LEAKY WAVES OF THE SECOND ORDER ON THE SLOTLINE

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Abstract - The interesting behaviour of 2nd higher order leaky waves on the slotline designed on the substrate with permittivity 10.8 is presented in this paper. It is shown that space and surface leaky waves can propagate simultaneously along the line. Strong slotwidth dependency of their dispersion characteristics is documented. These effects can influence the behaviour of slotline leaky wave antennas with a wide slot.

INTRODUCTION

The slotline has been known and used in circuits for many years, and has attracted the interest of researchers. Findings on surface leaky wave propagation on the slotline have been summarized in [1,2]. Investigation of space leaky waves has enabled application of the slotline as a leaky wave antenna. Sheen and Lin [3] published a study dealing with the surface-wave-like mode and the first higher order mode, which we in [4] term the first higher order bound wave and the space leaky wave of the first class.

This paper deals with the slotline and introduces new components of its leaky wave spectrum. We describe properties of the 2nd higher order surface and space leaky waves associated with the 2nd higher order bound wave. These waves can propagate simultaneously. The slotline designed on a higher permittivity substrate ε_r=10.8 was chosen for analysis, as its dispersion characteristics are clearly distinguishable and well separated.

LEAKY WAVES WITH EVEN SYMMETRY OF THE ELECTRIC FIELD

The standard slotline, the cross-section of which is shown in Fig. 1, was analyzed by the method of moments applied in the spectral domain. Dispersion characteristics of modes with even symmetry of the transversal electric field component with regard to a plane of symmetry placed in the middle of the slot are given in Fig. 2. The characteristics are plotted as normalized phase β/k_0 and leakage α/k_0 constants versus the normalized frequency h/λ_0. There are two classes of space leaky waves [4]. The wave of the first class $2ndSL_{C1}$ is directly associated with the 2nd higher order bound wave. Only one branch from a series of dispersion characteristics of the space leaky wave of the second order and of 2nd class $2ndSL_{C2}$ is plotted in Fig. 2.

The zoomed part of the plot around the cut-off of the second higher order bound wave is shown in Fig. 3. The 2nd higher order bound wave can propagate on the slotline from its cut-off frequency f_c when the line has a sufficiently wide slot and a sufficiently high substrate permittivity. When the frequency varies and crosses f_c, the standard transition to a surface leaky wave occurs, involving an improper real solution of the dispersion equation, similarly as in [5]. The surface leaky wave is physical in two separate frequency intervals, where its phase constant is higher than k_0 and at the same time lower than k_{TM0}. This wave can propagate simultaneously with the space leaky wave of the first class, which is physical when its phase constant is lower than k_0.

DEPENDENCE OF DISPERSION CHARACTERISTICS ON THE SLOTWIDTH

The dispersion characteristics of the space leaky wave of the first class are plotted in Fig. 4 in dependence on the slotwidth w. It is evident that for lower w (17 and 18.5 mm in Fig. 4) this wave is nonphysical, whereas it is able to leak power into space from a line with a wider slotwidth starting upward from a specific w (19.2 mm for the line belonging to Fig. 4).

The evolution of the surface leaky wave dispersion characteristics with increasing slotwidth is shown in Fig. 5. The dispersion characteristics of an additional complex mode, which is nonphysical at lower w (from 17 to 21.5 mm in Fig.5) are plotted by thin lines in Fig. 5. Solutions of the dispersion equation of these two modes get closer and closer with increasing w. For low w (17 mm in Fig. 5) the surface leaky wave is physical in a single, relatively wide frequency range. This range splits into two separate parts when the slotwidth becomes wide. Finally, e.g., at w=22 mm for the line in Fig. 5, the patterns of these two modes are exchanged. Now, and for higher w, the surface leaky wave is physical only on the upper side of the frequency range, whereas

