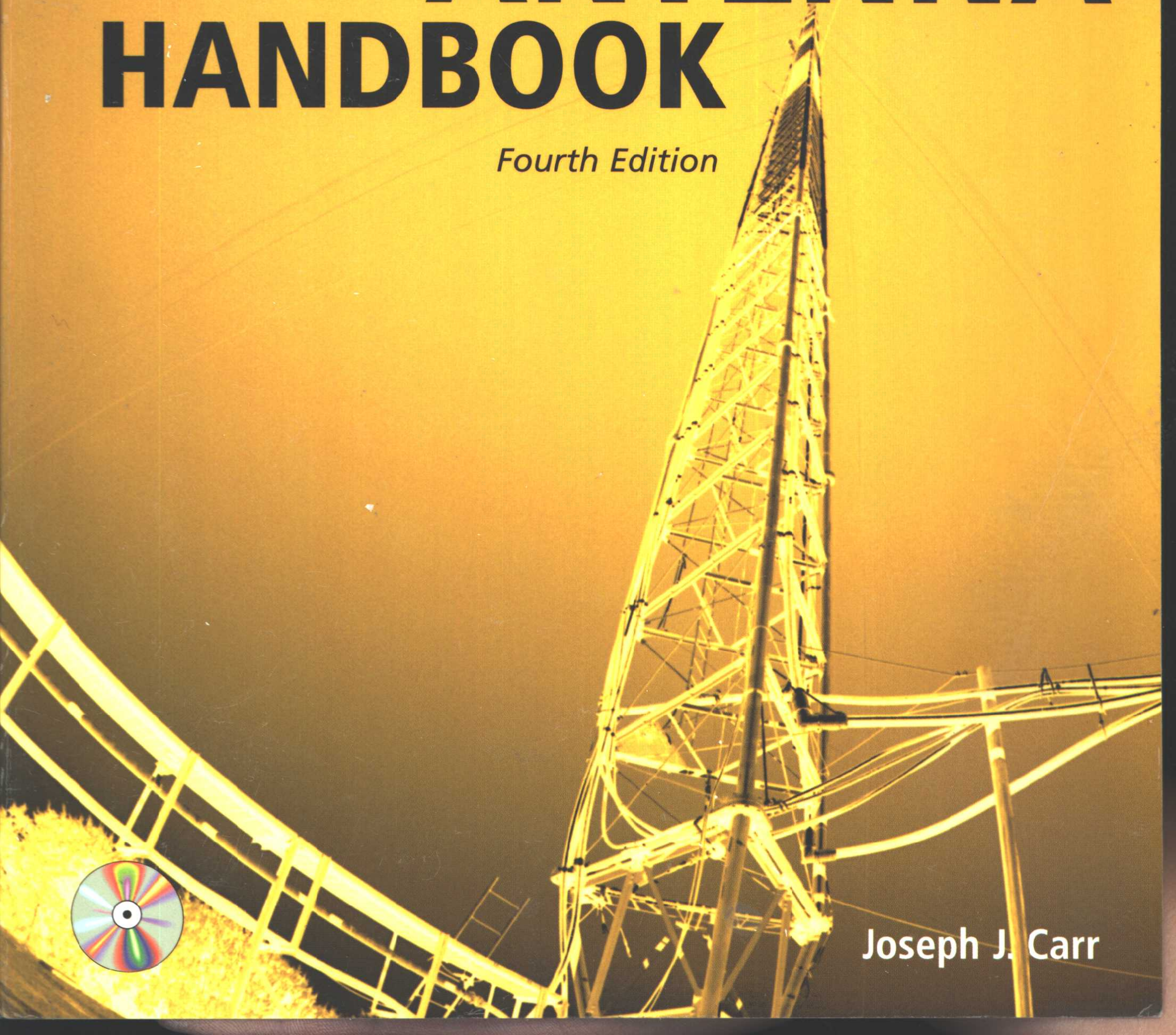
TAB ELECTRONICS

PRACTICAL ANTENNA HANDBOOK

Fourth Edition



Joseph J. Carr

Practical Antenna Handbook

Fourth Edition

Joseph J. Carr

McGraw-Hill

New York Chicago San Francisco Lisbon London
Madrid Mexico City Milan New Delhi San Juan Seoul
Singapore Sydney Toronto

