate. Fig.3(b) shows the plot at the same distance z=20 mm, and offers certainly a clear picture for the field of such a leaking narrow pulse.

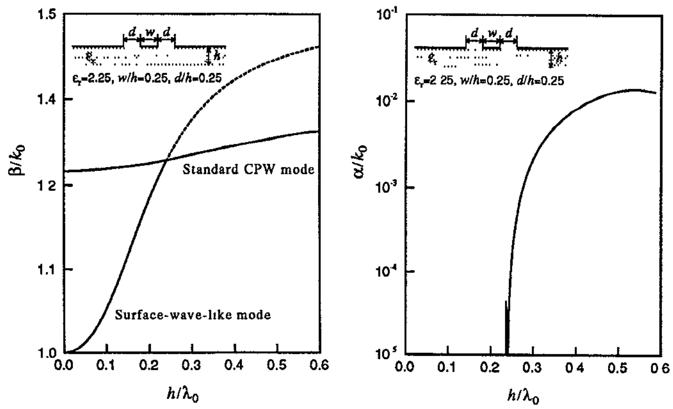
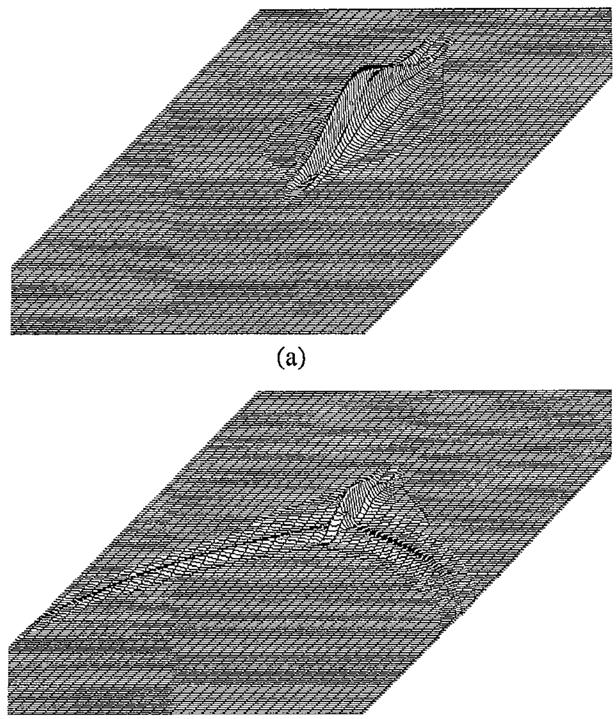


Fig.2. The behavior of the normalized phase constant β/k_0 and the normalized leakage constant α/k_0 with normalized frequency h/λ_0 for coplanar waveguide of infinite width.



(a)

(b)

Fig.3. Electric-field distribution on the xz plane at z=0. These plots show the E_y component when a Gaussian pulse travels 20 mm in length on the CPW of infinite width: (a) the wide pulse with the half-power width of 16.4 psec (the frequency spectrum spreads in the narrow half-power range from 0 to 13.4 GHz); and (b) the narrow pulse with 3.6 psec width, corresponding to the half-power range from 0 to 62.5 GHz, which accompanies clearly the leaking field.

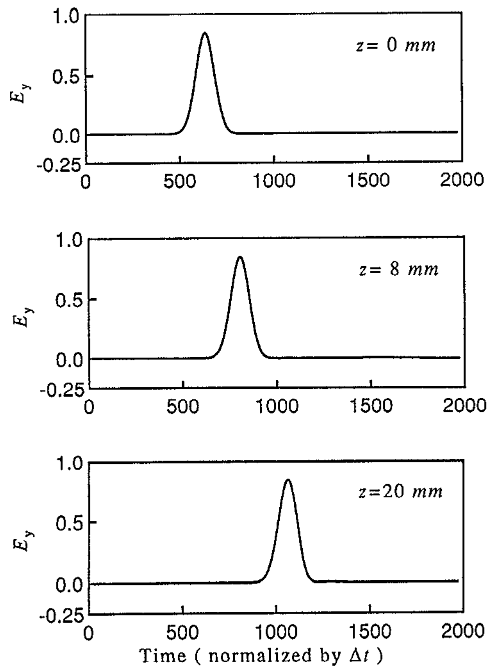


Fig.4. Pulse-shape history as the wide pulse with 16.4 psec time width travels along a uniform CPW. The top shows the pulse shape on the reference plane; z=0, while the middle and the bottom show the pulse shapes after traveling the distances 8 mm and 20 mm, respectively (Δt=0.2 psec).

