Sensitivity of Dispersion Characteristics of a Sandwiched Coplanar Waveguide at 0-70 GHz to Changes of Device Dimensions

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Abstract- In this paper the simulated dispersion characteristics of a Coplanar Waveguide (CPW) sandwiched between two dielectric substrates with changing dimensions are presented and analyzed in order to find out the sensitivity of the CPW's frequency dependent effective dielectric constant to various device dimensions' changes. The analysis in this paper will help optimize the design and fabrication of the CPW.

1. Introduction

The quasi-static TEM propagation modes of CPW have been studied a lot in the past and closed form expressions for the quasi-static effective dielectric constant, ε_{eff}, and characteristic impedance for CPWs of different forms can be found in many papers and books [1]. However CPWs also exhibit dispersion effects. There are only a few empirical and synthesis formulas for computation of the frequency dependence of the ε_{eff} for CPWs on one dielectric substrate [1] [2], but none for CPWs sandwiched between two dielectric substrates. In order to optimize the design of this type of CPW, it is very important to know what effects the changes of the device dimension would have on the dispersion of the CPW's ε_{eff}, and this will be discussed in this paper.

Here the upper substrate of the CPW is made of liquid crystals, the permittivity of which would vary in a range of values with increasing biased voltage. According to simulations and experiments, the permittivity of the liquid crystals will influence the ε_{eff} of the CPW and thus by changing the biased voltage applied to the liquid crystal layer, the ε_{eff} of the CPW could be controlled. Some simulations have been done to find out how different permittivities of liquid crystals would influence the dispersion of the ε_{eff} [4].

2. The Structure

The CPW studied in this paper is shown in Fig.1. It consists of a center strip conductor with two ground planes on either side mounted between two dielectric substrates. Rogers TMM10i was used as the lower substrate, the dielectric constant of which is 9.8. Dielectric-2 corresponds to a thin polyimide rubbing layer, that was neglected by the simulation software but is very thin and considered not influence the simulated results. The liquid crystal layer is enclosed with conductors.

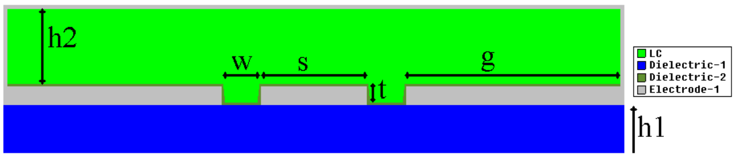


Fig.1: Cross-section of the CPW being studied [3]

Some previous research shows that in most cases the ε_{eff} of CPWs increases with increasing frequency [1] [2].In this case, this is because the concentration of the electric field in the lower dielectric increases at higher frequencies [2], and thus ε_{eff} approaches the permittivity of the lower dielectric, which is higher than the permittivity of the upper dielectric.

3. Experiment and Simulation

In our work, the lower substrate thickness and the electrodes thickness was chosen at h_1 = 381μm and t = 17μm [4] [6]. The height of the liquid crystal layer h_2 was 80μm. The width of the center conductor was s = 220μm while the ground plane was g = 490μm. The gaps between the center conductor and the ground planes were w = 80 µm wide each. According to previous work, the relative permittivity of liquid crystal in the unswitched state is 2.78 [9].

The simulated results were obtained by using CST MWS (Computer Simulation Technology, Microwave Studio) [8]. The polyimide rubbing layer and the conductors on the top and on the sides of the liquid crystal layer were set as infinitely thin sheet and all the conductors were considered as perfect electrical conductor. The length of the coplanar line was set at 5600µm. According to previous simulations, the change of the coplanar line length has little effect on the dispersion characteristics of the CPW.

Fig.2 shows the frequency dependent effective dielectric constant of the CPW, when the liquid crystal is in the unswitched state. Both simulated result and experimental result [5] are presented for comparison.

The experimental result showed that ε_{eff} decreases with increasing frequency at low frequencies, this might be caused by the frequency dependence of the line inductance due to the skin effect. [2]

