EE-2

A Generalized Method for the Distinction of Radiation and Surface-Wave Losses in Microstrip Discontinuities†

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Abstract

A generalized method for calculating both radiation and surface-wave losses is developed for microstrip discontinuities. The losses are determined by a rigorous Poynting vector analysis where the current distribution over the entire microstrip discontinuities is a result of a full-wave moment method solution. It is found that above a certain frequency, the surface-wave loss becomes more important than the radiation loss. A self-consistency check of the results based on power conservation is also presented.

Introduction

Radiation and surface waves are unavoidable physical effects of microstrip discontinuities associated with an open structure. In recent years, a full-wave analysis that includes these physical effects has been developed for various microstrip discontinuities [1-5]. Although both radiation and surface waves are included, the analysis only provides the total losses. One still can not distinguish the percentage of power losses due to radiation and due to surface waves. The full-wave analysis employs the moment method to find the currents in the microstrip circuits and subsequently, the circuit parameters of the discontinuities. From an antenna point of view, once the currents in a conductor are known, the time-harmonic fields can be computed. From the theory of printed circuit antennas [6], the radiated space waves are spherical waves in the hemisphere above the substrate; while surface waves are cylindrical waves guided along the planar direction of the substrate and decay exponentially toward the free space. The power due to radiation and surface waves can therefore be computed separately through a rigorous Poynting vector analysis. In this work, radiation and surface-wave losses for several types of microstrip discontinuities are investigated. These discontinuities include open-end, right-angle bend, rectangular patch and overlay electromagnetically coupled (EMC) lines.

Analysis

In the integral equation formulations, all field components can be expressed in terms of the dyadic Green's functions and the current components. Therefore, the current distribution over an entire discontinuity can be treated as a basic block [7] for this analysis. The radiation loss can be calculated by integrating the Poynting vector over an infinite plane (shown in Fig. 1) in the free space above the entire microstrip circuits. The expression is written as

$$P_{ra} = \frac{1}{2} R_e \iint_{\Sigma} (\vec{E} \times \vec{H}^*) \cdot \vec{ds} \qquad (1)$$

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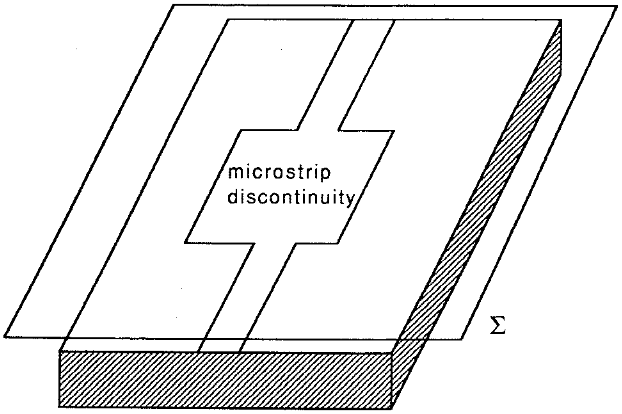

Fig. 1. Integration plane for calculating radiation loss.

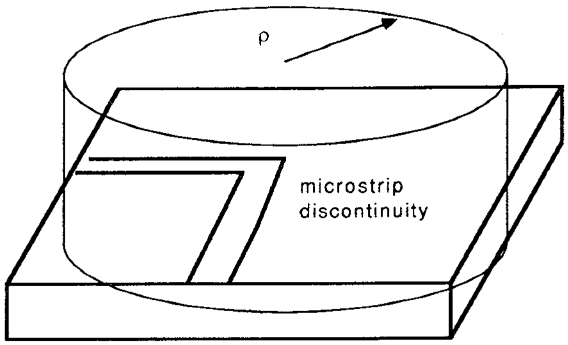

Fig. 2. Integration cylinder for calculating surface-wave loss.

