TRANSMISSION PROPERTIES OF MICROSTRIP LINES WITH A PERIODICAL GROUND PLANE

J.-F. KIANG
Department of Electrical Engineering and Graduate Institute of Communication Engineering
National Taiwan University
No.1, Sec.4, Roosevelt Rd., Taipei, Taiwan 10617, ROC
E-mail: jfkiang@cc.ee.ntu.edu.tw

H.-L. HSU and Z.-Y. CHEN
Department of Electrical Engineering, National Chung-Hsing University
Taichung, Taiwan 402, ROC

A mode-matching technique combined with a spectral domain representation is used to study the transmission properties of microstrip lines with a periodically corrugated ground plane. The field components in the corrugated region are expanded by standing wave mode functions in the propagation direction and by a Fourier integral in the transversal direction. Integral equations are formed in terms of the surface currents on the microstrip. The dispersion relation is obtained by applying method of moments to solve the integral equations. Various geometrical and electrical parameters affecting the passband/stopband characteristics of the first stopband are investigated.

1 Introduction

Frequency dispersion in microstirp lines cause signal distortion and have been discussed in [1-2]. Such distortions impact the design of IC layout. In a periodical wave guiding structure, stopbands exist due to the interaction of different Floquet modes when they have the same phase velocity. The interaction can be predicted by observing the intersection of dispersion curves of various Floquet modes. Such stopbands can be used in the filter designs, or viewed as artifacts that tend to deteriorate the guided signals. In [3], dispersion characteristics of nonuniform microstirp lines with periodical width-modulation are obtained by using a spectral domain technique and Floquet's theorem. The integral equations derived from boundary-value problems are solved by using Galerkin's method. It is indicated that such microstrip lines can provide filtering capability. In [4], a network-analytical approach is used to analyze striplines and fin lines with periodic stubs. Galerkin's method is used to obtain numerical results. The length, width, and period affect the stopband characteristics. The effect of higher order guided modes is briefly mentioned. In [5], a rigorous dyadic Green's function in the spectral domain and Galerkin's method are used to study the dispersion characteristics of striplines in the presence of metallic crossing strips. The dispersion properties are studied with crossing strips of finite and infinite length. The effects by the period, the length of crossing strips, and the separation between strips are reported. In [6], a vector integral equation method with a two-stage moment method is used to study microstrip lines on artificial periodic substrates. The condition when the guided modes become leaky waves is also discussed.

In this paper, we study the propagation properties of microstrip lines with a periodically corrugated ground plane. The properties can be used to model the ground plane bulge caused by thermal process, or they can be used as filters.

2 Formulation

Fig.1 shows a unit cell of a microstrip line backed by a periodically corrugated ground plane where the orientation of the corrugation is perpendicular to the microstrip line. The period is P, and each period of the ground plane is approximated by a set of connecting vertical and horizontal panels as shown. The region above the corrugation is modelled as a multilayered medium. Each corrugation is

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approximated by a cascade of parallel plate waveguides with different widths. The fields in each waveguide region are expanded in terms of the standing wave modes in that waveguide. The fields above the corrugations are expressed as a summation of Floquet modes. Reflection matrices are defined to facilitate the derivation. By imposing the boundary condition that the tangential electric and magnetic fields are continuous across the interfaces between adjacent layers, recursive formulas for the reflection matrices are obtained. The discontinuity of tangential magnetic fields accounts for the surface currents on the microstrip. All the field components can thus be expressed in term of the surface currents. Next, impose the boundary condition that the tangential electric field vanishes on the microstrip surface to obtain a set of integral equations. Method of moment is then applied to obtain a determinantal equation from which the dispersion relation can be obtained.

3 Results and Discussions

Fig.2 shows three profiles of corrugated ground plane analyzed in this paper. To check the accuracy of this approach, Fig.3 shows the effective dielectric constant of a microstrip line with a periodically corrugated ground plane calculated by using this approach. Since the corrugation depth (D) is only a small fraction of the substrate thickness (h), the stopband is barely observable, and the dispersion relation is very close to that of a microstrip line with a uniform ground plane [2].

