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COMPARATIVE STUDIES OF DISCONTINUITIES IN SINGLE AND DOUBLE LAYERED CONDUCTOR-BACKED COPLANAR WAVEGUIDES

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ABSTRACT

Comparative studies of discontinuities in conductor-backed coplanar waveguides (CBCPWs) with single and double layered dielectric substrates are implemented by using the FDTD method. Frequency dependence of the scattering parameters and losses associated with a variety of discontinuities are investigated, with emphasis on the comparison between the loss characteristics of the studied two types of CBCPWs. The presented results indicate clearly that losses associated with discontinuities in non-leaky coplanar (NLC) waveguides [8] are significantly smaller than those in conventional CBCPWs over a certain frequency range. The leakage control theory of NLC waveguides [8] is examined in all of the three-dimensional discontinuities under consideration, and the application potential of NLC waveguides at high frequencies is validated.

INTRODUCTION

Coplanar waveguide (CPW) structures offer an attractive alternative to conventional microstrip lines in high-frequency applications due to many appealing properties. These include low dispersion, high flexibility in the design of characteristic impedance, and ease of connecting shunt lumped elements, or devices without using via holes, etc. [1][2]. In addition to these advantages, a conductor-backed coplanar waveguide (CBCPW), as shown by Fig. 1, provides superior mechanical strength and heat sinking capabilities in comparison with CPWs. Moreover, the conductor-backing is particularly useful for multilayered integrated circuits and phased arrays [3] because it provides the required electrical isolation between different circuit levels.

On the other hand, the presence of conductor backing causes leakage of power in the transverse direction due to the excitation of parallel plate modes supported by the infinitely extended parallel plates [4]. This type of leakage may produce unwanted cross talk between neighboring parts of a circuit and unexpected package resonance effects, jeopardizing the use of CBCPW as a transmission line.

A number of research works have indicated that losses in planar transmission line structures caused by surface wave leakage can be alleviated by the use of multilayer dielectric substrates [5]-[7]. It was demonstrated by Liu and Itoh [8] that the surface wave leakage occurring in CBCPWs can be eliminated over a certain frequency range by the introduction of an additional dielectric layer with appropriately chosen geometry. One of the non-leaky coplanar (NLC) waveguide structures, proposed by [8], employs an additional dielectric layer in the substrate, as shown by Fig. 2. This structure is of particular interest because existing uniplanar techniques can be fully utilized.

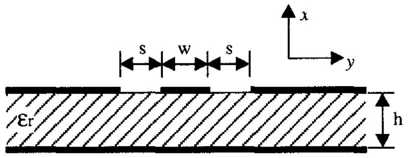

Figure 1: Cross section of a conductor-backed coplanar waveguide (CBCPW) with a single layered dielectric substrate.

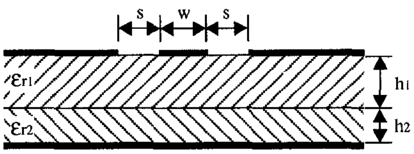

Figure 2: Cross section of a conductor-backed coplanar waveguide (CBCPW) with a double layered dielectric substrate.

The expected potential use of NLC waveguides at high frequencies propels research on NLC waveguides and circuits [9]. Although a large number of publications pertaining to conventional CBCPWs are available, there is little data and design guidelines for NLC waveguides. Therefore, research works on NLC waveguide structures are in demand.

