

Dispersion Characteristics of Coplanar Waveguides at Subterahertz Frequencies

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Abstract—We present experimental and simulated studies of the dispersion characteristics of coplanar waveguides (CPWs) at subterahertz frequencies. Two types of CPWs were studied, those with wide ground planes and those with narrow ground planes. In both cases, simulations closely followed the experimental results, thus giving us a basis for implementing the simulations in circuit-design models for a wide range of such waveguides.

1. Introduction

Coplanar waveguide (CPW) structures are commonly used in high-speed circuits and interconnect. Although the wave-propagation characteristics of CPWs have been well studied [1–11], only recently has this work been extended to the terahertz range for different geometries [6–9] and compared with experimental results [10, 11]. While our previous work focused on the attenuation characteristics [10, 11], in this paper we report results on the dispersion characteristics to complete the study. Our work is based on comparing experimental data with simulations that make use of full-wave analysis, allowing for direct verification of the validity of the latter. The effects of ground-plane width and lateral line dimensions have also been analyzed.

2. Background

CPWs are a family of transmission lines consisting of a center conductor strip and two ground conductor planes with variable widths. All three conductors are placed on the same side of a dielectric substrate, as shown in Figure 1.

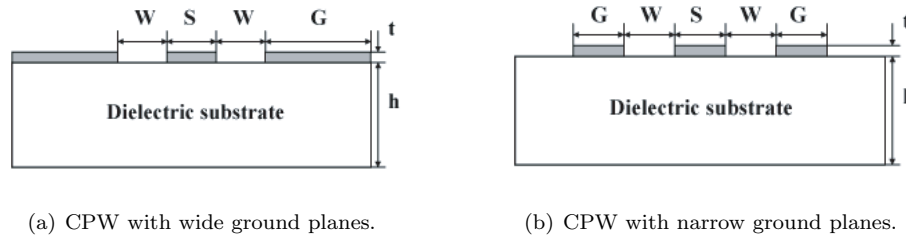


Figure 1: Cross-section of CPWs being investigated.

Two classes of CPWs were studied. The first contains ground planes at least 10 times wider than the center conductor or the conductor spacing and closely approximates an ideal CPW structure with infinitely wide ground planes. It should be pointed out that, for this class of transmission lines, closed-form analysis is in principle possible with the use of conformal mapping [12]. The second class uses ground planes with the same width as that of the center conductor, representing a practical geometry used in integrated circuits. For the latter category, theoretical studies are restricted to numerical simulations.

When an electromagnetic wave propagates on a CPW, the electric fields above conductors experience the permittivity of the air, while those below conductors experience the permittivity of the substrate. The effective permittivity thus takes on a value between that of the air and substrate. When the frequency of propagating wave increases, the effective permittivity approaches that of the substrate, as the density of electric field lines below the

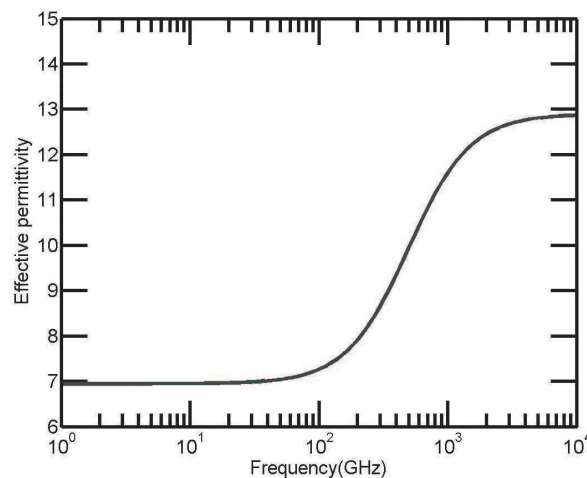


Figure 2: Effective permittivity of a CPW with wide ground planes. See Section 3 for geometry and electrical parameters.

conductors gets higher. The difference in the effective permittivity at different frequencies results in a modal dispersion that can be described with a frequency-dependent propagation constant:

$$\beta = 2\pi f \cdot 10^9 \cdot \frac{\sqrt{\varepsilon_{eff}}}{c} \quad (1)$$

where f is the frequency, c is the speed of light in free space, and ε_{eff} is the frequency-dependent effective permittivity. An example of ε_{eff} is demonstrated in Figure 2 [1].

