Advances in
Electronics and Electron Physics

EDITED BY
PETER W. HAWKES

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PREFACE

This volume of these *Advances* marks the introduction of a new theme, namely, image pick-up and display. Hitherto, a separate series of advances, edited by Dr. Benjamin Kazan, had been devoted to this subject. From now on, articles dealing with such topics will appear in *Advances in Electronics and Electron Physics* and Dr. Kazan will continue to be responsible for such chapters. We welcome the first of these, by J. Heinzl and C. H. Hertz, on ink-jet printing. The proliferation of electronic systems for processing and storage of information during the past few years has placed growing emphasis on the need for printing technologies that are capable of making this information available without the limitations associated with conventional impact-type printers such as bulk, noise, and speed. One of the most promising technologies now coming into commercial use is that of ink-jet printing, in which the deposition of fine droplets of ink on paper is electronically controlled. This has many advantages, which include silent operation, high speed, color capability, and the immediate creation of an image without further processing. The purpose of this chapter on ink-jet printing is, thus, to put the different systems currently being investigated into perspective and to provide a broad outline of the important principles involved for those readers not entirely familiar with the subject.

The other five chapters range from the mathematical analysis of microstrip antennas to electron image formation, with chapters on units and radiation theory and on the theory of surface electronic structure. The first of these complements the contributions by F. E. Gardiol in earlier volumes of this series. The article by Berthold W. Schumacher is a personal, perhaps even polemical, view of the suitability of SI units in such fields as radiative transfer.

The chapters on electron image formation are concerned with two aspects of this topic that have become of extreme importance. D. Van Dyck reconsiders the various methods employed for simulating high-resolution electron images, pointing out their strong points and their weaknesses, and shows how the latter can be circumvented. The slowly increasing availability of vector, parallel computers will certainly revolutionize this type of calculation, and I am sure that this survey will be appreciated by everyone who tries to employ these new machines to solve the problem of simulating images.

In the other chapter on electron imagery, H. Kohl and H. Rose explore in depth the theory of image formation by inelastically scattered electrons. This is the first satisfactory treatment of this difficult subject, of which there is no proper study in even the most recent textbooks. I am extremely pleased to see such a full account appear in these *Advances*.

The chapter by E. Wimmer, H. Krakauer, and A. J. Freeman on the theory of surface electronic structure is a major attempt to impose a pattern on a host of very complex material. I have no doubt that those working on this subject, not excluding relative newcomers, will be grateful for this rich survey of, and guidance through, a difficult field.

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ADVANCES IN ELECTRONICS AND ELECTRON PHYSICS, VOL. 65

Dyadic Green's Functions and Their Use in the Analysis of Microstrip Antennas

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I. SUMMARY

This chapter is concerned with the influence of the dielectric substrate on some electrical properties of microstrip antennas and uses dyadic Green's functions in media consisting of plane parallel or cylindrical concentric layers. The utilization of the cavity model with conducting magnetic side walls substantially simplifies the calculation of the radiation patterns. This model also allows a more detailed analysis of the excitation of surface waves along

the air–substrate interface. Analyses of the most commonly used microstrip antennas have indicated a pronounced influence of the characteristics of the substrate on the electrical properties of these antennas.

II. Introduction

The recent developments of the elements and arrays of microstrip antennas have been highly influenced by the large advance in the technology of microwave integrated circuits in the last few years. The basic concept of the microstrip antenna was first published by Deschamps (1953). The subject, however, did not receive much attention from the scientific community up to the end of the 1960s and the beginning of the 1970s, when Byron (1970) published a paper describing a new antenna consisting of a conducting patch separated from the ground plane by a dielectric layer. Not much after, a patent was granted to Munson (1973) for a microstrip antenna element, and Howell (1972) published studies on microstrip patch antenna elements with rectangular and circular geometries. From this time on, a large number of papers were published on microstrip antennas, with particular emphasis on the techniques for the implementation of these antennas and on the analyses of their electric behavior. Carver and Mink (1981) and Mailloux *et al.* (1981) published reviews that are useful for an immediate introduction to the subject.

An analysis of the theoretical and experimental contributions published on the subject indicates the necessity of further studies concerning the influences of the dielectric substrate on the electrical properties of microstrip antennas. Thus, as one of the main objectives of this work, dyadic Green's functions and the cavity model with conducting magnetic side walls are used to investigate the effect of the dielectric substrate on the far field and on the excitation of surface waves in microstrip antennas.

In Section III, the main properties and applications of microstrip antennas are discussed, and the cavity model with conducting magnetic side walls for the calculation of the radiated fields from the antenna is presented. In Section IV, the definition and basic properties of dyadic functions and of the free-space dyadic Green's functions for use in the following sections are presented.

In Section V, an introduction to the expansion of the free-space dyadic Green's functions in vector wave functions in the rectangular and cylindrical coordinate systems is presented. Expressions of the dyadic Green's functions for media with three and four layers, plane and parallel to each other, and with three concentric cylindrical layers are then obtained. Also obtained in this section are the asymptotic expressions of these dyadic Green's functions using the saddle point method or the method of steepest descent.

In Section VI, the solution of problems of microstrip antennas using the mathematical formalism introduced in the previous sections is presented. The effect of the dielectric substrate on the radiation patterns of the microstrip disk antenna and for two different modes of operation of the antenna cavity is analyzed.

