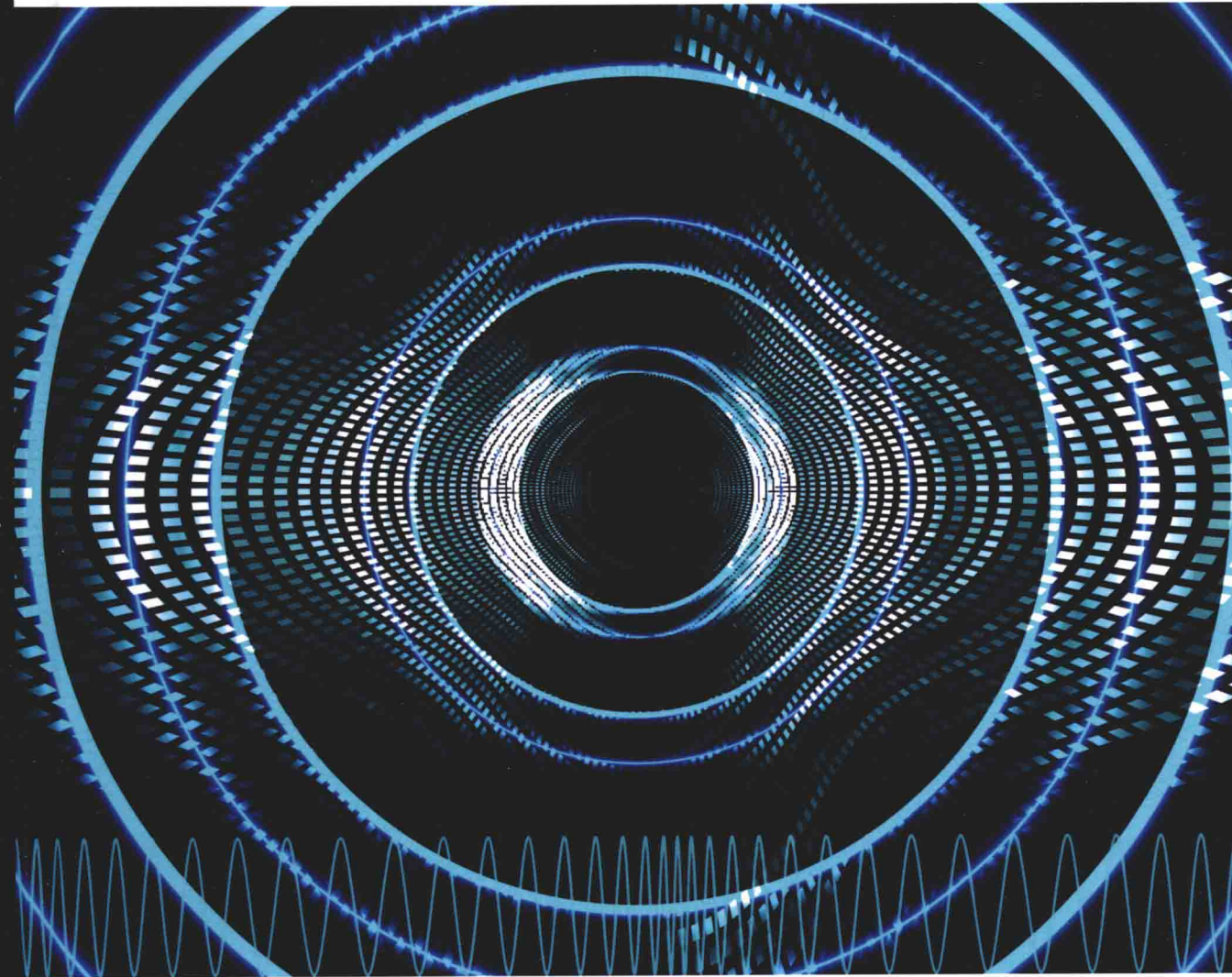


Introduction to Radio Engineering



Nathan Blaunstein
Christos Christodoulou
Mikhail Sergeev



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Engineering – Electrical

During the last 50 years, many radio elements, devices, and systems have been developed to satisfy the ever-increasing demand of modern radio engineering for wired and wireless communications and radar applications. It is well known that each completed radio system, wired or wireless, consists of several separate and independent layers. The first layer deals with a wide range of electronic devices and circuits, such as generators, radiators, and radiation detectors. The second layer deals with signal processing, including various kinds of modulation and demodulation schemes. The last layer deals with antennas as elements of radiation and reception of radio signals sent through any communication link. To integrate all these layers, an additional layer is introduced by the authors, referred to as the “physical and mathematical layer.”