the originally nonphysical mode is physical in the lower portion of the frequency band.
Electric field distributions of the surface leaky wave on the slotline with w=21.3 mm at two different normalized frequencies are compared in Fig. 6. The frequencies are chosen h/λ_O=0.0376 just below and h/λ_O=0.0389 just above the band where the wave is nonphysical. The amplitude and phase of the field grow much faster in the x direction at the lower frequency than at the higher frequency. The reason is in the Green function pole position that determines the wave propagation constant in the x direction. For h/λ_O=0.0376 the pole is 99.79+j77.92 and for h/λ_O=0.0389 it is 59.77+j36.88. The character of the field distribution at frequencies below and above the frequency band where surface leaky waves are nonphysical remains similar to those plotted in Fig. 6 when the slot is widened, i. e., when w≥22 mm.
We also studied leaky waves of the second order on the slotline designed on a substrate with low permittivity 2.6. We detected bound and surface leaky waves with dispersion characteristics similar to those plotted in Fig. 3 but without the interesting evolution described above. In addition, no space leaky wave of the first class was found in this case.
In addition to waves having even field symmetry, we also studied waves with odd field symmetry marked by odd indices. The leaky waves associated to the third bound wave on the slotline designed on the substrate 1.27 mm thick with permittivity 10.8 did not show the behaviour described here. The 3rd bound wave does not propagate on a slotline with low permittivity substrate and slotwidth comparable to the values mentioned above.

CONCLUSIONS

We have found new effects that take place when leaky waves of the second order propagate on a slotline with a wide slot and substrate permittivity 10.8. The dispersion characteristics of the 2nd higher order surface leaky wave strongly depend on the slotwidth. Slot widening results in a split into two parts of the frequency region in which this wave is physical. When the slotwidth significantly increases, this wave in the low frequency portion is replaced by a previously nonphysical mode, which now becomes physical. The 2nd higher order space leaky wave of the first class gradually becomes physical when the slotwidth increases, and propagates simultaneously with the surface leaky wave. These effects ought to be taken into account when slotline leaky wave antennas with a comparatively wide slot are designed.

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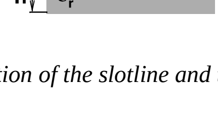

Fig. 1 Cross-section of the slotline and the coordinate system.

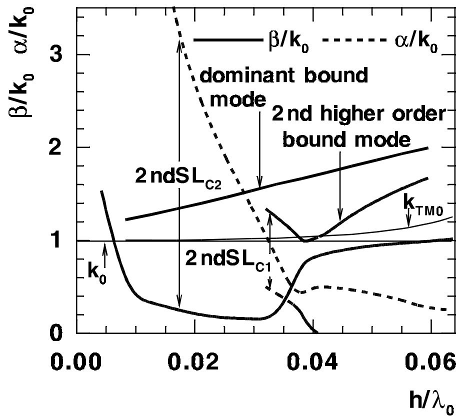

Fig. 2 Dispersion characteristics of the dominant, 2nd higher order bound wave, and the 2nd space leaky waves of class 1 and 2 on the slotline with ε_r=10.8, h=1.27 mm and w=20 mm.

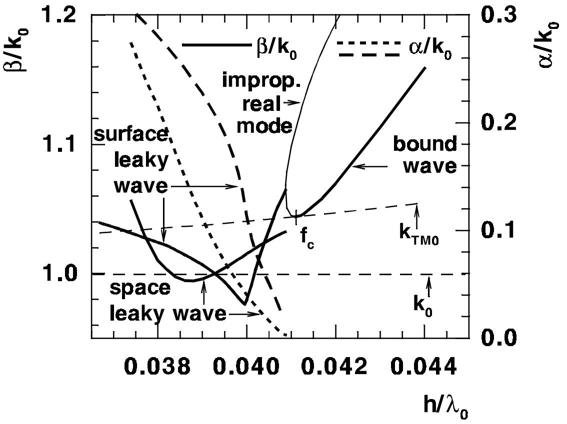

Fig. 3 Dispersion characteristics of the 2nd higher order waves on the slotline from Fig. 2.