Figure 2 shows that, with increasing frequency, the effective permittivity increases and a steep step is located at the position where the lowest-order surface-wave mode starts to interact with the CPW mode. For CPWs with infinitely wide ground planes, the TM_0 mode enters first and, at higher frequencies, this mode and higher-order modes contribute to the increase of ε_{eff} . For the case of narrow ground planes, the lowest-order surface-wave mode that can be supported is TE_0 mode [6]. Since the entry frequency of TM_0 mode is lower than that of TE_0 mode, CPW with wide ground planes supports more surface-wave modes and therefore suffers higher dispersion than CPW with narrow ground planes in the 100's GHz range.

3. Experiment and Simulation

In our work, the CPWs were fabricated on 500- μm -thick semi-insulating GaAs substrates. Gold was evaporated on the substrate and formed the transmission line patterns using a "lift-off" process [13]. The thickness of gold conductor was measured as $t = 290 \text{ nm}$. Each set of CPW had a center conductor and conductor spacing with a width of $S = W = 50$ or $10 \mu\text{m}$. The ground plane was chosen as $G = 500 \mu\text{m}$ for CPW with wide ground planes or as the lateral line dimension for CPW with narrow ground planes. With a testing method utilizing the non-uniform illumination of photoconductive switches together with electro-optic sampling, the broadband description of CPW characteristics has been obtained [11, 13]. The signal propagating along the CPW was measured in the time domain and then converted to the frequency domain by Fourier transform [13].

For comparison with the experiments, we used the software package Sonnet Suites to simulate the transmission lines. The simulation makes use of a modified method of moments based on Maxwell's equations to perform a three dimensional full-wave analysis of predominantly planar structures [14] and returns the values of the scattering matrices. The geometry and electrical parameters used for simulation are the same as those in the experiments. The simulated scattering matrices are then converted to propagation constant and, in turn, to the effective permittivity by (1).

4. Results and Discussion

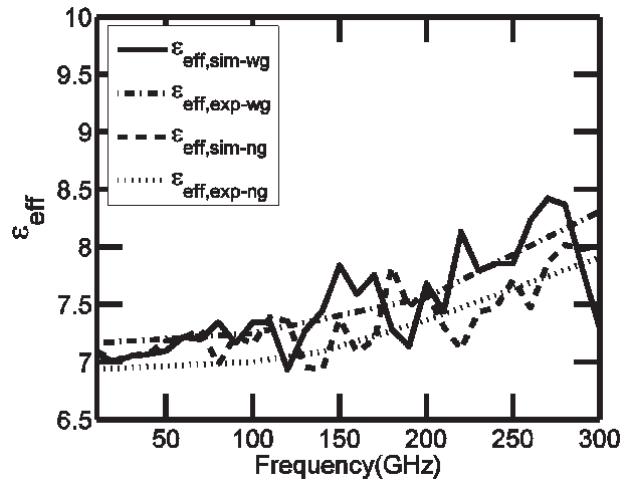


Figure 3: Simulated and experimental effective permittivity of CPWs with a 50- μm center conductor. $\varepsilon_{eff,sim-wg}$ and $\varepsilon_{eff,exp-wg}$ refer to simulated and experimental effective permittivity of the wide-ground CPW, respectively. $\varepsilon_{eff,sim-ng}$ and $\varepsilon_{eff,exp-ng}$ refer to simulated and experimental effective permittivity of the narrow-ground CPW, respectively.

Figure 3 shows the subterahertz effective permittivity of CPWs with a 50- μm center conductor as a function of the frequency. We present the simulated and experimental effective permittivity of CPWs with both wide and narrow ground planes for comparison. There is a good agreement except for the several peaks on the simulated

curves. These peaks are remnants of the poles in the Green's function used in the Sonnet Suites and correspond to the sequential entry of the surface-wave modes. Although the poles are removed one by one in the final results, some oscillations remain and are an unavoidable artifact.