Frequency (GHz)	Total Power	Reflected Power	Transmitted Power	Radiation Loss	Surface-wave Loss
20	1.001	0.134	0.822	0.022	0.023
21	0.997	0.153	0.787	0.027	0.030
22	1.001	0.172	0.755	0.033	0.041
23	1.005	0.193	0.719	0.039	0.054
24	1.007	0.208	0.678	0.048	0.073

Table 1. Power conservation check for right-angle bend discontinuity. (Parameters are the same as those in Fig. 4.)

Surface waves can be obtained from the residues of the Fourier integrals in the spectral domain approach. With the characteristics that surface waves propagate along the surface, the surface-wave loss can be found by integrating the Poynting vector over a cylinder (shown in Fig. 2) of large radius ρ. The expression of the surface-wave power is

$$P_{su} = \int_0^{\infty} \int_0^{2\pi} \frac{1}{2} R_e(\vec{E}_{res} \times \vec{H}^*_{res}) \cdot \hat{\rho}\rho d\phi dz \qquad (2)$$

Numerical Results and Discussions

Due to power conservation, the summation of each power should be equivalent to the incident power. An example of this check is shown in Table I. The incident power is normalized to 1. Due to power conservation, total power which is the summation of reflected, transmitted, radiated and surface-wave power should be equal to 1. The result in Table I shows excellent agreement.

Figs. 3-5 show the percentage of radiation loss, surface-wave loss, and total power loss as a function of frequency for open-end, right-angle bend, and overlay electromagnetically coupled lines respectively. It is seen that the losses due to both radiation and surface waves increase with frequency. At low frequencies, the losses are mainly due to radiation. When the frequency increases, surface-wave loss increases faster than the radiation loss. Above a certain frequency, the surface-wave loss is more significant than the radiation loss. Fig. 6 shows the power distributions of a rectangular patch antenna. It can be seen that the maximum radiation efficiency is about 65% in a very narrow band around 7.2GHz with about 10% surface wave loss and 25% return loss.

Conclusions

A generalized method to distinguish power

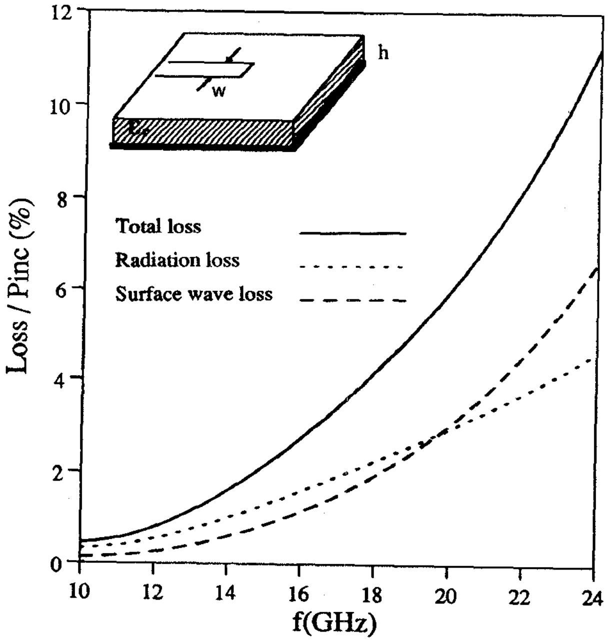

Fig. 3. Power losses versus frequency for open-end discontinuity. (ε_r = 10.2, w = 24mil, h = 25mil)