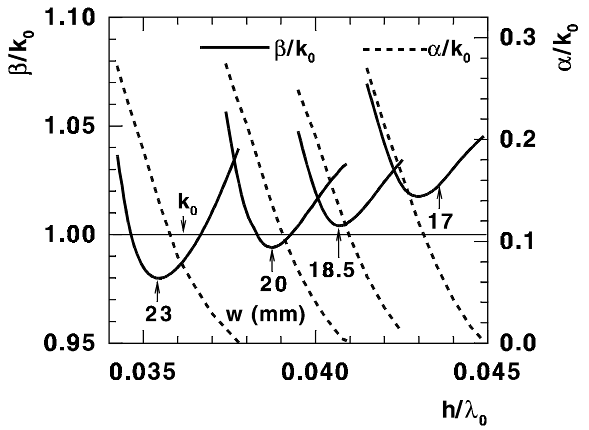

Fig. 4 Dispersion characteristics of the space leaky wave of the first class in dependence on the slotwidth w, ε_r=10.8, h=1.27 mm.

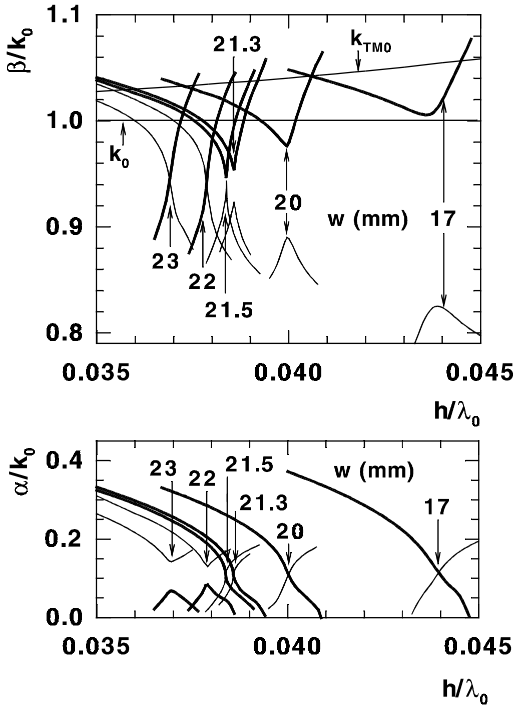

Fig. 5 Dispersion characteristics of the surface leaky wave in dependence on the slotwidth w, ε_r=10.8, h=1.27mm. Thick lines - surface leaky wave, thin lines - nonphysical complex mode (for w=22 and 23 mm this wave is physical at lower frequencies).

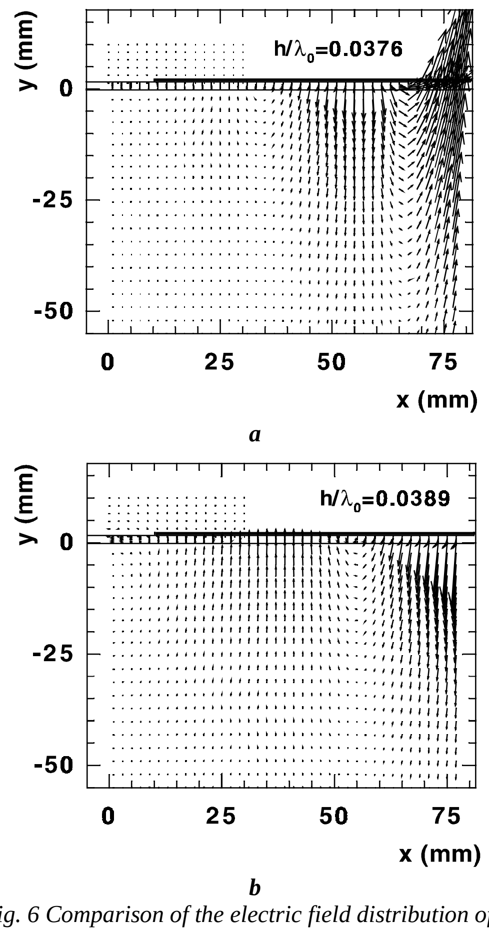

Fig. 6 Comparison of the electric field distribution of the surface leaky waves on the slotline from Fig. 5 at w=21.3 mm when h/λ_0=0.0376 – case a, and h/λ_0=0.0389 – case b.