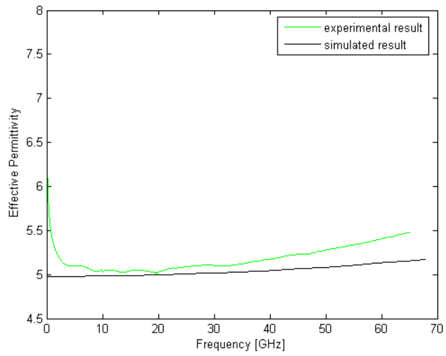
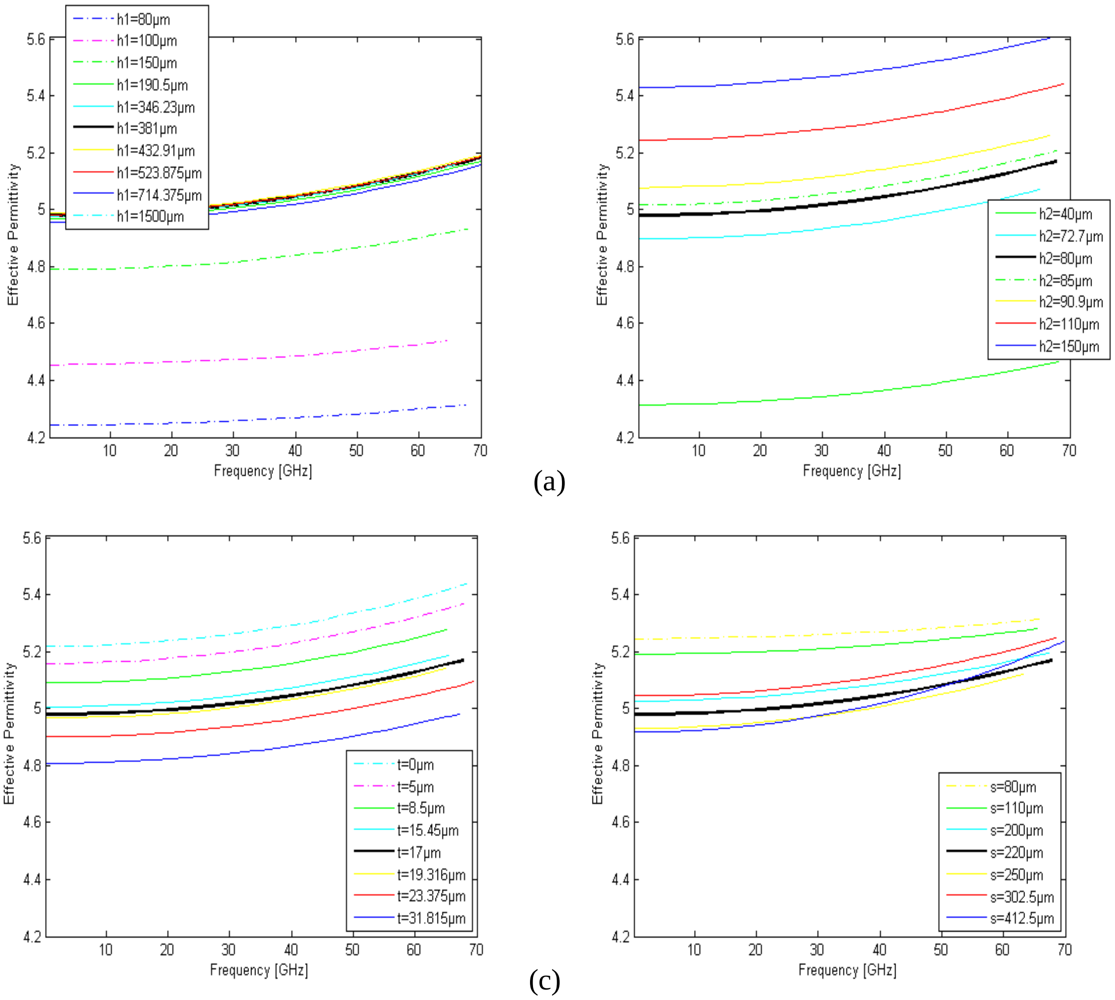


Fig.2: Experimental ε_{eff} vs. simulated ε_{eff}

Due to the difference between the experimental ε_{eff} and simulated ε_{eff}, various dimensions of the CPW in the CST model were changed to find out the sensitivity of CPW's ε_{eff} to these changes.