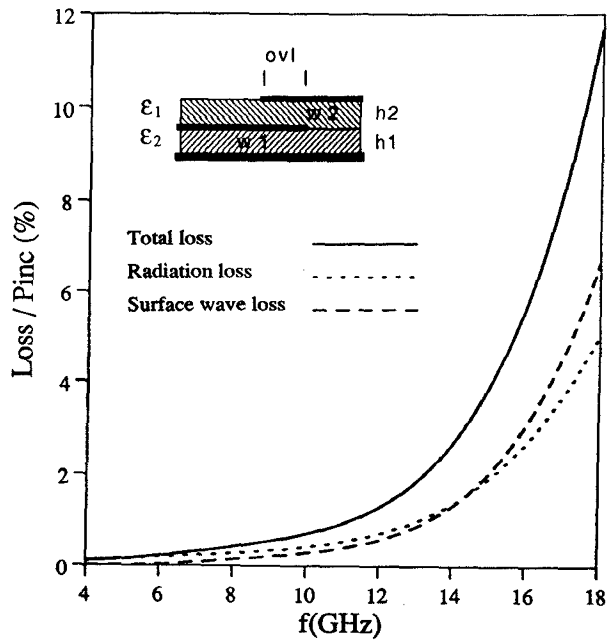

Fig. 5. Power losses versus frequency for overlay EMC lines. (ε_1 = 2.2, ε_2 = 10.2, h1 = 25mil, h2 = 25mil, w1= 42mil, w2=76mil , ovl = 83mil)

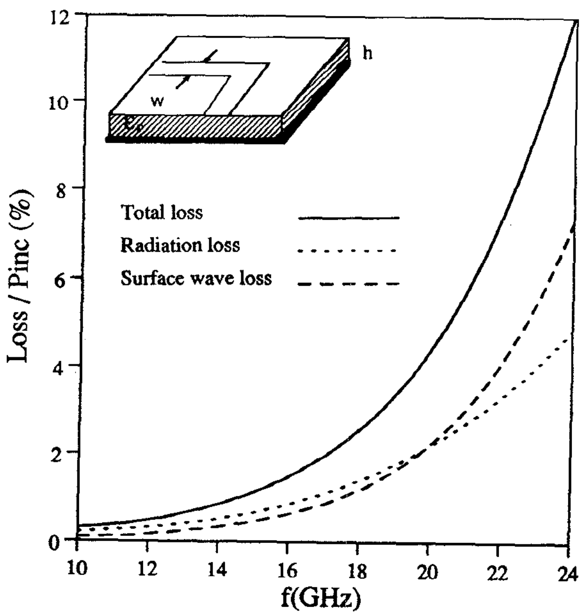

Fig. 4. Power losses versus frequency for right-angle bend discontinuity. (ε_r = 10.2, w = 24mil, h = 25mil)

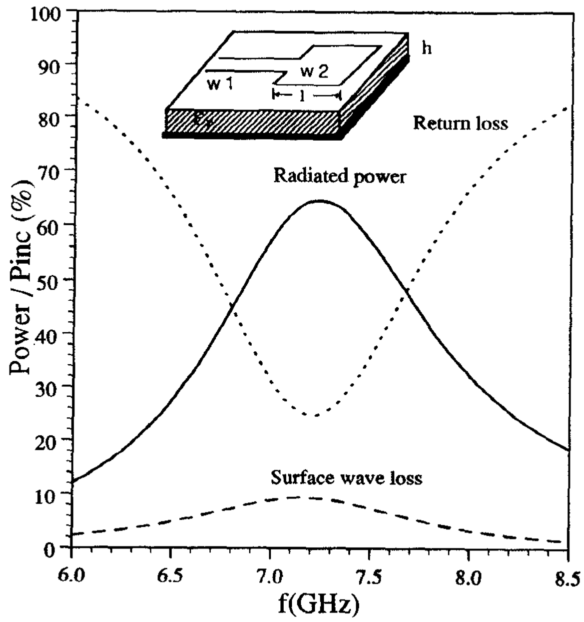

Fig. 6. Power distributions versus frequency for a rectangular patch antenna. (ε_r =2.33, w1= 50mil, h=62mil, w2=500mil, l=500mil)

losses due to radiation and surface wave is presented. This method should aid in CAD for minimizing power losses launched into radiated space waves and surface waves from arbitrary microstrip discontinuities and maximizing the radiation efficiency for arbitrary patch antennas. Power loss mechanism in other types of microstrip discontinuities, such as gap, step and stubline will be easily implemented in this analysis.

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