In Section VII, the effect of a dielectric cover on the radiation patterns of microstrip ring antennas is studied. In Section VIII, the effect of the dielectric substrate on the radiation patterns of wraparound antennas is considered. In Section IX, and analysis of the problem of excitation of surface waves in the dielectric-air boundary of microstrip disk antennas is developed with the objective of obtaining the effect of the dielectric substrate on the directivity and efficiency of excitation of space waves.

In Section X, concluding remarks are presented, based on the results obtained from the analyses developed in the previous sections.

III. Properties and Applications of Microstrip Antennas

A. Introduction

A brief discussion about the definition and basic properties of microstrip antennas is presented in this section. The cavity model with conducting magnetic side walls, which will be used in subsequent sections for the analysis of these antennas, will also be discussed.

B. Description of Microstrip Antennas

The most simple configuration of a microstrip antenna consists of a conducting patch separated from the ground plane by a dielectric substrate, as shown in Fig. 1.

The conducting patch may have various geometrical forms, such as rectangular, circular, triangular, and ring. There are also other types of microstrip antennas such as those that may be adapted to curved surfaces; these are discussed in Section VIII.

The feed of these antennas may be accomplished by means of microstrip lines connected to the side of the patch or by means of a coaxial cable with its central conductor passing through the ground plane and the dielectric substrate and connected to an adequate position of the patch. The conducting

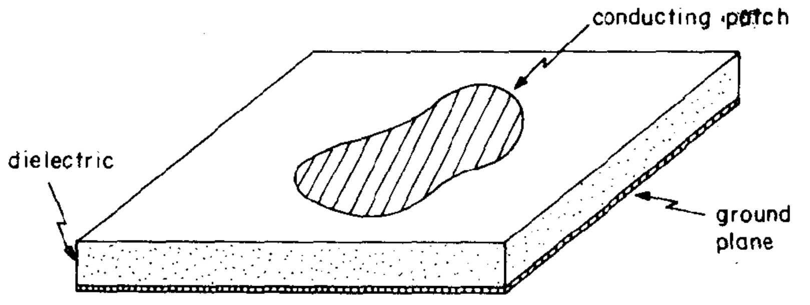

FIG. 1. View of a microstrip patch antenna.

materials are usually copper or gold and the dielectric substrates are of various types with relative permittivities varying from 2 to 10. These antennas have been widely investigated (Carver and Mink, 1981; Bahl and Bhartia, 1980). The mechanism of radiation is discussed in some detail by Bahl and Bhartia (1980).

C. *Applications of Microstrip Antennas*

Although the technology of microstrip antennas is still in its infancy, these antennas are finding uses in a variety of applications, some of them include (Carver and Mink, 1981; Munson, 1979) satellite communications, doppler radars and others, radio altimeters, command and control, high-speed vehicles (airplanes, missiles, and boosters), remote sensing, and radiators in biomedical applications.

The main advantages and disadvantages of these antennas are discussed by various authors (Carver and Mink, 1981; Howell, 1975; Derneryd, 1976, 1978; Agrawal and Bailey, 1977; Wood, 1980; Bahl *et al.*, 1980; Garvin and Munson, 1977; Munson, 1974; Collier, 1977; Bahl, 1979) and are summarized below:

(a) Advantages

Low weight and small volume

Low profile and possibility of adapting on surfaces of various forms

Low production cost

Possibility of obtaining linear and circular polarizations by adequate choices of the feeding point

Can be easily integrated with other devices

Feeding lines and matching devices can be fabricated simultaneously with the antenna structure.

(b) Disadvantages
Narrow frequency band
Low gain
Radiation in one hemisphere only
Low isolation between feeding and radiating elements
Possibility of excitation of surface waves
Low power capacity

The effects of some of these disadvantages may be minimized with a careful antenna design. For example, the excitation of surface waves (as will be discussed in Section IX) may be decreased with the use of substrates with small thicknesses and low values of relative dielectric permittivities.

D. *Cavity Model with Conducting Magnetic Side Walls*

In the analysis of microstrip antennas, a theoretical model is quite often used, based on the following observations (Lo *et al.*, 1979):

(a) The electric field in the region between the conducting patch and the ground plane has only the component normal to the plane of the patch, and the magnetic field has only the components parallel to this plane. This is a reasonable assumption for the usual cases since the thickness is commonly much smaller than the wavelength.

(b) The electromagnetic fields in the region between the two conductors do not vary along the direction normal to the plane of the conducting patch. This is a reasonable approximation since the substrate thickness d is much smaller than the wavelength in the substrate λ for the frequencies of interest.

(c) The magnetic field component tangent to the edges of the patch is equal to zero. This results from the fact that there is no electric current component normal to the edges of the patch.

Based on these observations, the region between the patch and the ground plane may be treated as a cavity having upper and lower electric conducting planes and conducting magnetic side walls. Thus, the fields in the antenna are considered as those existing inside the cavity. The knowledge of the electric field component tangent to the conducting magnetic side wall allows the definition of an equivalent magnetic current density in this wall based on the Huygen's or equivalence principle (Harrington, 1961). The problem of obtaining the radiated fields from a microstrip antenna may thus be changed into a much more convenient problem of obtaining the radiated fields from a magnetic current source located in a stratified medium.

The formalism often used to analyze microstrip antennas neglects the presence of the dielectric substrate that separates the conducting patch from