Fig.4 shows the real and imaginary part of the propagation constant of a microstrip line with a step corrugation. A stopband occurs when the Bragg condition $k_y P = \pi$ is satisfied. In the stopband, the phase constant equals π / P, and the attenuation constant is nonzero, having a maximum near the center of it. Fig.5 shows the effects of corrugation depth on the characteristics of the first stopband for three different profiles. Seven layers are used to approximate each corrugation profile. The normalized center frequency is defined as $k_c P = (2\pi\ f_c / c)P$, where f_c is the center frequency of the stopband, and c is the speed of light in free space. It is found that deeper corrugation incurs higher center frequency. Lower substrate dielectric constant also incurs higher center frequency. The first stopband occurs when the reflected waves from the discontinuities in each period add up in phase. Thus, the power is enhanced in the backward direction to establish the stopband. Substituting $k_y = (2\pi\ f / c)\sqrt{\varepsilon_{eff}}$ into the Bragg condition, it is found that for higher effective dielectric constant, the Bargg condition is satisfied at lower frequency, hence the stopband occurs at low frequency [1].

The associated bandwidth of the first stopband is shown in Fig.5(b). The normalized bandwidth is defined as $k_b P = (2\pi\ f_b / c)P$, where f_b is the bandwidth of the first stopband. Reflection may occur at more places along a deep profile than along a shallow one. Thus, the bandwidth of the first stopband is wider for a deeper profile. Fig.5(c) shows the normalized maximum attenuation constant. It is found that deeper corrugation implies stronger discontinuity. Thus, the reflected wave becomes stronger, and results in larger attenuation constant.

Fig.6 shows the effects of the profile depth on the characteristics of the first stopband, with the relative permittivity of the substrate increased to 8.875. Fig.6(a) shows the normalized center frequency of the first stopband. Comparing to Fig.5(a), it is also observed that for higher effective dielectric constant, the stopband occurs at lower frequency. Figs. 6(b) and 6(c) also show that a deeper profile incurs wider bandwidth and larger attenuation constant in the first stopband as in Figs. 5(b) and 5(c). The maximum attenuation constant is larger than that in Fig.5(c). It is conjectured that the electric field tends to be confined in a substrate with higher permittivity, hence the discontinuities beneath the substrate has stronger effect on the electric field distribution than when the substrate permittivity is low.

4 Conclusions

A mode-matching technique combined with a spectral domain representation has been used to develop an integral equation to study the propagation characteristics of a microstrip line with a periodically corrugated ground plane. Three different corrugation profiles are chosen to demonstrate the effects of corrugation depth and substrate permittivity on the characteristics of the first stopband. Such ground plane can be used either to model a bulge ground or to design a transmission line filter.

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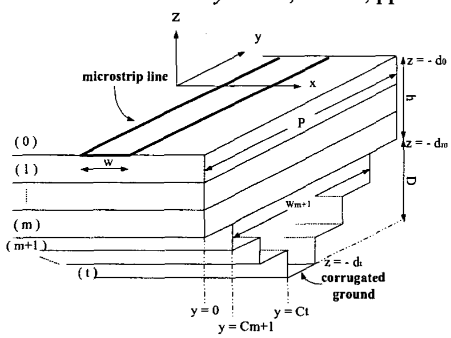

Fig.1 Geometrical configuration of a microstrip line with a periodically corrugated ground plane.

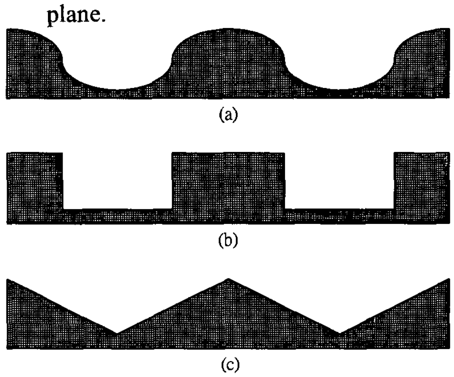

Fig.2 Three types of corrugated ground plane: (a) cosine profile, (b) step profile, and (c) triangular profile.

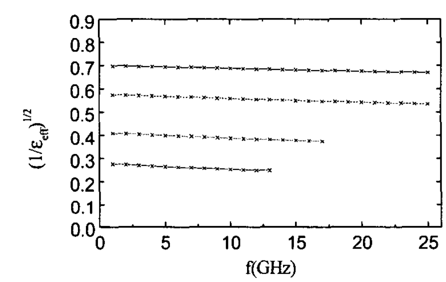

Fig.3 Effective dielectric constant of a microstrip line with a shallow step corrugation, P=1mm, w=1.27mm, h=1.27mm, D/h=0.01, _ : ε_r = 2.65, ... : ε_r = 4.20, ... : ε_r = 8.875, _._ : ε_r = 20, x : data from [2].