In this paper, comparative studies of discontinuities in two types of CBCPWs are implemented by using the finite-difference time-domain (FDTD) method. One is the conventional single layered CBCPW, whose cross section is illustrated in Fig. 1. The other is the so-called NLC waveguide with a double layered dielectric substrate, as shown by Fig. 2. Scattering parameters of typical discontinuities, like gaps and steps in the center conductor of these CBCPWs, are investigated over a wide frequency range. Special consideration is given to the frequency-dependent loss characteristics of the studied discontinuities. The presented results indicate clearly that losses associated with discontinuities in NLC waveguides are significantly smaller than those in conventional CBCPWs over a certain frequency range. The leakage control theory of NLC waveguides, reported by [8] for two-dimensional uniform

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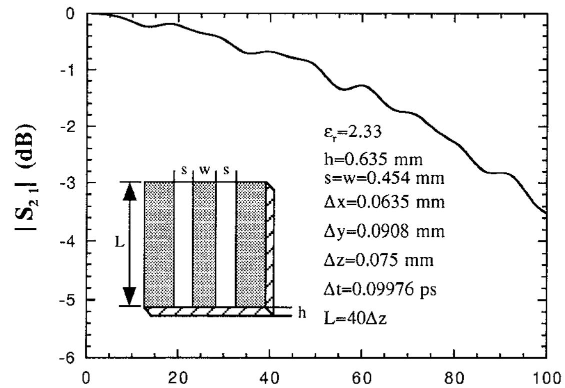
CBCPWs, is examined in the three-dimensional discontinuities under considerations.

NUMERICAL RESULTS AND DISCUSSIONS

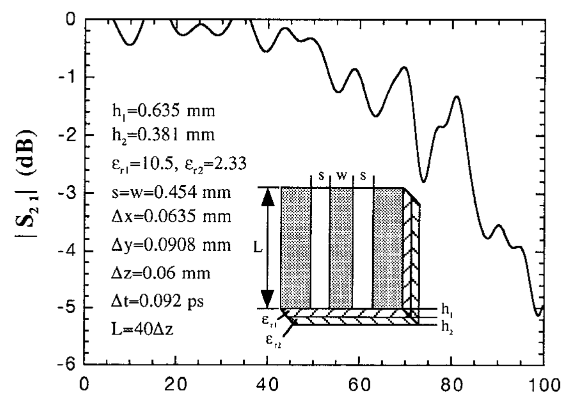
The FDTD method using Yee's orthogonal cells and Mur's second order absorbing boundary condition [10] has been implemented and its validity carefully verified for all the structures simulated in this paper. At first, uniform CBCPWs with single and double layered dielectric substrates are analyzed. Structural parameters of the two CBCPWs are given by the insets in Figs. 3(a) and (b). These parameters are chosen to be close to those of examples in [8], so that the guidance and leakage characteristics of the lines are known. Transmission coefficients of these CBCPWs are calculated and illustrated in Figs. 3(a) and (b). It is seen that in the case of the single layered CBCPW, the value of the transmission coefficient starts decaying at low frequencies, and continues to decay with the increase of frequency, indicating larger loss of power at higher frequencies. Such a frequency dependence of the transmission coefficient is expected for the conventional CBCPW, due to the existence of a parallel plate mode which has no cutoff frequency and produces leakage of power throughout the whole frequency range.

The transmission coefficient of the double layered CBCPW (NLC waveguide) demonstrates quite a different variation with frequency, as shown by Fig. 3(b). Its amplitude oscillates in the vicinity of unity at frequencies lower than approximately 46 GHz, after which rapid decay is encountered at higher frequencies. This phenomena agrees well with the result of [8], where it was found that the double layered NLC waveguide becomes leaky when $f > 46.5$ GHz. Ripples appearing in the curve of Fig. 3(b) are mainly caused by the reflections of fields at the Mur's absorbing boundaries placed around the CBCPW for defining a limited computational domain.