Cataloging-in-Publication Data is on file with the Library of Congress

McGraw-Hill

A Division of The McGraw-Hill Companies

1 2 3 4 5 6 7 8 9 DOC/DOC 0 7 6 5 4 3 2 1

P/N 137686-0
Part of
ISBN 0-07-137435-3

The sponsoring editor for this book was Scott H. Grillo, the editing supervisor was Carol Levine, and the production supervisor was Pamela Pelton. This book was set in Century Schoolbook per the EL1 design by McGraw-Hill's Professional Book Group composition unit, Hightstown, N.J.

Printed and bound by R. R. Donnelley & Sons Company.

Practical Antenna Handbook

Other Books by Joseph J. Carr

DC Power Supplies
Old Time Radios! Restoration and Repair
Secrets of RF Circuit Design

Dedication

Dedicated in memoriam to Johnnie Harper Thorne, K4NFU:
a friend and colleague for nearly 30 years who is sorely missed.
Johnnie was a genius who knew some real smoke about antennas.
Killed by a drunk driver. . .

From the Publisher

The fourth edition of this book is published in memory of Joe Carr who passed away shortly after completing his manuscript. Joe was a valuable member of the McGraw-Hill family of authors and the electronics community as a whole. He will be missed by us all.

Scott L. Grillo
Editor-in-Chief

Introduction to the fourth edition

IT WAS WITH GREAT PLEASURE THAT I WROTE THIS FOURTH EDITION OF *PRACTICAL Antenna Handbook*. The original intent when the first edition was planned was to provide the reader with a practical, yet theoretical, book that could be used with only a minimal effort to actually design and install radio antennas. It was assumed that the readership would possess a wide range of levels of antenna sophistication, from the novice "newbie" to the professional engineer. That assumption proved to be correct as I have received letters from a wide variety of people.

The success of the three previous editions of *Practical Antenna Handbook* has been most gratifying. Clerks in radio stores told me that this book was outselling other titles 2:1. They confirmed that the types of people who buy the book meet the profile above. It was with surprise and delight that I noted that clerks in one radio store could cite the McGraw-Hill catalog number from memory, when they could not do that for other antenna books.

While the sales are deeply appreciated (they are an honor), there was one comment that stood out. The salesman at one radio store introduced me to an instructor from a U.S. Government communications school. He typically bought twenty copies of *Practical Antenna Handbook* at a time for use by his students in a training class. He told me that the reason why he selected my book over others was "...it's the *only book on the market* that people can give to a secretary, or clerk-typist, and expect them to be able to put up a working half-wavelength dipole two hours later." And, he stated, in his business that could literally happen any time.

Antennas have changed a lot over the years. Figure I-1 shows how antennas were between 1913 and 1940. This facility was the first U.S. Navy radio station (NAA) in Arlington, VA.[1] Those two 600- and 400-ft towers were taken down in 1940 to make room for National Airport (Washington, D.C.). The towers were reassembled in Annapolis, MD, where they lasted until recently.