Therefore, all the aspects described in **Introduction to Radio Engineering** regarding radio engineering start from basic mathematical and physical explanations of matter, and then they progress to other, more complex engineering concepts, covering the three main radio layers mentioned above. Each engineering aspect is demonstrated with corresponding examples, giving the reader the ability to use the information obtained in the design of modern communications and radiolocation systems.

If you're a practicing radio scientist or radio engineer who is concerned with the design, operation, and service of wired and wireless radio systems for resolving both the direct and the inverse problems of radio communication and radiolocation, or teaching a course, this is the book you've been awaiting. It introduces the main aspects of modern radio engineering and radio physics in a way that has not been covered until now. The authors use the experience of many years of teaching courses in this area to undergraduate and graduate

The book introduces the basic foundations of radio engineering. It explains the basic aspects of classical electrodynamics and antenna theory. Then, it shows how to use this knowledge readers investigate various radio problems. It explains the role of antennas in the process of transmission of radio signals between the terminals. Finally, it shows the relation between the main operational characteristics of each kind of radar and the corresponding knowledge obtained from the previous chapters.

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Introduction to Radio Frequency Engineering



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Preface

The book is intended to appeal to any practicing radio scientist or radio engineer who is concerned with the design, operation, and service of wired and wireless radio systems for resolving both the direct and the inverse problems of radio communication and radiolocation.

During the last 50 years, many radio elements, devices, and systems have been developed to satisfy the ever-increasing demand of modern radio engineering for wired and wireless communications and radar applications. It is well known that each completed radio system, wired or wireless, consists of several separate and independent “layers.” The first “layer” deals with a wide range of electronic devices and circuits, such as generators, radiators, and radiation detectors. The second “layer” deals with signal processing, including various kinds of modulation and demodulation schemes. The last “layer” deals with antennas as elements of radiation and reception of radio signals sent through any communication link. To integrate all these “layers,” an additional layer is introduced by the authors, referred to as the “physical and mathematical layer.”

Therefore, all the aspects described in this book regarding radio engineering start from basic mathematical and physical explanations of matter, and then they progress to other, more complex engineering concepts, covering the three main radio “layers” mentioned above. Each engineering aspect is demonstrated with corresponding examples, giving the reader the ability to use the information obtained in the design of modern communications and radiolocation systems.

The main goal of this book is to introduce the main aspects of modern radio engineering and radio physics, in a way that has not been covered before in literature. The authors use the experience of many years of teaching courses in this area to undergraduate and graduate students.

The book is composed of fifteen chapters, divided into five sections. Section I, titled “Mathematical Foundations for Radio Engineering,” consists of two chapters. Chapter 1 presents elements of basic mathematics, complex analysis, vector analysis, and tensor analysis. Chapter 2 covers differential and integral operators and formulas that are introduced for future explanation of fundamentals in classical electrodynamics, discussed in Chapters 3 through 5. These formulas and operators are also used during Chapters 6 through 14 to describe the operation of the basic aspects of guiding structures, antennas, and radars.

Section II, titled “Introduction to Classical Electrodynamics,” consists of three chapters. In Chapter 3, the main laws of electrodynamics are presented in both differential and integral form. The main equations describing fundamental aspects of the propagation of electromagnetic waves and their characteristic distributions in the space and time domains are presented in this chapter. In Chapter 4, the propagation of electromagnetic waves, in plane, cylindrical, and spherical form, and their polarizations are described. Then, the propagation of a plane wave in various material media is discussed through the analysis of the corresponding wave and media characteristics. Various propagation media situations are discussed: propagation in nonideal dielectric media, ideal dielectric media, nonideal conductors, and ideal conductors. It is shown how to obtain

the wave properties by knowing the various parameters and characteristics of the medium, and the possibility of resolving the inverse problem, that is, finding the parameters of the medium using knowledge of the parameters of the wave propagating through such a medium. Chapter 5 describes the boundary conditions if wave propagation occurs through the boundary of two different media. The corresponding formulas for the reflection and refraction coefficients for two types of wave polarization, vertical and horizontal, are presented. All the four chapters are accompanied by related examples.