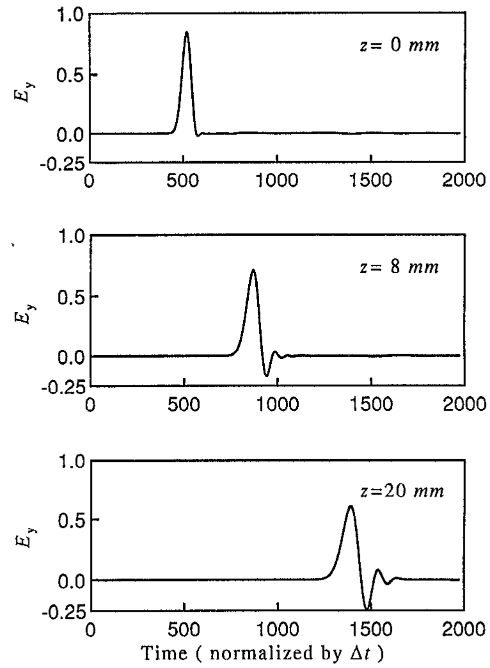


Fig.5. Pulse-shape history as the narrow pulse with 3.6 psec time width travels along a uniform CPW. The top shows the pulse shape on the reference plane; z=0, while the middle and the bottom show the pulse shapes after traveling the distances 8 mm and 20 mm, respectively (Δt=0.2 psec).

B. The Subpicosecond-Pulse Deformation

Fig.4 shows the pulse-shape history as the relatively wide pulse used in Fig.3(a) travels along the uniform conventional CPW with the dispersion characteristics indicated in Fig.2. The top shows the pulse shape on the reference plane, z=0 mm; this point is 4 mm away from the launching end, while the middle and the bottom show the pulse shapes after traveling the distances 8 mm and 20 mm, respectively. We can understand that although these pulses are affected by the dispersive characteristics of two dominant modes and negligibly by the leakage effect, the effect of the CPW-SWL mode is insignificant because of the scheme of the present pulse excitation. Therefore, the wide pulse results in a negligible deformation in the pulse shapes.

On the other hand, Fig.5 shows the pulse history similar to Fig.4, for the narrow pulse used in Fig.3(b). The deformation is certainly significant and serious, and its main cause is, of course, the leakage effect. Inspection of Figs.4 and 5 reveals this fact.

C. Dynamic Coupling or Cross Talk

We next show the feature of the narrow-pulse transmission, viewing from the angle of the dynamic coupling with neighboring circuits. As mentioned above, a part of the power carried by the high-frequency spectra leaks inevitably in the form of the TM_0 surface wave, when a narrow pulse travels on the CPW. This surface wave spreads out on the whole area of the substrate as the pulse travels along the CPW axis, so that the leaking surface wave can couple dynamically to neighboring circuits, even if they are enough distance beyond the reactive-coupling distance. Of course, neighboring circuits must have discontinuities in appropriate forms to produce such a dynamic coupling.

A numerical model is shown in Fig.6, where a short end of neighboring CPW circuits is close to the main CPW, on which the narrow pulse used in Fig.3(b) travels along the z direction, accompanying the leakage field which consists of only the high-frequency spectral part of the main pulse. Therefore, the dynamic coupling occurs, and the time-derivative Gaussian pulse will begin to propagate to the x direction on the sub CPW. A typical example of the field intensity distribution is shown in Fig.7, where we can see clearly the dynamically coupled filed on the sub CPW, which produces an unexpected cross talk. Fig.8 shows the coupled pulse-shape history as the narrow pulse used in Fig.3(b) travels along the uniform conventional CPW with the dispersion characteristics indicated in Fig.2. The new type of coupling mentioned here is serious when high performance, high-speed integrated circuits are designed.