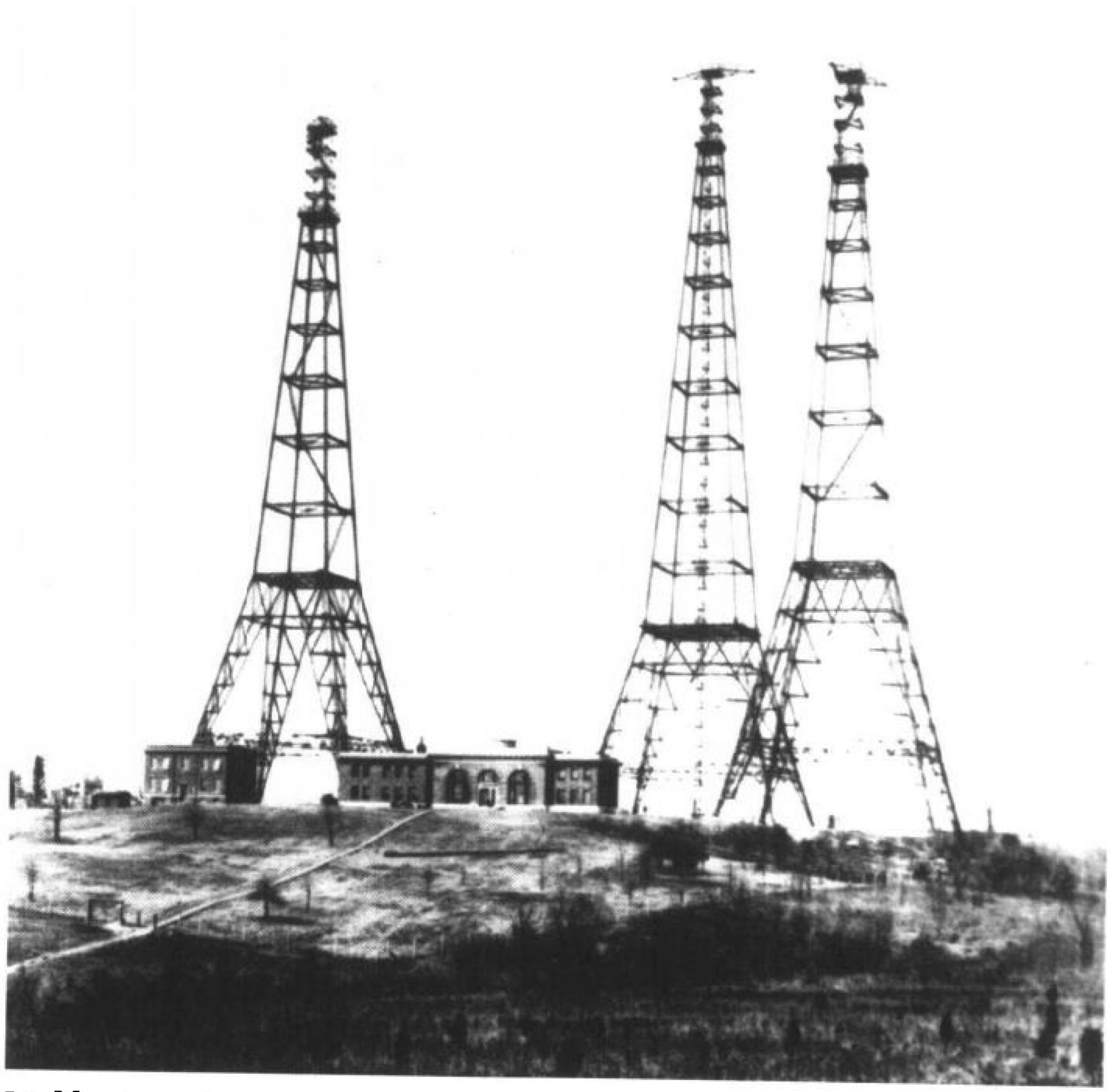
Antenna technology has changed since 1940. In preparing this fourth edition of *Practical Antenna Handbook* all previous material was reviewed for accuracy and relevance. Additional material was added for the following topics:

- Wire antenna construction methods
- Antenna modeling software (miniNEC, WinNEC, and EZNEC for Windows)
- Antenna noise temperature
- Antennas for radio astronomy
- Antennas for Radio Direction Finding

I hope that you find this fourth edition as useful as the previous three editions. And thank you very much for honoring me by spending your hard-earned money on my book.

Joseph J. Carr, MSEE

[1] The NAA callsign has since been reassigned to the VLF station at Cutler, ME.



I-1 Massive antenna towers at Navy "Radio Arlington" (1913-1940). (Courtesy of the NAA.)

Contents

1
CHAPTER
Introduction to radio broadcasting and communications

RADIO BROADCASTING AND COMMUNICATIONS SEEMS TO HOLD A STRANGE KIND OF magical allure that attracts a wide variety of people and holds them for years. There is something fascinating about the ability to project yourself over vast intercontinental distances.

