Leakage Phenomena in Multilayered Conductor-Backed Coplanar Waveguides

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***Abstract*— Leakage phenomena possible in the multilayered conductor-backed CPW's are investigated using the spectral domain technique with a complex root searching procedure. The obtained phase and attenuation constants confirm that the leakage is due to the presence of parallel plate mode which is slower than dominant CPW mode. It is found that the leakage can be controlled by introducing an additional dielectric layer. Two different multilayered structures are given as examples.**

I. Introduction

The conductor-backed coplanar waveguide (CBCPW) has found wide applications in the MMIC's due to several advantages, such as improved mechanical strength and heat sinking ability. However, the presence of conductor backing can cause certain serious problems such as the power leakage into transverse direction, resulting in unexpected or even harmful coupling to the neighboring transmission lines or devices. Such leakage phenomena have drawn significant interest due to their importance in both basic understanding of guided wave phenomena and practical applications. Several theoretical methods have been proposed to investigate the wave propagation characteristics of these structures, such as mode-matching [1], Weiner-Hopf/generalized scattering matrix technique (WH/GSMT)[2] and spectral domain method [3], [4].

In this paper, two different multilayered structures are proposed to control the leakage. The first one is the structure with an additional top layer whose dielectric constant is higher that of substrate, the second is the one with such an additional layer placed between metal and substrate. These structures are analyzed by the spectral domain technique with a complex root searching procedure similar to the one described in [4]. The obtained results for the phase and attenuation constants show that the structures have a sharp transition from leaky to unleaky when the thickness of the additional layer is increased, indicating that these structures are no longer leaky and can be used to prevent the leakage. The results further confirm the leakage is due to presence of parallel plate mode which is slower than the dominant mode of coplanar waveguide.

II. Analysis of Multilayered Conductor-Backed CPW

The conventional conductor-backed coplanar waveguide shown in Fig. 1(a) always leaks energy into transverse direction. The qualitative reasoning for the leakage is as follows. The EDC (effective dielectric constant) of the dominant CPW mode of conductor-backed CPW is between ε_{r2} and $\varepsilon_{r1}(\varepsilon_{r1} = 1)$ and less than ε_{r2}, while EDC of dominant parallel plate mode supported by the infinitely extended parallel plates is ε_{r2}. Thus the dominant CPW mode is always faster than the dominant parallel plate mode. As a consequence, the dominant CPW mode is unconditionally leaky over all frequency range. At a low frequency, only the dominant parallel plate mode (TEM mode) makes contribution to the energy leakage. However, the higher-order parallel plate modes may propagate and have higher effective dielectric constants than that of the dominant CPW mode when the working frequency is very high. Under this situation, the higher-order parallel plate modes will join the dominant parallel plate mode to make contribution to energy leakage. The wave propagation characteristics of such a leaky waveguide can be analyzed by the spectral domain method. In this method, the integration contour in the spectral domain is deformed from the real axis to include the residue contribution associated with the wave propagation of one or more parallel plate modes [3], [4]. A complex root searching is then applied to find out the complex propagation constant. Its real part gives the phase constant, while its imaginary part represents the attenuation constant.

Most of the previous work addresses the analysis of conventional conductor-backed coplanar waveguide. In this paper, we propose multilayered structures which may be used to control leakage. The idea is to make the effective dielectric constant of the dominant CPW mode higher than that of dominant parallel plate mode by introducing an additional dielectric layer. The first structure is the one with an additional top layer whose dielectric constant is higher than that of substrate, as shown in Fig. 1(b). In second structure, such an additional layer is placed between metal and substrate as shown in Fig. 1(c). The second structure can also be viewed as the one with an additional bottom layer whose dielectric constant is lower than that of substrate. The spectral domain method is then applied to these two structures to investigate wave propagation characteristics.

Fig. 2 shows the calculated normalized phase constant (square root of effective dielectric constant) and normalized attenuation constant for the structure shown in Fig. 1(b). The dominant CPW mode is leaky for small thickness $h_2(< 0.02$ mm) because the dominant CPW mode is faster than the dominant parallel plate mode. As the thickness h_2 is increased, the normalized phase constant of dominant CPW mode will increase and the normalized attenuation constant

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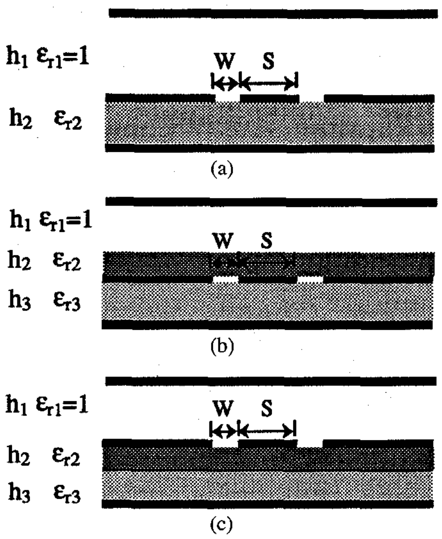

Fig. 1. Different types of conductor-backed coplanar waveguides.

