ENGINEERING APPLICATIONS OF LASERS AND HOLOGRAPHY

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PREFACE

This book is intended for upperclass college students as an introduction to the growing field of coherent optics and to the increasing number of its applications, and also for those versed in other fields who wish to gain perspective and insight without detailed calculations. It is an outgrowth of the author's Science Study Series book *Lasers and Holography.** Besides being an updated and expanded version of that book, it includes discussions of numerous recent applications. It differs in its slightly higher analytical level and in the inclusion of large numbers of references, which enable the reader to obtain further information on subjects of interest to him. The level was selected to match the capabilities of students in their middle college years so as to permit them to make an early assessment of possible career interests in any of the many interdisciplinary fields now embracing the technologies of modern optics.

It is hoped that the book can be used (as has occurred rather extensively with another of the author's Science Study Series books, *Sound Waves and Light Waves*†) as an auxiliary reading assignment for students in various disciplines. The author strongly believes that the promise of continued growth in this field, as evidenced by the extensive participation in technology developments by industry, both within the U.S. and abroad, identifies the subject as

* Doubleday, 1969 (hard cover and paperback). This book was chosen by Heinemann Education Books, Ltd. for No. 39 in their Science Series (1972, hard cover), by Editorial Universitaria De Buenos Aires (EUDEBA) for No. 42 in their New Science Collection (1972, paperback), by World Publishing (MIR, Moscow) for their Science and Technology Series (1971, paperback), and by Kawade Shobo (Tokyo) for No. 41 in their Science Series (1971, paperback).

† Doubleday, 1965, also widely translated: No. 109 in the Springer Verstandliche Wissenschaft series (1971, paperback), No. 17 in the Zanichelli Scientific Monograph series (Rome, 1966, paperback), No. 27 in the Kawade Shobo Science Series, (Tokyo, 1969, paperback), and in the World Publishing Science and Technology Series (MIR, Moscow, 1966, paperback).

one of more than average significance to engineering students, and the auxiliary reading assignment procedure would enable the student to become aware of the future importance of this new technology. Several chapters include an introductory review of the history and growth of the field discussed so as to further permit the reader to recognize the impact that modern optics is making in that area.

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INTRODUCTION

Holography and photography are two ways of recording, on film, information about a scene we view with our eyes. The basic mechanisms by which they accomplish their purpose, and the images which result, however, are quite different. As the words *holo* (complete) and *gram* (message) connote, the hologram captures the entire message of the scene in all its visual properties, including the realism of three dimensions. The photograph, on the other hand, collapses into one plane, the plane of the print, all the scenic depth we perceive in the actual scene.

The Hungarian-born British scientist Dennis Gabor conceived of holography in 1947 as a new method for photographically recording a three-dimensional image. As is true of many exceptional ideas, it is hard to understand why holography had not been thought of sooner. As we shall see, it involves merely the process of photographically recording the pattern formed by two interfering sets of light waves, one of these wave sets being a *reference wave*. When Gabor conceived this idea, the special kind of light (a single-frequency form called coherent light) needed to demonstrate the full capabilities of holography was not readily available. It became available only after the *laser*, a new light source first demonstrated in 1960, was developed. An atomic process called *stimulated emission* is responsible for the light generated in a laser, and the name laser is an acronym formed from the words *l*ight *a*mplification by the *s*timulated *e*mission of *r*adiation. Because the light sources available to Gabor in 1947 could not demonstrate it fully, holography lay almost dormant for many years. In 1963, the American scientist Emmett N. Leith introduced the laser to holography. The subsequent advances made by him, by another American scientist, George W. Stroke, and by their many co-workers, led to a tremendous explosion in holography development.

A hologram records the interference pattern formed by the combination of a reference wave with the light waves issuing from a scene, and when this photographic record is developed and again illuminated with laser light, the original scene is presented to the viewer as a reconstructed image. This image manifests such vivid realism that the viewer is tempted to reach out and try to touch the objects of the scene. The hologram plate itself resembles a window with the imaged scene appearing behind it in full depth. The viewer has available to him many views of the scene; to see around an object in the foreground, he simply raises his head or moves it left or right. This is in contrast to the older, two-photograph stereopictures, which provide an excellent three-dimensional view of the scene, but only one view. Also, photography uses lenses, and lenses allow only objects at a certain distance from the camera to be in truly sharp focus. In the hologram process, no lenses are used, and all objects near and far, are portrayed in its image in extremely sharp focus.

