# FDTD Study of Surface Waves in Microstrip and Patch Structures

Elena Semouchkina[1], George Semouchkin[1], Wenwu Cao[1], and Raj Mittra[2]

[1]Materials Research Institute, [2]Department of Electrical Engineering, The Pennsylvania State University, University Park, Pennsylvania 16802, USA

***Abstract* — The Finite Difference Time Domain (FDTD) method is employed to visualize surface wave propagation in microstrip line and patch structures. Signal distortion in microstrip lines caused by surface waves is studied in substrates with different permittivities. Electric and magnetic field components of surface waves, excited by different sources, are analyzed and different types of surface waves are identified. An efficient method to suppress surface wave propagation using low-K plugs inserted in higher-K substrate is demonstrated.**

## I. INTRODUCTION

Fabrication of microwave devices with high permittivity (high-K) substrates is attractive because of size reduction. However, strong surface waves excited in higher-K substrates exacerbate mutual coupling effects and introduce uncontrolled radiation at the substrate edges [1]. Since the present trend is to push the operating frequencies into the millimeter wave range, the role of surface waves is expected to increase even further in the future. In fact, a patch-type microstrip antenna can lose as much as 70% of the power in surface wave radiation [2]. A number of techniques have been proposed to suppress surface wave propagation, including special antenna designs [3], micromachining the substrate [4] and employing photonic bandgap structures [2, 5]. However, the problem is still far from being resolved. One of the difficulties in tackling the suppression problem is the lack of availability of direct methods for investigating surface waves. Conventionally, the presence of surface waves is estimated indirectly by analyzing the ripples in the antenna radiation pattern. Gonzalo *et al.* [6] have recently made an attempt to visualize surface waves in patch antenna substrates by using FEM simulations and have presented resonance patterns caused by reflections of surface waves from the edges of the substrate. However, the above method is not well suited for studying the excitation and propagation of surface waves.

In a previous work [7] dealing with the simulation of ring resonators with high-K dielectric substrates, we have shown that the FDTD method provides a means for visualizing surface waves in the time domain. In this study we present the results of additional investigation of the surface wave phenomenon by using the FDTD in three types of structures: infinite microstrip lines with substrates of different permittivity; open-ended microstrip lines; and patch-type microstrip structures.

## II. RESULTS AND DISCUSSION

### A. Infinite Microstrip Line

Fig. 1 presents contour plots and side-views of the normal component of the electric field on the plane below the microstrip, for substrates with different permittivities.

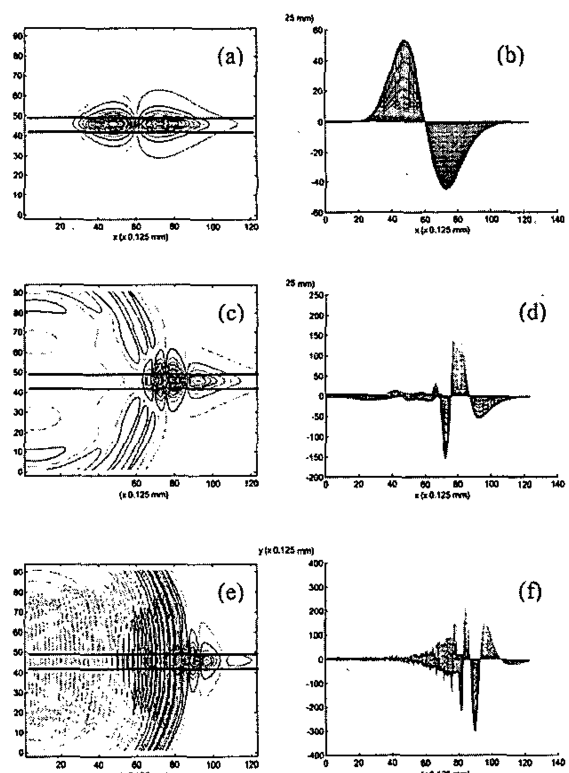


Fig. 1. (a, c, e) Contour plots and (b, d, f) side views of the normal electric field component distribution in the plane below the microstrip in substrates: (a, b) alumina (K=8.4), (c, d) rutile (K=84), and (e, f) potassium niobate (K=420).