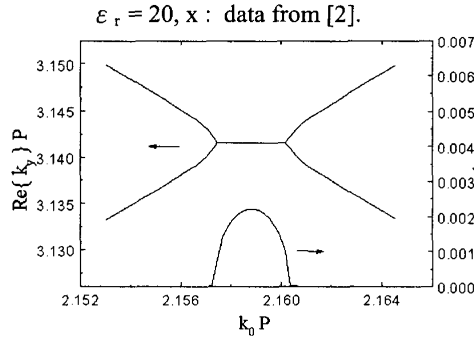

Fig.4 Propagation constants near the first stopband with a step corrugation profile, P = 1cm, w = 1.27mm, h = 1.27mm, D/h=0.01.

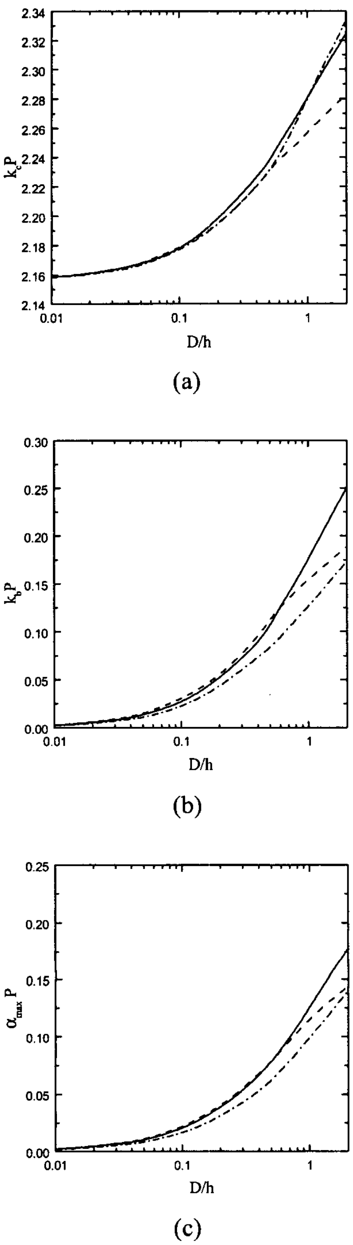

Fig.5 Effect of profile depth on the characteristics of the first stopband for three corrugation profiles, P=1cm, w=1.27mm, h=1.27mm, $\varepsilon_r = 2.65$, — : cosine profile, -- : step profile, ···:triangular profile.

(a) normalized center frequency,
(b) normalized bandwidth,
(c) normalized maximum attenuation constant.

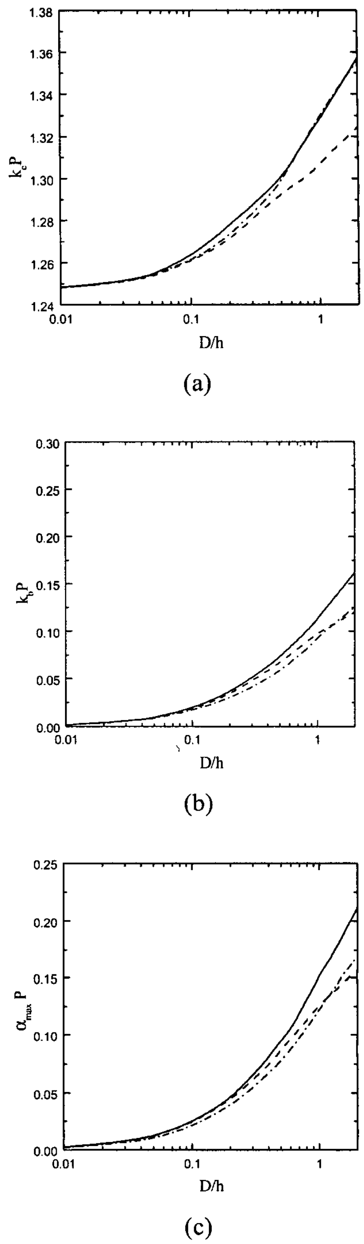

Fig.6 Effect of profile depth on the characteristics of the first stopband for three corrugation profiles. The parameters are the same as in Fig. 5, except ε_r=8.875.