Section III, titled “Guiding Structures and Guiding Waves,” consists of four chapters. In Chapter 6, the main guiding structures that are used in most applications in practice today are described. The types of electromagnetic waves that can propagate in such structures are presented with the corresponding equations obtained from basic electrodynamics concepts mentioned in previous chapters. Chapter 7 emphasizes wave propagation in lossless two-wire transmission lines. In Chapter 8, the main characteristics and parameters of coaxial cables, as guiding wire structures, are described, and the corresponding types of propagating waves are presented. For each type of waves, several examples are presented to enhance the understanding of practical applications of coaxial cables. Separately, the leaky coaxial cable is described as a special case of coax lines.

Chapter 9 deals with various types of waveguide structures: plane, rectangular, and cylindrical. For all these types of guiding structures, the relations between characteristics of waves and the structures are presented and discussed.

Section IV, titled “Antenna Fundamentals,” consists of only one chapter, Chapter 10, in which the basic antenna types and their characteristics are presented and discussed. The main equation of antennas in free space is presented, and it is shown how it is usually used and modified for different propagating media in wireless communications and radar systems. Finally, a brief description of types of antennas that are usually used in communication networks and radar systems is presented. Here, the authors describe not only the well-known types of antennas, such as dipole, loop, and antenna arrays, but also multibeam and phased-array antennas, which have become more attractive and effective in modern wired, wireless, and radar systems.

Section V, titled “Radar Fundamentals,” consists of five chapters. Chapter 11 describes the basic characteristics and parameters of various types of radars, their classification associated with types of radiated signals, and their applications. Then, the path loss of the radar signals in various environments is briefly discussed: in free space, above terrain, and in the atmosphere and ionosphere, which characterize different kinds of radars, from ground based to atmospheric and ionospheric. The main radar equation is given by taking into consideration environmental and target effects. In Chapter 12, the main properties of active and passive millimeter wave radar are presented and discussed, accounting for clutter, environmental, and target effects. Chapter 13 deals with the description of ground-penetrating radars based on leaky coaxial cables, the main parameters and characteristics of which are covered in Chapter 8. The basic equation of such a radar operation, its regions of operation, and the radiation pattern and radiation characteristics for various types of ground-penetrating radar are presented and discussed. Next, various effects of clutter on buried leaky coaxial cables are discussed, and the corresponding comparison with experimental data is presented. In Chapter 14, the theoretical frameworks and models regarding ground-penetrating radars and remote sensing systems that are most applicable today are presented, with a brief coverage of the problems associated with their design and the influence of the subsoil or any clutter environment. Several recommendations are given for future practical applications. Chapter 15 introduces the methodology of ultra-wideband, extremely-short-pulse

ground-penetrating radars and remote sensing systems, their operation, their description, and the corresponding operational problems and challenges. Then, the most important applications in practice of such ground-penetrating radars and remote sensing systems are briefly presented and compared with the corresponding theoretical prediction presented in Chapter 14.

Acknowledgments

The authors are grateful for the contributions of Professor Alexander Shepena with his insights on radar theory and radar applications, and also acknowledge the computational work of PhD student Vadim Nenashev in ground-to-air radar applications.

The authors also acknowledge the theoretical and experimental work of Mihael Mejibovsky in modeling radio propagation in subsoil media for ground-penetrating radar applications.

In addition, we thank Dr. Gregory Samelsohn for his contributions to the theoretical analysis of guiding radar systems based on leaky coaxial cables hidden in various clutter subsoil environments.

We are greatly indebted to the Taylor & Francis staff, the reviewers, and technical editors, for the presentation of this book with clarity and precision.

Authors

Nathan Blaunstein earned his MSc degree in radiophysics and electronics from Tomsk University, Tomsk, Russia, in 1972, and his PhD, DSc, and professor degrees in radiophysics and electronics from the Institute of Geomagnetism, Ionosphere, and Radiowave Propagation (IZMIR), Academy of Science USSR, Moscow, Russia, in 1985 and 1991, respectively.

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His research interests include problems of radio-wave propagation, diffraction, and scattering in various media (subsoil and underwater media, terrestrial environments, the atmosphere, and the ionosphere) for the purposes of radiolocation, terrestrial, aircraft, and mobile-satellite wireless communications, remote sensing, and signal processing.