An electric field Gaussian-shaped pulse, modulated by a sine wave, was applied between the microstrip and the ground plane to excite the structures. The K values correspond to: alumina ceramics (K=8.4), rutile ceramics (K=84) and potassium niobate (K=420). While the signal propagating in alumina substrate is similar to the signature of the excitation pulse (Figs. 1a and 1b), the signals propagating along the microstrip lines in higher K substrates are accompanied by surface waves radially spreading from the signal source (Figs. 1c and 1d). Dominant field component of these waves is electric component directed normally to the substrate surface. Therefore, these waves could be regarded as transverse magnetic (TM) waves [8]. The intensity of the waves dramatically increases with increasing K, as expected for TM waves [9].

The plots show that the velocity of surface waves is less than the velocity of signal propagation in microstrip line. However, the difference in the two velocities is so small that the signal tail becomes distorted due to surface waves. Figs. 1e and 1f reveal that surface waves are also generated by the signal propagating along the microstrip line, as is evident from the picture of interference between these waves and surface waves generated by the excitation source. These results are in agreement with those obtained by Nghiem *et al.* [10], who have shown, by using spectral domain technique, that the dominant mode in the transmission line should leak into TM surface waves.

### *B. Suppression of Surface Waves*

We have also investigated the possibility of suppressing the surface waves by inserting low-K dielectric plugs into high-K dielectric substrates.

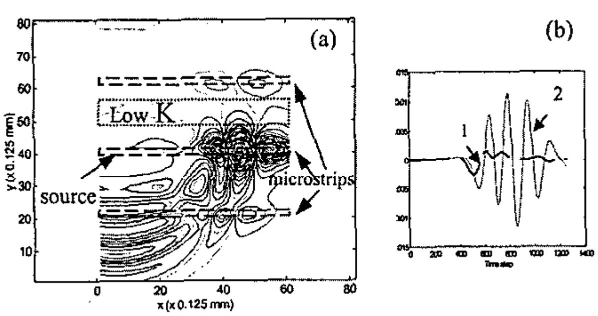


Fig. 2. (a) Visualization of surface wave suppression by a low K plug (K=8.4) placed between the upper and the central microstrip lines in the substrate with K=84. (b) Voltages induced in the upper (1) and the lower (2) microstrip lines.

Fig. 2a demonstrates that thin plugs of K=8.4 can effectively protect the region with permittivity K=84 from penetration of surface waves excited by the signal source. Fig. 2b shows voltage signals induced in the upper and lower microstrip lines after signal excitation in the central line (see Fig. 1a). As seen from the plot, voltage signal in the upper line is close to zero due to suppression of coupling between the upper and the central lines by the low K plug.

### *C. Open-Ended Microstrip Line*

To investigate surface waves radiated by open-ended microstrip line and by patch structures, it was necessary to prevent the substrate waves excited by the source from penetrating into the region under study. Low-K (K=8.4) plugs were inserted into a high-K (K=84) substrate for this purpose, as shown in Fig. 3a.