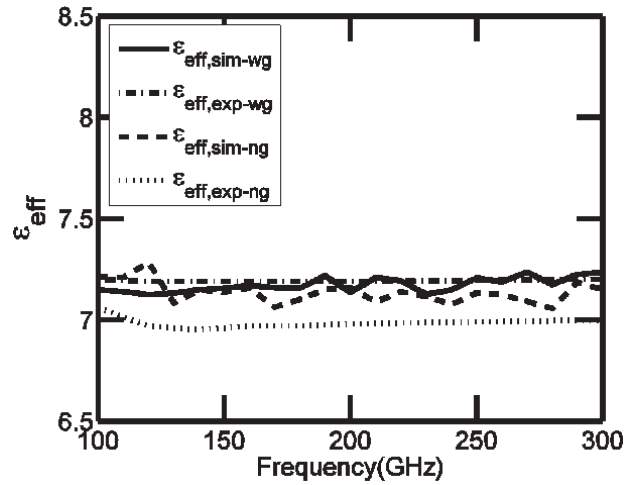


Figure 4: Simulated and experimental effective permittivity of CPWs with a 10- μm center conductor. $\epsilon_{eff,sim-wg}$ and $\epsilon_{eff,exp-wg}$ refer to simulated and experimental effective permittivity of the wide-ground CPW, respectively. $\epsilon_{eff,sim-ng}$ and $\epsilon_{eff,exp-ng}$ refer to simulated and experimental effective permittivity of the narrow-ground CPW, respectively.

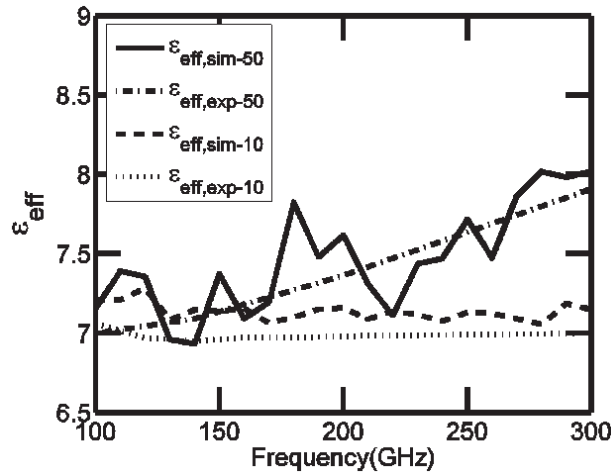


Figure 5: Simulated and experimental effective permittivity of CPWs with narrow ground planes. The lateral line dimensions are 50 μm and 10 μm , respectively. $\epsilon_{eff,sim-50}$ and $\epsilon_{eff,exp-50}$ refer to simulated and experimental effective permittivity of the CPW with a 50- μm center conductor, respectively. $\epsilon_{eff,sim-10}$ and $\epsilon_{eff,exp-10}$ refer to simulated and experimental effective permittivity of the CPW with a 10- μm center conductor, respectively.

An important observation of Figure 3 is that one clearly sees that the CPW with narrower ground planes returns a lower effective permittivity and reduced dispersion in both the experimental and simulated data. The reduced ground-plane width gives rise to a reduction in coupling between the CPW mode and surface-wave modes, which consequently decreases dispersion along the CPW.

We also investigated dispersion characteristics of CPWs with narrower lines. Figure 4 shows the subterahertz effective permittivity of CPWs with a 10- μm center conductor. Again, it can be seen that CPW with narrow ground planes encounters lower effective permittivity than CPW with wide ground planes. Dispersion is slightly improved in CPW with narrow ground planes.

To examine the effect of lateral line dimension, we combine the narrow-ground CPW data into Figure 5. It

is clearly seen that the effective permittivity of CPW with a 10- μm center conductor is lower than that of CPW with a 50- μm center conductor and the overall dispersion is much less.

5. Conclusion

In summary, we present experimental and simulated dispersion characteristics of CPWs with wide and narrow ground planes. The simulation results agree well with the experimental data up to subterahertz frequencies. It is shown that CPW with narrow ground planes suffers lower dispersion than CPW with wide ground planes. Furthermore, dispersion can be reduced by reducing the lateral line dimension of the CPW. Combining our previous studies on the attenuation characteristics [10, 11] and the current work on dispersion, we conclude that in the frequency range where radiation effects dominate (100's GHz for the lines considered in this report), the narrow-ground CPWs perform better in both aspects.

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