Radio communications have been with us now for the entire twentieth century and into the twenty-first. Experiments are on record as early as 1867, and by the turn of the century "wireless telegraphy" (as radio was called then) sparked the imaginations of countless people across the world. Radio communications began in earnest, however, when Guglielmo Marconi successfully demonstrated wireless telegraphy as a commercially viable entity. The "wireless" aspect to radio so radically changed communications that the word is still used to denote radio communications in many countries of the world. Marconi made a big leap to international fame on a cold December day in 1903, when he and a team of colleagues successfully demonstrated transatlantic wireless telegraphy. Until that time, wireless was a neighborhood—or crosstown at best—endeavor that was of limited usefulness. Of course, ships close to shore, or each other, could summon aid in times of emergency, but the ability to communicate over truly long distances was absent. All that changed on that fateful day in Newfoundland when Marconi heard the Morse letter "S" tickle his ears.

Wireless telegraphy was pressed into service by shipping companies because it immediately provided an element of safety that was missing in the prewireless days. Indeed, a ship that sank, leaving its crew and passengers afloat on a forbidding sea, was alone. Any survivors often succumbed to the elements before a chance encounter with a rescue vessel. Some early shipping companies advertised that their ships were safer because of wireless aboard. It was not until 1909, however, that wireless telegraphy proved its usefulness on the high seas. Two ships collided in the foggy Atlantic Ocean and were sinking. All passengers and crew members of both ships were in imminent danger of death in the icy waters. But radio operator Jack

Binns became the first man in history to send out a maritime distress call. There is some debate over which distress call Binns transmitted, but one thing is certain: It was not "SOS" (today's distress call), because SOS was not adopted until later. Binns probably transmitted either "CQD" or "CQE," both of which were recognized in those days before standardization. Regardless of which call was sent, however, it was received and relayed from ship to ship, allowing another vessel to come to the aid of the stricken pair of ships.

All radio prior to about 1916 was carried on via telegraphy (i.e., the on-off keying of a radio signal in the Morse code). But in 1916 some more magic happened. On a little hill in Arlington, Virginia, on a site that now overlooks the Pentagon and the U.S. Marine Corps base called *Henderson Hall*, there were (and still are) a pair of two-story brick buildings housing the naval radio station NAA (callsign since reassigned to the VLF station at Cutler, ME). On a night in 1916, radio operators and monitors up and down the Atlantic seaboard—from the midwest to the coast and out to sea for hundreds of miles—heard something that must have startled them out of their wits, for crackling out of the "ether," amidst the whining of Alexanderson alternators and "ZZZCHHT" of spark-gap transmitters, came a new sound—a human voice. Engineers and scientists at the Naval Research Laboratory had transmitted the first practical amplitude-modulated (AM) radio signal. Earlier attempts, prior to 1910, had been successful as scientific experiments, but they did not use commercially viable equipment.

Although radio activity in the early years was unregulated and chaotic, today it is quite heavily regulated. Order was brought to the bands (don't laugh, ye who tune the shortwaves) that was lacking before. Internationally radio is regulated by the International Telecommunications Union (ITU) in Geneva, Switzerland through the treaties arising from World Administrative Radio Conferences (WARC) held every 10 to 15 years. In the United States, radio communications are regulated by the Federal Communications Commission (FCC), headquartered in Washington, D.C.

Amateur radio has grown from a few thousand "hams" prior to World War I to more than 900,000 today, about one-third of them in the United States. Amateur operators were ordered off the air during World War I, and almost did not make a comeback after the war. There were, by that time, many powerful commercial interests that greedily coveted the frequencies used by amateurs, and they almost succeeded in keeping postwar amateurs off the air. But the amateurs won the dispute, at least partially. In those days, it was the frequencies with wavelengths longer than 200 m (i.e., 20 to 1500 kHz) that were valuable for communications.

The cynical attitude attributed to the commercial interests regarding amateurs was, "put 'em on 200 meters and below . . . they'll never get out of their backyards there!" But there was a surprise in store for those commercial operators, because the wavelengths shorter than 200 m are in the high-frequency region that we now call "shortwaves." Today, the shortwaves are well-known for their ability to communicate over transcontinental distances, but in 1919 that ability was not suspected.