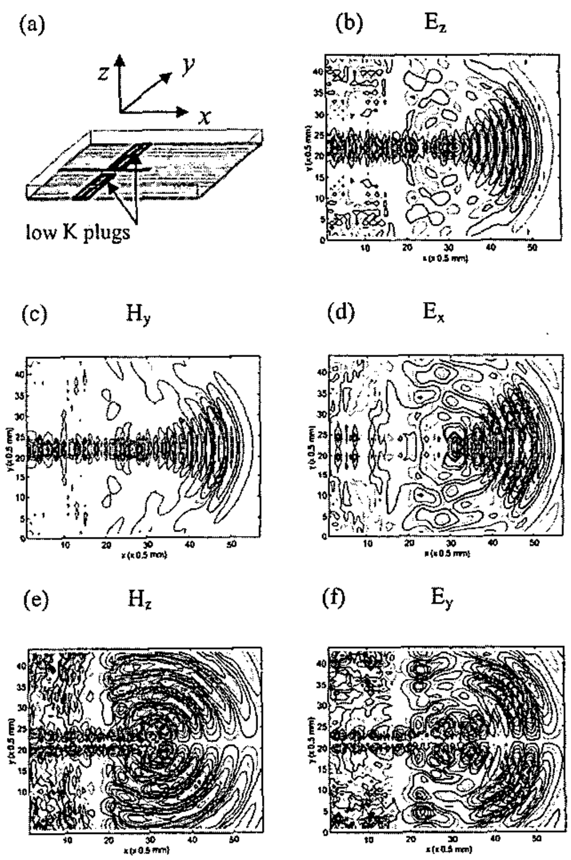


Fig. 3. (a) Geometry used to simulate the open-ended microstrip line and (b-f) contour plots of field components in the plane below the microstrip: (b) $E_z$, (c) $H_y$, (d) $E_x$, (e) Hz, and (f) $E_y$.

Figs.3 (b-f) present the contour plots of some of the field components in the plane located below the air-substrate interface. The field patterns of the normal component $E_z$ (see Fig. 3b) and of the transverse component $H_y$ (fig. 3c) show that the open-end of the microstrip line excites surface waves that spread symmetrically relative to the the microstrip line axis in an angle, which is less than 90 degrees. This mode resembles the dominant TEM mode propagating along the microstrip line, however, it has a pronounced longitudinal component of the electric field $E_x$ (see Fig. 3d).

The patterns of the normal magnetic field component $H_z$ (Fig. 3e) and of the longitudinal electric field component $E_x$ (Fig. 3d) show that in the sectors adjacent to the one containing the TEM-type beam, there is another mode that spreads radially away from the open end. This mode has the wavelength about twice as large as that of the TEM-type mode. Since the field components of this mode to the left and right of the microstrip line are directed opposite to each other, it leads to the interpretation that the mode originates from the $H_z$ component of the dominant mode, which has opposite directions at the two sides of the microstrip. The pronounced $H_z$ component of this mode leads one to interpret it as a TE–type mode. The patterns of the $H_x$ and $E_y$ components are very similar and have opposite directions at the two sides of the microstrip line, similar to the fringing fields on these sides.

*C. Patch Structures.*

Radiating edges of microstrip patch antennas are usually supposed to be the sources of surface waves excitation [11]. Therefore, one approach to suppress surface waves is to locate parasitic patches opposite to the radiating edges of the patch [12].

We have previously shown [13] that symmetrically-fed rectangular patch structures can support half-wavelength (1, 0) resonance only in the longitudinal direction (direction of the feedline axis). The lowest transverse resonance is of (0, 2) type and it does not support the radiation because the fringing fields of the (0, 2) mode are coplanar in both the E-and H-planes [14]. Therefore, the patch edges normal to the feedline axis are the only radiating edges of symmetrically fed rectangular patches of any geometry. In asymmetrically fed patch with its width larger than its length, the first half-wavelength resonance occurs in the transverse direction [13] and supports radiation from the sides parallel to the feedline axis. Hence, one would expect surface waves to be excited by different parallel sides of the patch depending on the type of feeding.

Figs. 4 (a-c) present the contour plots of the normal electric field component in the plane located below the air-substrate interface for the rectangular patch structures with different geometries. The plots show that all the patterns have the following common features: (a) there is a pronounced wide beam originating from the patch side located opposite to the feedline input; (b) no similar beams are observed from any other patch side; and (c) the input point of the patch also acts as a source of radially spreading waves.