Christos Christodoulou earned his PhD degree in electrical engineering from North Carolina State University in 1985. He is a fellow member of the Institute of Electrical and Electronics Engineers, a member of Commission B of the Union Radio-Scientifique Internationale, and a distinguished professor at the University of New Mexico. Currently, he is the associate dean of research for the School of Engineering at the University of New Mexico. He is the recipient of the 2010 Institute of Electrical and Electronics Engineers John Krauss Antenna Award for his work on reconfigurable fractal antennas using micro-electro-mechanical system switches, the Lawton-Ellis Award, and the Gardner Zemke Professorship at the University of New Mexico.

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Symbols and Abbreviations

A	arbitrary vectors of electromagnetic field
B	vector of induction of magnetic field component of the electromagnetic wave
$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$	velocity of light in free space
$\text{curl} \equiv \text{rot} = \nabla \times$	rotor of arbitrary vector field or the vector product of the operator Nabla
\hat{C}	capacity of the cable or transmission line normalized over their line
$\text{div} \equiv \nabla \cdot$	a flow of arbitrary vector or a scalar product (“Nabla dot”) of the field
$d\mathbf{l}$	differential of the vector of line l
$d\mathbf{S}$	differential of the vector of surface S
$d\mathbf{V}$	differential of the vector of volume V
D	vector of induction of electric field component of the electromagnetic wave
E	vector of electric field component of the electromagnetic wave
$\tilde{\mathbf{E}}(z)$	phasor of the electrical component of the electromagnetic wave
$\mathbf{E}(z, t)$	2-D distribution of the vector of electrical component of the electromagnetic wave
$\text{grad } \Phi = \nabla \Phi$	gradient of arbitrary scalar field or effect of Nabla operator on the scalar field
\hat{G}	conductivity of the cable or transmission line normalized over their line
H	vector of magnetic field component of the electromagnetic wave
$\tilde{\mathbf{H}}(z)$	phasor of the magnetic component of the electromagnetic wave
$\mathbf{H}(z, t)$	2-D distribution of the vector of magnetic component of the electromagnetic wave
$i = \sqrt{-1}$	ort of imaginary part of the complex number

$\mathbf{i}_r, \mathbf{i}_\phi, \mathbf{i}_\theta$	unit vectors (orts) in spherical coordinate system
$\mathbf{i}_\rho, \mathbf{i}_\phi, \mathbf{i}_z$	unit vectors (orts) in cylindrical coordinate system
$\mathbf{i}_x, \mathbf{i}_y, \mathbf{i}_z$	unit vectors (orts) in Cartesian coordinate system
$I(z, t)$	wave of current in circuits, transmission lines, and cables
I_0	constant current in circuits, transmission lines, and cables
\mathbf{j}	vector of electric current density
\mathbf{j}_c	conductivity current density
\mathbf{j}_d	displacement current density
\mathbf{J}	vector of the full current in medium/circuit
\hat{L}	inductance of the cable or transmission line normalized over their line
\mathbf{M}	momentum of the magnetic ambient source
\mathbf{P}	vector of polarization
Q	full charge in circuit, material, or medium
$\{r, \phi, \theta\}$	spherical coordinate system
\hat{R}	resistance of the cable or transmission line normalized over their line
S	area of arbitrary surface
T	coefficient of refraction (transfer of the wave into the medium)
v_{gr}	wave group velocity
v_{ph}	wave phase velocity
V	volume of arbitrary surface
VSWR	vertical standing-wave ratio
$V(z, t)$	the wave of voltage in circuits, transmission lines, and cables
V_0	constant voltage or potential difference
W	energy of arbitrary field
$\{x, y, z\}$	Cartesian coordinate system
$\hat{Y} = \hat{G} + i\omega\hat{C}$	full normalized complex conductivity of the cable or transmission line
$z = a + ib$	complex number: a , its real part; b , its imaginary part
$\hat{Z} = \hat{R} + i\omega\hat{L}$	full normalized complex impedance of the cable or transmission line
Z_c	intrinsic impedance of the transmission line or cable
Z_L	loading (shunt) impedance of the transmission line or cable
α	parameter of wave attenuation in arbitrary medium