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Dedication

To Batya, Rebecca (Becky) Miriam, Abraham Solomon (Solly), Annie Sara Khaya, Leora, Arielle Bella, Aliza Rose, and Walter John

I think the history of science gives ample examples that pure investigation has enormous benefit.... And lovely things turn up.

—James A. Van Allen, 1999

Many of today's electrical devices (e.g., **radios**) can trace their roots to the basic research conducted by Michael Faraday in 1831. He discovered the **principle of electromagnetic induction,** that is, the relationship between **electricity** and **magnetism.**

—http://www.lbl.gov/Education/ELSI/Frames/research-basic-history-f.html (accessed Oct. 2006)

Look on the streets of almost any city in the world, however, and you will see people clutching tiny, pocket computers, better known as mobile phones. Already, even basic handsets have simple web-browsers, calculators and other computing functions. Mobile phones are cheaper, simpler and more reliable than PCs, and market forces — in particular, the combination of prepaid billing plans and microcredit schemes — are already putting them into the hands of even the world's poorest people. Initiatives to spread PCs in the developing world, in contrast, rely on top-down funding from governments or aid agencies, rather than bottom-up adoption by consumers.

Merchants in Zambia use mobile phones for banking; farmers in Senegal use them to monitor prices; health workers in South Africa use them to update records while visiting patients. All kinds of firms, from giants such as Google to start-ups such as CellBazaar, are working to bring the full benefits of the web to mobile phones. There is no question that the PC has democratised computing and unleashed innovation; but it is the mobile phone that now seems most likely to carry the dream of the "personal computer" to its conclusion.

—The Economist, July 27, 2006

Figure Legends

List of Tables

Preface

Wireless communications is based on the launching, propagation, and detection of electromagnetic waves usually at radio or microwave frequencies. It has its roots in the middle of the 19th century when James Clerk Maxwell formulated the basic laws of electromagnetism (viz., Maxwell's equations) and Heinrich Hertz demonstrated propagation of radio waves across his laboratory. By the start of the 20th century, Guglielmo Marconi had invented the wireless telegraph and sent signals across the Atlantic Ocean using reflection off the ionosphere. Subsequent early embodiments of wireless communication systems included wireless telephony, AM and FM radio, shortwave radio, television broadcasting, and radar. Engineering breakthroughs after World War II, including launching artificial satellites, the miniaturization of electronics, and the invention of electronic computers, led to new embodiments of wireless communication systems that have revolutionized modern lifestyles and created dominant new industries. These include cellular telephones, satellite TV beaming, satellite data transmission, satellite telephones, and wireless networks of computers.

The present textbook presents descriptions of the salient features of these modern wireless communication systems together with rigorous analyses of the devices and physical mechanisms that constitute the physical layers of these systems. Starting with a review of Maxwell's equations, the operation of antennas and antenna arrays is explained in sufficient detail to allow for design calculations. Propagation of electromagnetic waves is also explored, leading to useful descriptions of mean path loss through the streets of a city or inside an office building. The principles of probability theory are reviewed so that students will be able to calculate the margins that must be allowed to account for statistical variation in path loss. The physics of geostationary earth orbiting (GEO) satellites and low earth orbiting (LEO) satellites are covered in sufficient detail to evaluate and make first-order designs of satellite communications (SATCOM) systems.

This textbook is the outgrowth of a course in the physics of wireless communications that I have taught to electrical engineering seniors and first-year graduate students at the University of Maryland for the past seven years. I have also been invited by Tel Aviv University (TAU) to present an accelerated version of the course to graduate students and working engineers at wireless communication companies; I have presented such a course at TAU on two occasions, in 2003 and 2004–2005. The course at the University of Maryland is a senior elective course that is normally limited to 30 students, but because of its popularity the class size was expanded to as many as 60 students. Problem sets have also been developed and are included; a solutions manual is available for instructors.

Previous textbooks have tended to be of two types:

1. Those that stress systems and signal processing aspects of wireless communications with relatively light treatment of antennas and propagation
2. Those that stress antennas and propagation with little attention paid to the details of modern communication systems

The present textbook aims to integrate the topical area of antennas and propagation with consideration of its application to designing the physical layer in modern communication systems. This textbook aims to provide the following:

1. Historical treatment of wireless communications from Marconi's wireless telegraph to today's multimedia wideband transmissions
2. Starting from Maxwell's equations, analysis of antennas and propagation as they relate to modern communication systems
3. Relevant treatments of noise and statistical analysis
4. Integration of electromagnetic analysis with complete descriptions of the physical layer in the most important wireless systems, including cellular/(PCS) personal communications services telephones, wireless local area networks of computers, and GEO and LEO SATCOM

Victor Granatstein
Silver Spring, Maryland
January 2007

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About the Author

Victor L. Granatstein was born and raised in Toronto, Canada. He received a Ph.D. degree in electrical engineering from Columbia University, New York, in 1963. After a year of postdoctoral work at Columbia, he became a research scientist at Bell Telephone Laboratories from 1964 to 1972, where he studied microwave scattering from turbulent plasma. In 1972, he joined the Naval Research Laboratory (NRL) as a research physicist, and from 1978 to 1983, he served as head of NRL's High Power Electromagnetic Radiation Branch.

In August 1983, he became a professor in the Electrical Engineering Department of the University of Maryland, College Park. From 1988 to 1998, he was director of the Institute for Plasma Research at the University of Maryland. His research has involved the invention and development of high-power microwave sources for heating plasmas in controlled thermonuclear fusion experiments, for driving electron accelerators used in high-energy physics research, and for radar systems with advanced capabilities. He also has led studies of the effects of high-power microwaves on integrated electronics. He has co-authored more than 250 research papers in scientific journals and has co-edited three books. He holds a number of patents on active and passive microwave devices.

Dr. Granatstein is a fellow of the American Physical Society and a life fellow of the Institute of Electrical and Electronic Engineers. He has received a number of major research awards, including the E. O. Hulbert Annual Science Award (1979), the Superior Civilian Service Award (1980), the Captain Robert Dexter Conrad Award for Scientific Achievement (awarded by the Secretary of the Navy, 1981), the IEEE Plasma Science and Applications Award (1991), and the Robert L. Woods Award for Excellence in Electronics Technology (1998).

He lives in Silver Spring, Maryland, with his wife, Batya; they recently celebrated their 50th wedding anniversary. They have three children, Becky, Solly, and Annie, and, to date, three grandchildren, Leora, Arielle, and Aliza.

Table of Contents