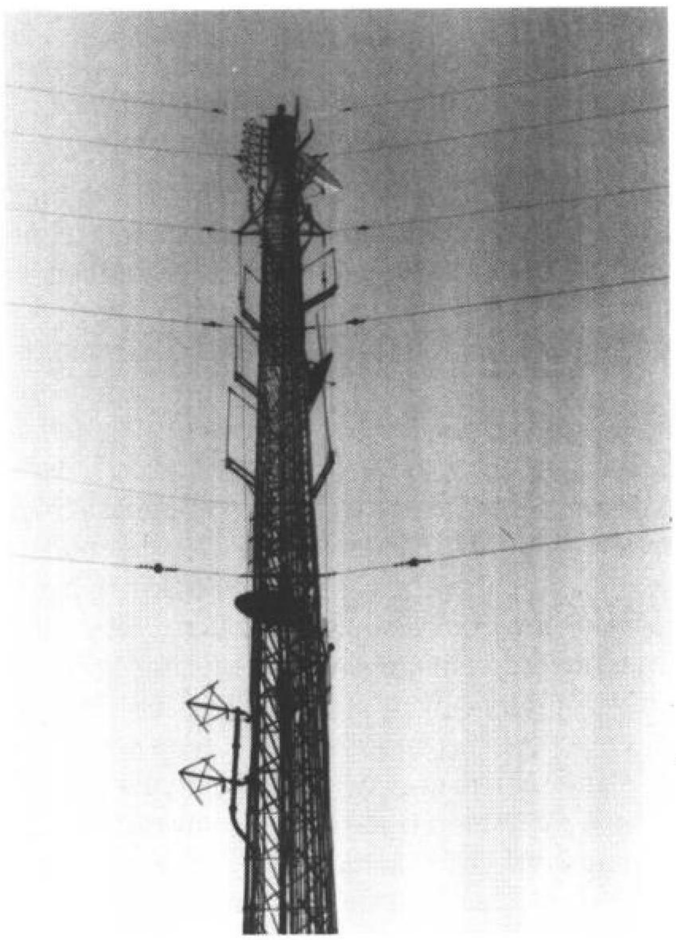
I once heard an anecdote from an amateur operator "who was there." In the summer of 1921 this man owned a large, beautiful wire "flattop" antenna array for frequencies close to 200 m on his family's farm in southwestern Virginia. Using those frequencies he was used to communicating several hundred miles into eastern Ohio and down to the Carolinas. But, in September 1921 he went to college to study electrical engineering at the University of Virginia in Charlottesville. When he returned home for Thanksgiving he noticed that his younger brother had replaced the long flattop array with a short dipole antenna. He was furious, but managed through great effort to contain the anger until after dinner. Confronting his brother over the incredible sacrilege, he was told that they no longer used 150 to 200 m, but rather were using 40 m instead. Everyone "knew" that 40 m was useless for communications over more than a few blocks, so (undoubtedly fuming) the guy took a turn at the key. He sent out a "CQ" (general call) and was answered by a station with a callsign like "8XX." Thinking that the other station was in the 8th U.S. call district (WV, OH, MI) he asked him to relay a message to a college buddy in Cincinnati, OH. The other station replied in the affirmative, but suggested that ". . . you are in a better position to reach Cincinnati than me, I am *FRENCH* 8XX." (Callsigns in 1921 did not have national prefixes that are used today.) The age of international amateur communications had arrived! And with it came a new problem—the national identifiers in call signs became necessary (which is why American call signs begin with K, W, or N).

During the 1930s, radio communications and broadcasting spread like wildfire as technology and techniques improved. World War II became the first war to be fought with extensive electronics. Immediately prior to the war, the British developed a new weapon called RADAR (radio detection and ranging; now spelled radar). This tool allowed them to see and be forewarned of German aircraft streaming across the English Channel to strike targets in the United Kingdom. The German planes were guided by (then sophisticated) wireless highways in the sky, while British fighters defended the home island by radio vectoring from ground controllers. With night fighters equipped with the first "centimetric" (i.e., microwave) radar, the Royal Air Force was able to strike the invaders accurately—even at night. The first kill occurred one dark, foggy, moonless night when a *Beaufighter* closed on a spot in the sky where the radar in the belly of the plane said an enemy plane was flying. Briefly thinking he saw a form in the fog, the pilot cut loose a burst from his quad mount of 20-mm guns slung in the former bomb bay. Nothing. Thinking that the new toy had failed, the pilot returned to base—only to be told that ground observers had reported that a German *Heinkle* bomber fell from the overcast sky at the exact spot where the pilot had his ghostly encounter.