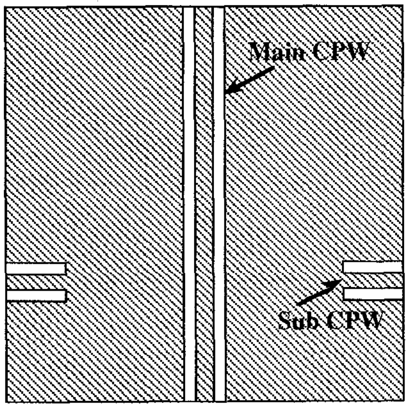


Fig.6. Numerical model for investigating the dynamic coupling due to leaky wave, where a shorted end of neighboring CPW circuits is close to the main CPW, but is enough distance beyond the reactive coupling distance.

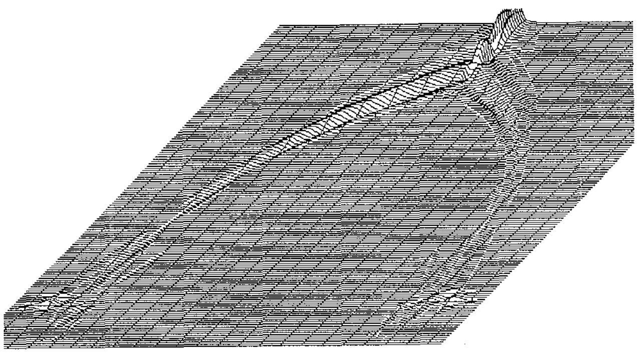


Fig.7. Electric-field distribution of dynamically coupled pulse while the narrow pulse shown in Figs.3(b) and 5 travels along the main CPW.

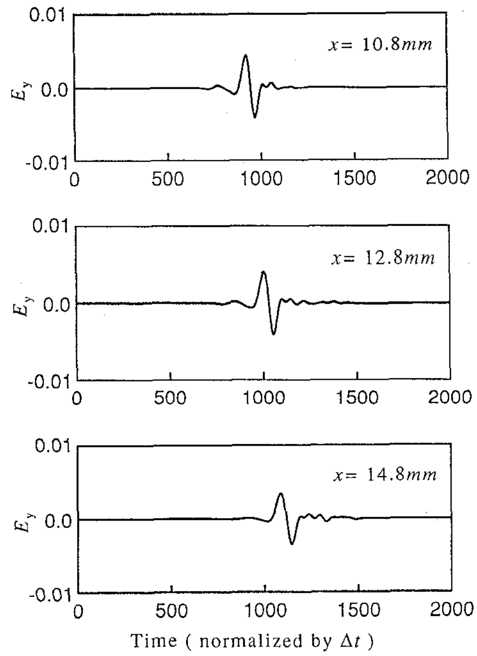


Fig.8. Pulse-shape history of the dynamically coupled pulse with the neighboring CPW. This pulse is excited by the leaked field of the main pulse. The spectrum of the coupled pulse is consisted of only the high frequency component of the spectrum of the main Gaussian pulse, so that the coupled pulse has the time-derivative shape of it.

Therefore, our presentation will explain this type of coupling in more detail, viewing from both physical and experimental standpoints.

III. CONCLUSIONS

It has been shown in this paper for the first time that the conventional CPW deforms seriously the transmitting pulse shape when the pulse width becomes narrower toward the subpicosecond range or more. This result is explained by the leakage effect inevitable to the conventional CPW at high frequencies, and is clearly shown by Figs.4 and 5.

In connection with this leakage effect, we have pointed out one more serious problem in an integrated circuit context. It is the inevitable dynamic coupling of pulse power to the neighboring circuits. Example results shown in Figs.7 and 8 have revealed this type of coupling. These results mentioned here are quite useful to understand the feature of the narrow-pulse transmission in its right perspective.

ACKNOWLEDGMENT

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