

# Preface

This book is devoted to the theory of thin vibrator antennas using an impedance approach, developed by the authors as a generalization of the classic theory of perfectly conducting thin vibrators. The notion of impedance, due to the wide spectrum of electrodynamics problems solvable by such an approach, has become one of the most universal methods for modeling wave processes. It provides a wonderful opportunity for analytical solution searching, simplifying the mathematical formulation of the boundary problem. Of course, the restrictions imposed on parameters during problem formulation and solution somewhat limit such a possibility. However, from a practical point of view, the necessary restrictions turn out to be natural for thin vibrator antennas. The universality of the impedance model and the naturalness of the antecedent suppositions have made it possible to create a theory of thin impedance vibrator antennas in a single framework as a generalization and continuation of classical electrodynamic theory for thin perfectly conducting vibrators. The scope of this book includes conducting cylindrical radiators, corrugated and ribbed vibrators, radiators with isolating coverings, and so on, and it covers different cases both of impedance vibrator antenna excitation and their location in spatial regions of different geometries, including regions filled by a material medium. This concept allows one to control and optimize the electrodynamic characteristics of vibrator antennas and finally makes it possible to widen the boundaries of the application of vibrator antennas application to complex, modern radio and electronic systems and devices, taking into account requirements concerning their mobility and reliability in a hostile environment.

It should be noted that the mentioned theory of thin vibrator antennas with distributed surface impedance has been formulated in separate papers (mostly by the authors of this monograph) and published over last 30 years in a variety of scientific publications. However, these results have never been generalized and assembled in a separate publication, and that impelled us to write the book.

This monograph comprises seven chapters and five appendices. References are given at the end of each chapter and are indicated by a number in square brackets, e.g., [3] in Chap. 2.

Chapter 1 is introductory. It briefly presents equations of macroscopic electrodynamics and the approximating analytical methods of their solution. We hope that this information will make it possible to read the succeeding chapters without consulting the specialized literature.

Chapter 2 is essentially methodological and is devoted to the key problem concerning radiation of electromagnetic waves by a thin impedance vibrator located in free space or in an infinite absorbing material medium. The asymptotic solution for the current on the impedance vibrator is obtained by the averaging method. The agreement of this solution with results obtained by other methods for symmetric perfectly conducting vibrators is analyzed in detail. Section 2.2.2 is worthy of special attention. Here asymptotic formulas for complex surface impedances representing different metal-dielectric structures are given for reference. They include a solid cylindrical conductor with skin effect, a periodically corrugated or ribbed cylindrical conductor, a cylindrical conductor with isolating magnetodielectric covering, a cylindrical conductor with transverse periodic dielectric insertions, and a dielectric cylinder. These formulas relate vibrator structure and the numerical value of the surface impedance, which may be used as a parameter in a mathematical model.

Resonant properties of impedance vibrators in dependence on surface impedance value are also analyzed in this chapter. It should be noted that the formula for resonant vibrator length allows for the evaluation of its value by surface impedance only for the required degree of radiator miniaturization. Radiation fields of resonant impedance vibrators in infinite medium are also covered in this chapter. Since impedance vibrators are widely used in medicine, the near-field analysis is made for biological tissues.

At present, impedance vibrator antennas, particularly in multilayered dielectric shells, are used in various medium with electrophysical parameters sufficiently different from those of air. The vibrators are applied in devices for underground and undersea radio communication, medical diagnostics and hyperthermia, geophysical investigations, and so on, and are located near metallic bodies of various configurations. The simplest configuration consists of an infinite perfectly conducting plane, which, in turn, is a good model for the approximation of screens in the form of finite-dimensional plates.

In Chap. 3, we consider the problem of radiation of electromagnetic waves by impedance vibrators in material medium located over an infinite perfectly conducting plane. Since the problem for a vertical asymmetric vibrator (monopole) reduces by a mirror-image technique to that for a symmetric vibrator, as analyzed in Chap. 2, a horizontal vibrator is chosen for this study. In this chapter, we obtain by the averaging method approximate analytical formulas for currents and full electromagnetic fields exited by a single horizontal impedance vibrator and by a system of crossed vibrators over a perfectly conducting plane in a half-infinite homogeneous medium with losses. The spatial distribution of the near fields in dependence on the medium's material parameters and the influence of the plane is investigated numerically. The formation of a radiation field with given spatial-polarization characteristics by a system of crossed impedance vibrators is also analyzed.