4. Results and Discussion



(a) (b) (c) (d)

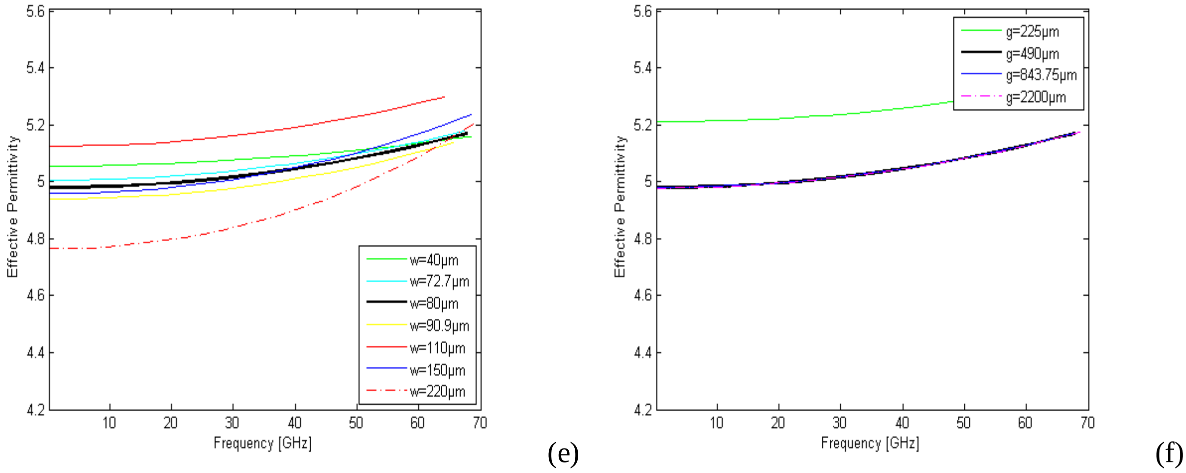


Fig.3: Simulated εeff of a CPW with various dimensions. Every graph represents the dispersion characteristics with one dimension's change: (a) variation with h_1 (b) variation with h_2 (c) variation with *t* (d) variation with *s* (e) variation with *w* (f) variation with *g*

Each graph in Fig.3 represents the frequency dependent ε_{eff} of a CPW with different values of a certain dimension. The thicker black line in each graph stands for data corresponding to dimensions at Section3. For the solid the ratio between each new dimension and its original value has the following values: blue line: 1.875; red line: 1.375; yellow line: 1.136; cerulean line: 0.9091; green line: 0.5. The dash-dot line lines are for additional data which are considered to be interesting to look at.

According to Fig.3, the following conclusions can be made:

1. The ε_{eff} of the CPW is most sensitive to the change of the liquid crystal layer thickness h_2. As Fig.3 (b) shows, ε_{eff} increases with the increasing h_2, but the slope of the dispersion curve remains almost the same all the time as h_2 varies.

2. The ε_{eff} of the CPW is sensitive to both the change of the center conductor's width *s* and the change of the gap width *w*, yet it is more sensitive to the change of s than to that of w. According to Fig.3 (d) and (e), when *s* or *w* increases, ε_{eff} increases more quickly as the frequency increases.

3. In Fig.2, the simulated ε_{eff} is a bit lower than the experimental ε_{eff}, and that's probably because experimentally the electrode dimensions will differ slightly due to over-etching [4]. The ε_{eff} of the CPW is quite sensitive to the change of the electrodes' thickness *t*. The value of ε_{eff} drops with the increasing *t*. But the change of *t* doesn't affect how ε_{eff} varies with changing frequency (see Fig.3 (c)).

4. Fig.3 (a) and (f) show that the change of the width of the ground plane *g* or the change of the thickness of the lower substrate h_1 doesn't have a significant influence on the ε_{eff} of the CPW unless *g* becomes very narrow and approaches the center conductor's width *s*, or h_1 becomes very thin. ε_{eff} increases as g becomes narrower but the slope of the dispersion curve doesn't change much. In the ideal case the ground planes of the CPW should be very wide relative to the center conductor's width s and the lower substrate is very thick. [7] That's because so long as $g>>s$, $g>>h_2$ and the value of h_1 is very big, there is no dependence of ε_{eff} on *g* or h_1, but when *g* approaches the value of *s* or h_2, or h_1 becomes very thin, the shape of the electrical field lines will change and will depend on the boundary conditions around the CPW, that's why when *g* OR h_1 becomes quite small ε_{eff} experiences significant change from the data obtained with big *g* and h_2.

5. Conclusion and Future work

According to simulated results and the discussions above, in the process of the CPW's fabrication, special attention needs to be paid to the accuracy of the thickness of the liquid crystal layer. It would be better if the widths of the center conductor and the gap between every two electrodes, together with the thickness of the electrodes should also be known accurately.

Additionally Dr Richard James found it necessary to include some anisotropy in the lower substrate; he made the permittivity 10% higher tangential to the substrate [4]. I intend to attempt this change and check how it influences the effective permittivity of the device.

To match the experimental results with the simulation more accurately, will require the detail of the coupling to the waveguide used in the experiment to be included in the simulation.

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