Visualization of surface wave leakage control phenomena occurring in NLC waveguides can be accomplished by plotting the spatial distribution of electromagnetic fields in the NLC waveguides. For this purpose, two Gaussian pulses with different widths are chosen as the launching sources of the waveguides. First, a narrow Gaussian pulse with a spectrum wider than 100 GHz is selected. The spatial distributions of the electric field component normal to the metal surfaces in a plane just beneath the upper metallization layer of the CBCPWs are shown in Figs. 4(a) and (b), respectively, for the single layered and double layered CBCPWs discussed above. In both cases, surface waves going outwards from the center conductors of the CBCPWs are clearly observed. This is expected since the spectrum of the excitation spans over 100 GHz, and the high frequency parts of the signal are leaky in both the single and double layered CBCPWs. A wider Gaussian pulse with a useful spectrum in the range of $0 < f < 40$ GHz is then utilized as the excitation. This time, the propagating surface wave is only visible in the field distribution of the single layered CBCPW, as shown by Fig. 4(c). No surface wave is observed in the field distribution of the double layered CBCPW, as shown by Fig. 4(d), because, as we have discussed above, the double layered CBCPW is non-leaky at frequencies lower than 46 GHz.



(a)



(b)

Figure 3: Frequency dependence of the transmission coefficients of, (a) a single layered CBCPW, and (b) a double layered CBCPW.

Scattering parameters of gaps in the center conductors of the two types of CBCPWs are presented in Figs. 5(a) and (b). It is seen that variation patterns of the scattering parameters are primarily the same in both cases, with some differences in the amplitudes of the scattering parameters. Frequency dependence of the loss factors, defined as $|S_{11}|^2 + |S_{21}|^2$, of the gaps is illustrated in Fig. 6. We observed that the loss factor of the single layered CBCPW, indicated by the dashed line, decreases over the whole frequency range. In contrast, the loss factor of the double layered CBCPW remains a large value at frequencies up to approximately 47 GHz, and drops sharply at about $f = 47$ GHz. At frequencies higher than 47 GHz, the loss factors of the two structures are of the same order, as can be seen from Fig. 6.

Finally in Figs. 7 and 8, scattering parameters and loss factors of double steps in the center conductors of the two types of CBCPWs are provided. Again similar variation in behaviors of the scattering parameter curves is found in the last two structures. The interesting leakage control phenomena is verified once again by the loss factor curves in Fig. 8 for double step discontinuities.

CONCLUSIONS

Comparative studies of discontinuities in single layered and double layered CBCPWs have been performed by using the FDTD method. Frequency dependence of scattering parameters and loss factors are presented for representative discontinuities, including gaps and steps in the center conductors of the CBCPWs. Special consideration is given to the loss characteristics of the two types of CBCPWs under investigation. Visualization of surface wave leakage control phenomena occurring in NLC waveguides is realized by comparing the spatial field distributions in the single layered and double layered CBCPWs excited by a narrow and a wide pulse, respectively. The leakage control mechanism in NLC waveguides is confirmed by the low-loss property of all of the three-dimensional discontinuities studied in this paper, and this encourages high-frequency application of NLC waveguides.

