Interaction between a waveguide-fed narrow slot and a nearby conducting strip in millimeter-wave scanning microscopy

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(Received 14 February 2000; accepted for publication 21 August 2000)

Millimeter-wave microscopy is investigated with the aid of a simplified model. The model consists of a parallel plate waveguide opening into a ground plane and radiating in the presence of a perfectly conducting strip. The method of moments is used together with a quasi-static approximation to solve for the reflection coefficient. Numerical results included indicate that high resolutions are feasible with this apparatus. © 2000 American Institute of Physics.

I. INTRODUCTION

The goal of millimeter-wave scanning microscopy is a device that creates an image from the resistivity of the matter examined. Such a device would be useful for nondestructive testing of super- and semiconductors, printed circuits, and conducting polymers. Different designs have been suggested in recent years.1–5 In this article we analyze a simple configuration that contains the essential features of such a probing device: a parallel-plate waveguide, along which a transverse electromagnetic microscopy (TEM) mode is propagating, is terminated by a ground plane in which a narrow slot (or aperture—these terms will be used interchangeably) is cut. A narrow conducting strip is placed in front of the slot and parallel to it (see Fig. 1). Changes in the reflection coefficient can be used to locate the strip. In contrast with optical microscopes, the resolution is not determined by the wavelength, but by the physical dimensions of the probing device. Exploring the dependence of the resolution on these dimensions is the aim of this article, where we solve the electromagnetic field equations with the method of moments (MoM).

The formulation used for setting up the MoM solution is the generalized network formulation as outlined in Ref. 6, which is useful in the solution of problems of coupling through apertures. In this formulation, a perfect conductor and magnetic currents radiating on both its sides replace the slot. The problem is then divided into two parts, one for the waveguide region (region a) as shown in Fig. 2(a), and another one for the half-space region containing the strip (region b) as shown in Fig. 2(b). Discretization of the integral equations describing the problem leads to a set of linear equations. When these are written in matrix form, they are readily seen to be analogous to equations of an electrical network, where each region is represented by appropriate matrices. All parameters of interest can be readily calculated from the solution of these generalized network equations.

The organization of this article is as follows: In Sec. II we use the equivalence theorem and image theory to derive a set of two simultaneous integral equations that represent the problem. Next, we arrive at their discrete form by application of the MoM. In Sec. III we use modal analysis to calculate the waveguide region admittance matrix. Section IV presents the techniques used for evaluating the half-space region generalized network matrices. Section V contains a few numerical results, displaying the dependence of the dominant-mode reflection coefficient on the strip’s position. Finally, Sec. VI summarizes the article.

II. SETTING UP A METHOD OF MOMENTS SOLUTION

A. Continuous operator equations

In what follows we derive a set of two simultaneous integrodifferential operator equations for the problem. A perfectly conducting plane replaces the slot, dividing the problem into two separate regions (see Fig. 2). In order to account for the fact that the tangential electric field in the original situation is not zero, but continuous across the slot, surface magnetic current distributions are placed in the vicinity of the ground plane on both its sides. If \( \mathbf{E} \) denotes the field on the aperture in the original (undivided) problem, then on one side of the plane the magnetic current \( \mathbf{M} \), is given by

\[
\mathbf{M} = \hat{z} \times \mathbf{E}
\]

(1)

while on the other side it is \( -\mathbf{M} \). Furthermore, the perfectly conducting strip is replaced by an equivalent electric current on its surface. The boundary condition on the strip (zero total tangential electric field) is used to form a relation between the electric current on the conductor and the magnetic current on the slot. In order to use the free space Green’s function, image theory is applied to eliminate the ground plane, as shown in Fig. 3. From the above, the first operator equation readily follows. We have

\[
\hat{z} \times [\mathbf{E}_0(-\mathbf{M}) + \mathbf{E}_0(\mathbf{J})] = 0
\]

(2)

on the strip.