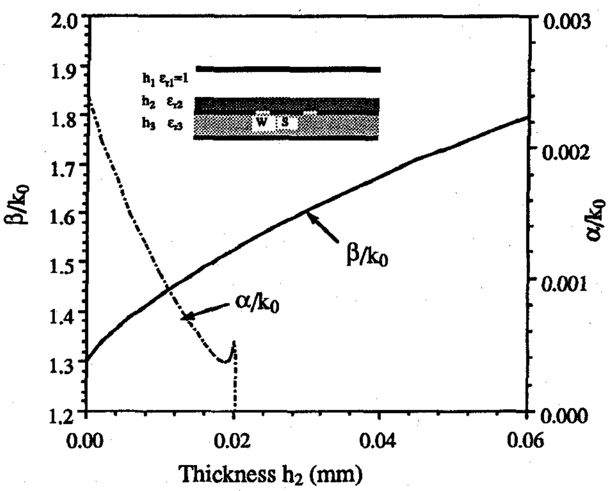

Fig. 2. Normalized phase and attenuation for different thickness h_2. ε_{r2} = 10.5, ε_{r3} = 2.33, W = 0.254 mm, S = 0.254 mm, h_3 = 0.635 mm, h_1 = 15 mm, f = 10 Ghz.

will decrease. The attenuation constant suddenly drops to zero at the point $h_2 = 0.02$ mm where normalized phase constant reaches the square root of relative dielectric constant of the substrate($\sqrt{\varepsilon_{r3}} = \sqrt{2.33} = 1.526$). As h_2 is increased further, the normalized phase constant keeps increasing and attenuation constant keeps zero, indicating the structure is no longer leaky. This also clearly shows that leakage is due to the presence of parallel plate mode which is slower than dominant CPW mode.

In contrast to the structure shown in Fig. 1(b), the additional layer in the structure shown in Fig. 1(c) will not only increase the effective dielectric constant of CPW mode, but also increase that of parallel plate modes. However, the increase of the effective dielectric constant of dominant CPW mode is much larger than that of dominant parallel plate mode. On the other hand, if structure shown in Fig 1(c) is considered as the one with an additional bottom layer whose dielectric constant is less than that of the substrate, the introducing of this bottom layer will decrease the effective dielectric constant of both dominant CPW mode and parallel plate modes. The

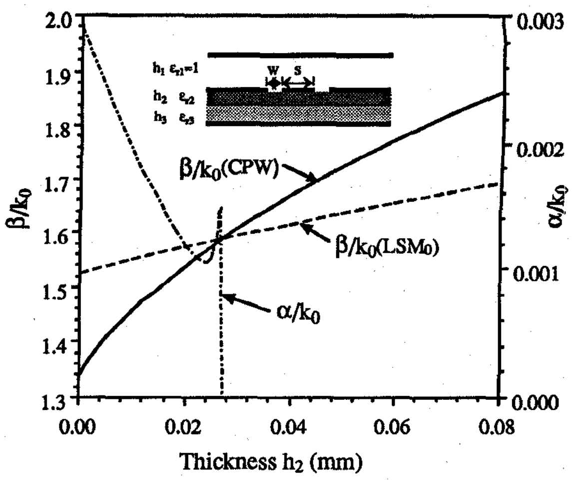

Fig. 3. Normalized phase and attenuation for different thickness h_2. ε_{r2} = 10.5, ε_{r3} =2.33, W = 0.254 mm, S = 0.254 mm, h_3 = 0.635 mm, h_1 = 15 mm, f = 10 Ghz.

decrease of effective dielectric constant of dominant parallel plate mode is much larger than that of dominant CPW mode. The dominant parallel mode in this case is LSM_0 and its propagation constant can be calculated by a root searching procedure [5]. As shown in Fig. 3, the normalized phase constant of dominant CPW mode is smaller than that of dominant parallel plate mode and the structure is leaky for small thickness $h_2(< 0.027$ mm). However, it will increase quickly as the thickness h_2 is increased and will reach that of dominant parallel plate mode where the attenuation constant drops to zero. As h_2 is increased further, the dominant CPW mode will have higher effective dielectric constant than that dominant parallel plate mode. Thus dominant CPW mode is slower than the dominant parallel plate mode and hence the structure is no longer leaky.

III. Conclusion

Leakage phenomena in multilayered conductor-backed coplanar waveguides have been investigated by spectral domain method with a complex root searching procedure. Two multilayered structures are proposed to control the leakage. The simulation results show these structures are no longer leaky under certain conditions. It is further confirmed that the leakage is due to the presence of the parallel plate mode.

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