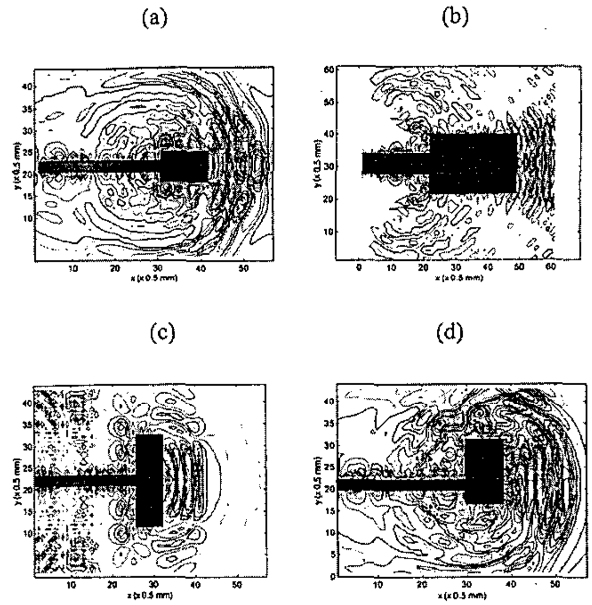


Fig. 4. Contour plots of the normal electric field component $E_z$ in the plane below the substrate surface for the patch structures with different geometry: (a) symmetrically fed, with E-plane parallel to the feedline axis, (b) ) symmetrically fed patch with matching slots and E-plane parallel to the feedline axis, (c) symmetrically fed, with E-plane normal to the feedline axis, and (d) asymmetrically fed, with E-plane normal to the feedline axis.

The wide beam in Figs. 4 is composed of three beams. The central beam propagates along the feedline axis and is similar to the one excited by an open-ended microstrip line. The two other beams spread to the left and right of the central beam. The side beams have 180 degrees phase shift relative to the central beam.

The radially spreading waves appear to originate from the fringing fields at the sides of the microstrip feedline, because the components of these waves have the same directivity as the fringing fields. They are quite similar to the waves spreading radially in the case of the open-ended microstrip. It is obvious that the discontinuities are of the same type in both cases, insofar as the excitation of surface waves is concerned.

Fig. 4d presents the contour plot of the normal electric field component of surface waves launched by an asymmetrically-fed patch structure. The pattern is asymmetric, but has no indication on surface waves emanating from the radiating sides. Along with the results obtained for symmetrically-fed patch structures, this result for the asymmetric case indicates that surface waves do not necessarily originate from the radiating edges of the patch structure. Instead, multibeam radiation of the surface waves from nonradiating edge is observed in the asymmetrically-fed patch. The central beam resembles the quasi-TEM mode excited by an open-ended microstrip line and by symmetrically-fed patches. Radially spreading waves are also observed in the asymmetrically-fed patch, but they are less intensive than those for the case of symmetrical feeding.

## V. CONCLUSIONS

The demonstrated capability of the FDTD method to visualize surface waves in high-K substrates enables us to re-examine the existing views on the excitation and propagation of surface waves. A few important observations are summarized below:

(i) Signal source of "electric wall" type excites intensive surface waves of TM-type spreading radially from the source. A signal propagating along the microstrip serves as another source of TM surface waves that interfere with similar waves generated by the excitation source.

(ii) Surface waves are excited by the discontinuities in guided wave systems. In particular, both the open end of a microstrip line and patch edges located opposite to the feedline input excite surface waves. At the same time, radiating edges of the patch, which usually are considered to be the sources of surface waves, do not contribute to their excitation.

(iii) Open-ended microstrip line and side-fed patch structures are found to be the principal sources of excitation two types of surface waves. The most intensive beam corresponds to a TEM-type of mode propagating along the microstrip line axis. Surface waves of another type spread radially in the form of a TE-type of mode. The last waves appear to originate from the fringing fields of the microstrip line or patch-type structures.

(iv) Low-K dielectric plugs embedded in higher-K substrates are found to be effective in blocking surface wave propagation.


## ACKNOWLEDGEMENT

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