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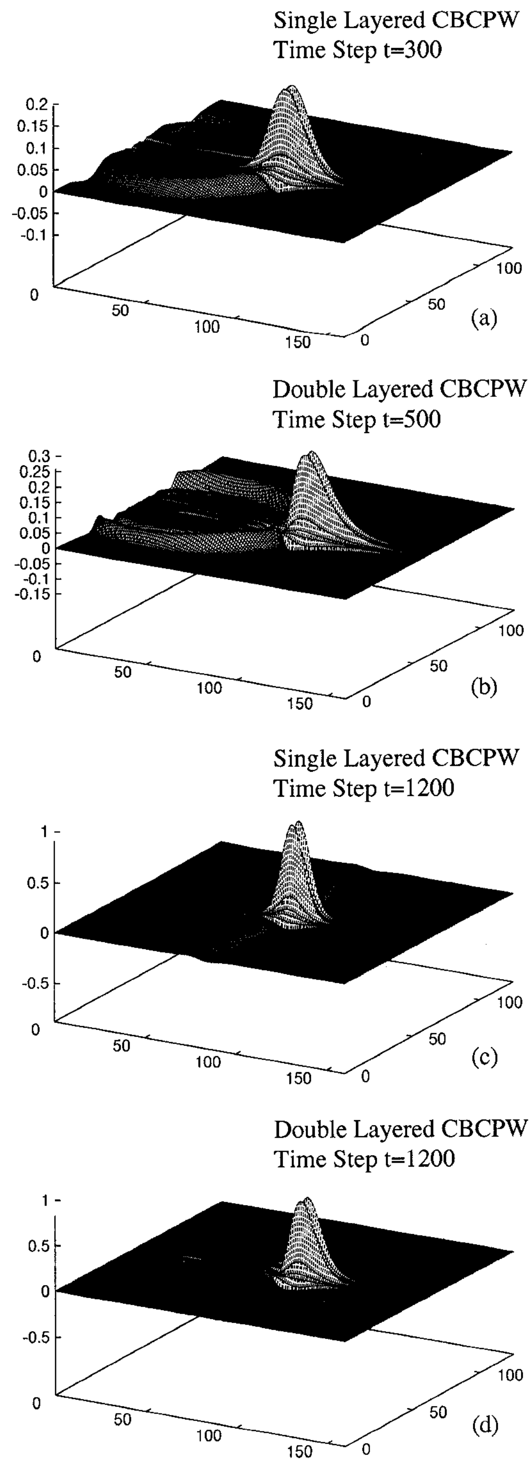

Figure 4: Spatial field distributions of the two types of CBCPWs excited by narrow and wide Gaussian pulses. (a) Single layered CBCPW, a narrow pulse excitation. (b) Double layered CBCPW, a narrow pulse excitation. (c) Single layered CBCPW, a wide pulse excitation. (d) Double layered CBCPW, a wide pulse excitation.

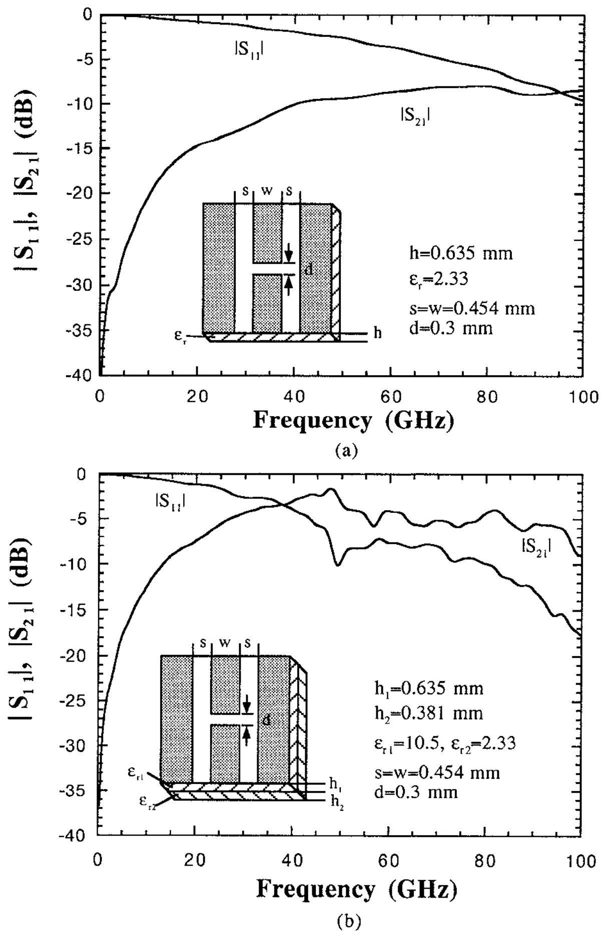

Figure 5: Variation of the scattering parameters of the gap discontinuity in, (a) a single layered CBCPW, and (b) a double layered CBCPW.