Radio, television, radar, and a wide variety of services, are available today under the general rubric "radio communications and broadcasting." Homeowners, and other nonprofessionals in radio, can own a receiver system in their backyard that picks up television and radio signals from satellites in geosynchronous orbit 23,000 mi out in space. Amateur operators are able to communicate worldwide on low power, and have even launched their own "OSCAR" satellites.

Some people had written off the HF radio spectrum in recent years, citing satellite technology as the reason. But the no-code license for amateur radio operators, which does not carry HF privileges, has proven to be a stepping stone to higher-class licenses, which do. Also, the shortwave broadcasting market received a tremendous boost during the Gulf War. When the troops of *Operation Desert Shield* and *Desert Storm* were assembling to take back Kuwait from the Iraqis, the sales of shortwave receivers jumped dramatically. And, following January 16, 1991, when the forces started pouring across the border into the actual fight, the sales skyrocketed out of sight. One dealer told me that he couldn't keep receivers in stock, and that he had sold out most models. That interest seems to have matured into long-term interest on the part of a significant number of listeners and new ham operators.

The antenna is arguably one of the most important parts of the receiving and/or transmitting station (Fig. 1-1). That is what this book is all about.



1-1 This AM/FM broadcast antenna tower bristles with two-way antennas.

2
CHAPTER

Radio-wave propagation

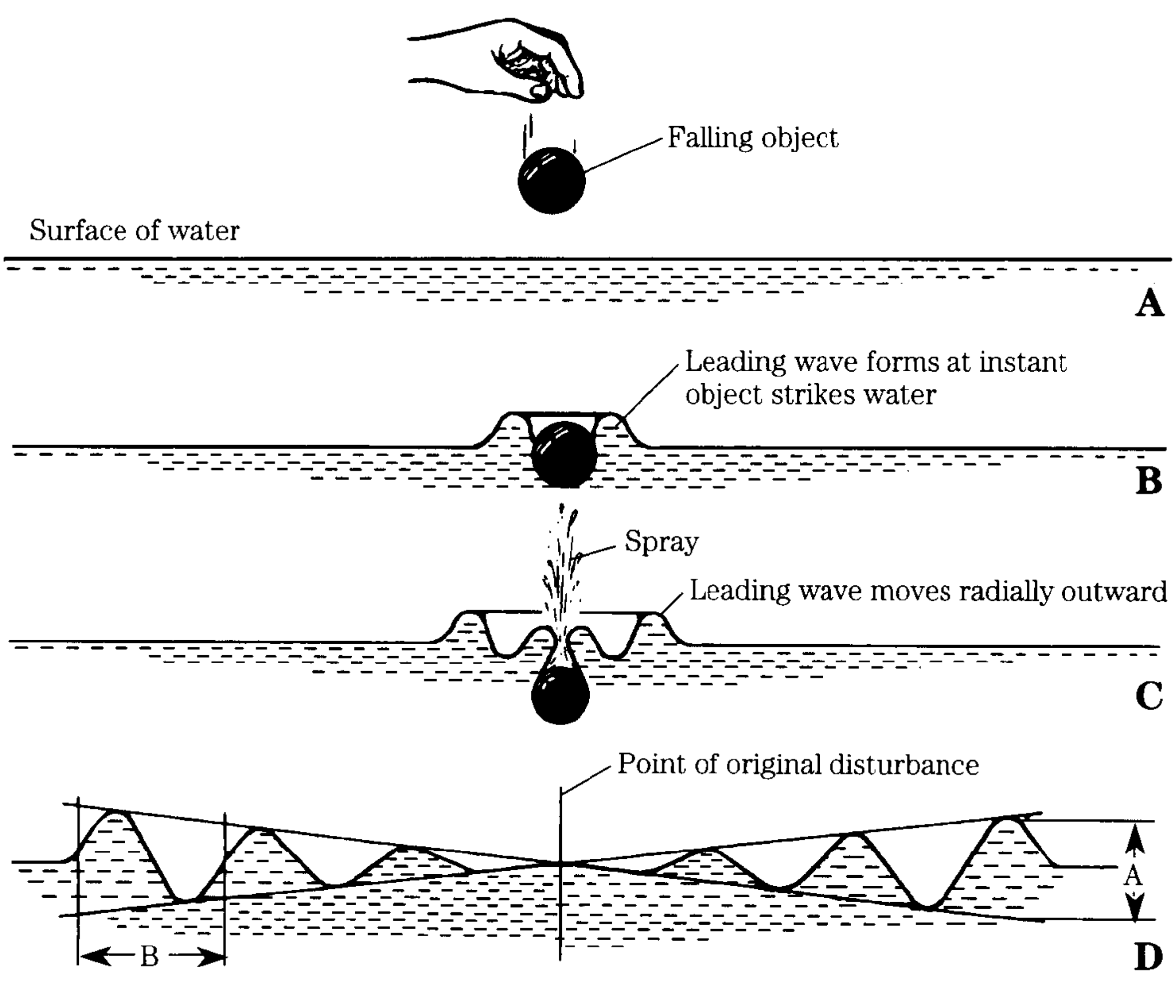
THE PROPAGATION OF RADIO SIGNALS IS NOT THE SIMPLE MATTER THAT IT SEEMS AT first glance. Intuitively, radio signal propagation seems similar to light propagation; after all, light and radio signals are both electromagnetic waves. But simple inverse square law predictions, based on the optics of visible light, fall down radically at radio frequencies because other factors come into play. In the microwave region of the spectrum, the differences are more profound because atmospheric pressure and water vapor content become more important than for light. For similar reasons, the properties of microwave propagation differ from lower VHF and HF propagation. In the HF region, solar ionization of the upper reaches of the atmosphere causes the kind of effects that lead to long-distance "skip" communications and intercontinental broadcasting. This chapter examines radio propagation phenomena so that you have a better understanding of what an antenna is used for and what parameters are important to ensure the propagation results that you desire.