The vibrator's cross section and the distribution of surface impedance can serve as additional parameters to obtain the required electrodynamic characteristics for cylindrical vibrator antennas. Such rather specific, at first glance, nonregular vibrators are treated in Chap. 4. Here, to avoid overlapping with results in the literature while retaining the generality of the problem, the problem of excitation of a nonregular vibrator in free space by an incident-plane electromagnetic wave is considered. The normalized backscattering cross section is chosen as a parameter in a numerical simulation. In addition, this chapter deals with some other questions as well. As expected, structural complications of vibrators lead to difficulties in obtaining approximate analytical solutions for the vibrator current. These solutions, except in some specific cases, become too cumbersome and of little use in engineering practice. Such a situation arises, for example, in the analysis of multielement vibrator antennas. Therefore, in Chap. 4 a new numerical-analytic method for solving scattering problems, the generalized method of induced electromotive forces (EMF), is proposed and validated. The novelty of the proposed method lies in the fact that the functional dependencies found by analytical solutions, preliminarily obtained for the vibrator current by the averaging method, are used as the basis function (functions) for approximation of the vibrator current.

In Chap. 5, we investigate, by the generalized method of induced EMF, several multifaceted problems (for an impedance vibrator with arbitrary excitation point in free space; for an impedance monopole in a material medium; for a vibrator with symmetric and antisymmetric components of impedance along its length; for a system of impedance vibrators), thus proving the efficiency of our proposed method for solving various problems in electrodynamics. Numerical results are compared with the solutions, and experimental data obtained by other investigators and comparison results are thoroughly analyzed.

Thin impedance vibrator antennas are widely used in various mobile objects, including air and space vehicles. The bodies of these mobile objects often have a spherical form, or they can be approximated by a sphere. Here the dominant configuration is an asymmetric radially oriented monopole. Naturally, a mathematical model of such antennas in a strict electrodynamic formulation for a particular vibrator geometry and a spherical object has a large practical significance. Therefore, Chap. 6 presents a problem on the radiation of electromagnetic waves by a thin impedance radial monopole located on a perfectly conducting sphere. The solution here is derived by approximate analytical expression for the monopole current in terms of the spherical Bessel functions, allowing, with the Green's function for the space outside the sphere, integration of the expressions for the vibrator fields in spherical coordinates by known formulas. Of course, an approximation is also essential for application of the generalized method of induced EMF to vibrator systems located on a sphere. In this section, we also study impedance vibrators, both for arbitrary location of the excitation point on the vibrator and for a monopole fed at the contact point of a sphere and a monopole. The radiation fields for the vibrator antenna are also represented here.

In contrast to previous chapters, where outer excitation problems for impedance vibrators are studied, Chap. 7 deals with inner electrodynamics problems for vibrator structures located in a rectangular waveguide. The aim here is twofold. Firstly, we would like to demonstrate how the methods proposed in this monograph are applied to problems in closed spatial regions, namely in a rectangular waveguide. The choice is related to the fact that vibrator elements are widely used in waveguide devices in different applications, and the problems have independent applied significance. Secondly, we want to confirm new theoretic results for impedance vibrators by original experimental investigations, which in laboratory environments prove to be simpler and more reliable than waveguide experiments. It should be noted that these aims have been successfully attained by investigating electromagnetic wave scattering by vibrators with constant and variable surface impedances and also by impedance vibrators of variable radius.

Appendix A contains the formulas for the electrical Green's functions for various electrodynamic volumes considered in this monograph. In Appendix B, the basics of the method of moments extensively used for the numerical solution of the integral equations for currents on vibrator radiators are briefly outlined. In Appendix C, the formulas for generalized integral functions are given, and in Appendix D, we describe a method of series summation for functions of the self-field of a vibrator in a rectangular waveguide. Since the absolute Gaussian system of units (CGS) is used in this monograph, Appendix E gives conversion factors for equations and units between the CGS and SI systems.

The authors refuse to finish this book with the traditional terminal punctuation sign, the period or "full stop". Instead, we close with a more-optimistic ellipsis. In this final section we propose a list of problems of "nearest perspective" that can be solved for thin vibrators in the framework of the theoretical approaches presented in the book.

This monograph is written in an academic style, and it can be used by students and graduates of technical universities. It should be noted that any of the current applied problems presented in the concluding section may serve as the basis of a doctoral dissertation. On the other hand, the results of numerical modeling and asymptotic formulas obtained by the authors will be useful for practicing engineers and designers of antenna and waveguide systems, including those for mobile objects and medical devices operating under conditions of a demanding environment.

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Kharkov, Ukraine

Mikhail V. Nesterenko  
Victor A. Katrich  
Yuriy M. Penkin  
Victor M. Dakhov  
Sergey L. Berdnik

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Nesterenko, M.V.; Katrich, V.A.; Penkin, Y.M.; Dakhov,  
V.M.; Berdnik, S.L.

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