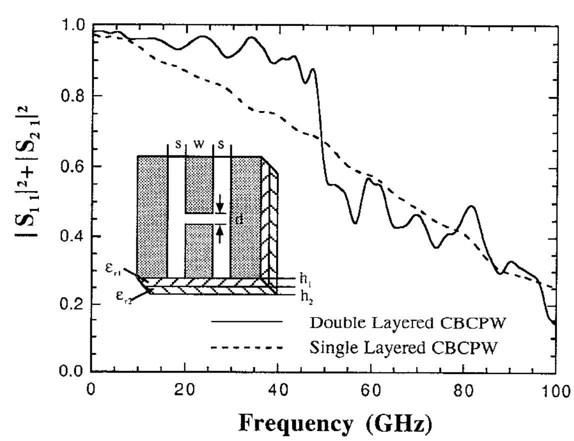

Figure 6: Comparison between the loss factors, $|S_{11}|^2+|S_{21}|^2$, of the gap discontinuities in a single layered and double layered CBCPWs.

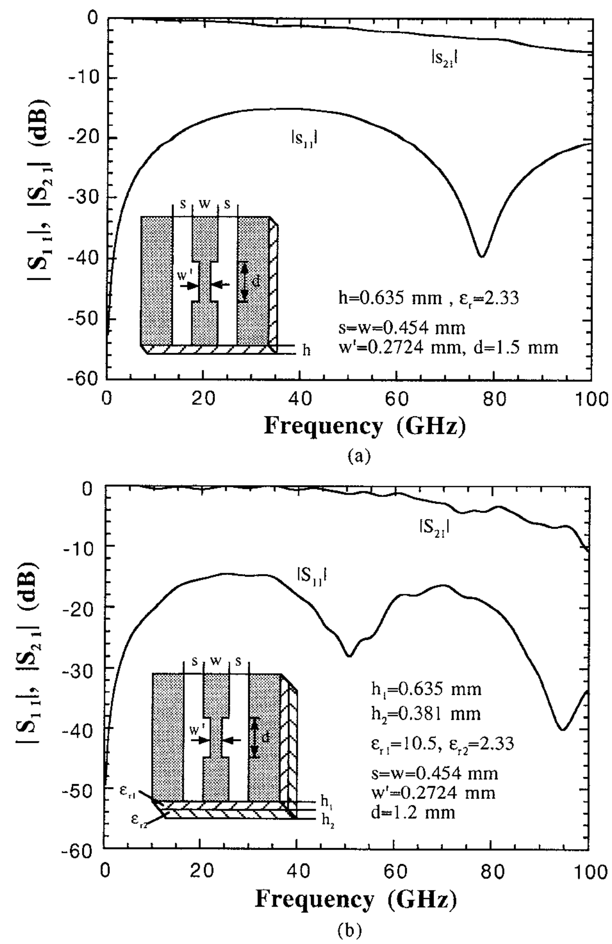

Figure 7: Variation of the scattering parameters of the double step discontinuity in, (a) a single layered CBCPW, and (b) a double layered CBCPW.

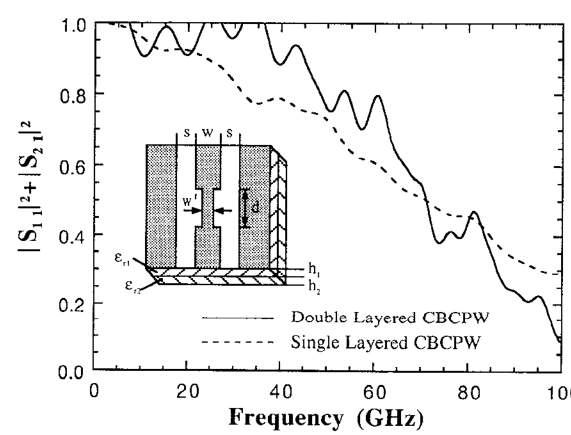

Figure 8: Comparison between the loss factors, $|S_{11}|^2+|S_{21}|^2$, of double step discontinuities in a single layered and double layered CBCPWs.