Radio waves

Although today it is well recognized that radio signals travel in a wave-like manner, that fact was not always so clear. It was well known in the first half of the nineteenth century that wires carrying electrical currents produced an *induction field* surrounding the wire, which is capable of causing action over short distances. It was also known that this induction field is a magnetic field, and that knowledge formed the basis for electrical motors. In 1887, physicist Heinrich Hertz demonstrated that radio signals were *electromagnetic waves*, like light. Like the induction field, the electromagnetic wave is created by an electrical current moving in a conductor (e.g., a wire). Unlike the induction field, however, the *radiated field* leaves the conductor and propagates through space as an electromagnetic wave.

The *propagation* of waves is easily seen in the "water analogy." Although not a perfect match to radio waves, it serves to illustrate the point. Figure 2-1 shows a body of water into which a ball is dropped (Fig. 2-1A). When the ball hits the water (Fig. 2-1B), it displaces water at its point of impact, and pushes a leading wall of water away from itself. The ball continues to sink and the wave propagates away from it until the energy is dissipated. Although Fig. 2-1 shows the action in only one dimension (a side view), the actual waves propagate outward in all directions, forming concentric circles when viewed from above.

The wave produced by a dropped ball is not continuous, but rather is *damped* (i.e., it will reduce in amplitude on successive crests until the energy is dissipated and the wave ceases to exist). But to make the analogy to radio waves more realistic, the wave must exist in a continuous fashion. Figure 2-2 shows how this is done: a ball is dipped up and down in a rhythmic, or cyclic manner, successively rein-



Notes: A Amplitude of leading wave
B Corresponds to 1 cycle of oscillation

2-1 A ball dropped into water generates a wavefront that spreads out from the point of original disturbances.