Gabor was the first to use the term hologram, and Stroke proposed the term holography. Both have become the generally accepted terms, with the first now generally considered as the record, the second as the process. To give the reader a general overview of holography, the first chapters review the underlying wave concepts including coherence, diffraction, and interference. Next, the nature of the holograms themselves is discussed, followed by a description of recent developments in lasers. The last eight chapters describe some of the many fields in which the two techniques are finding applications. A list of suggested further readings is given at the back of the book.

1

FUNDAMENTAL WAVE PROPERTIES

Certain properties of wave motion are manifested by water waves, such as those formed when a pebble is dropped on the surface of a still pond, as shown in Figure 1.1. Because all wave energy travels with a certain speed, such water waves move outward with a wave speed or *velocity of propagation*,

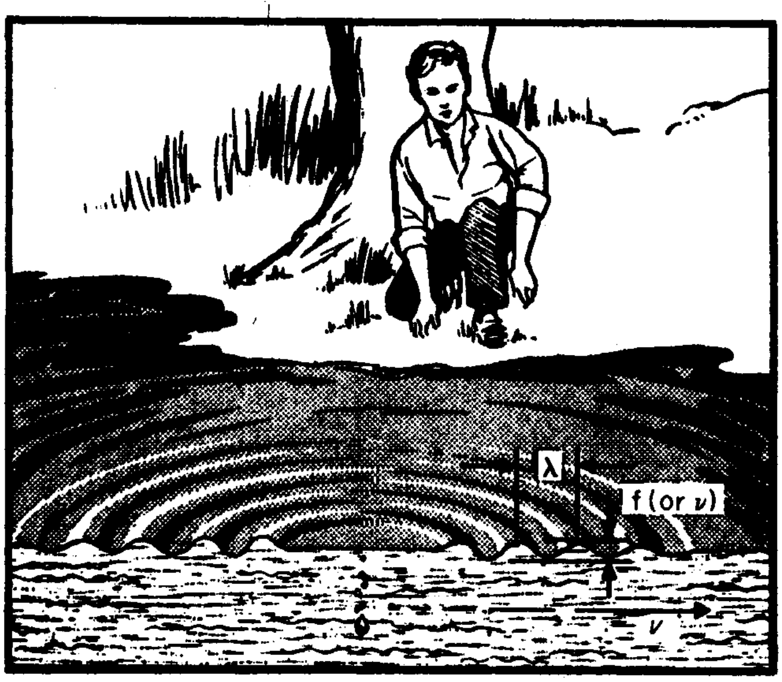

FIGURE 1.1. Water waves on a pond. The velocity of propagation is v, the distance from crest to crest is the wavelength λ, and the periodicity of the up-and-down motion of a point on the surface is the frequency f (or ν).

v. Waves also have a *wavelength*, the distance from crest to crest; it is usually designated, as shown, by the Greek letter λ. If, in Figure 1.1, we were to position one finger so that it just touched the crests of the waves, we could feel each crest as it passes by. If the successive crests are widely separated, they touch our finger less often, less frequently, than if the crests are close together. The expression *frequency* is therefore used to designate how frequently (how many times in one second) the crests pass a given point. The velocity, the wavelength, and the frequency [stated as cycles per second or hertz (Hz)] are thus related by

$$f = v/\lambda \tag{1.1}$$

This says simply that the shorter the wavelength the more frequently the wave crests pass a given point, and similarly, the higher the velocity, the more frequently the crests pass. No proportionality constant is needed in Equation (1.1) if the same unit of length is used for both the wavelength and the velocity and if the same unit of time (usually the second) is used for both the frequency and the velocity.

1.1 Wave Interference

If a simple and uniform set of waves, as in Figure 1.1, were to meet a second set of similarly uniform, single-wavelength waves, a phenomenon called *interference* would result. (The wave fields add algebraically.) At certain points, they reinforce (a condition called *constructive* interference), and at others they cancel (a condition called *destructive* interference). As shown at the left of Figure 1.2, when the *crests* of one wave set, A, coincide with the *crests* of a second set, B, constructive interference occurs, and the height of the combined crests increases. When, on the other hand, the *crests* of one source coincide with the *troughs* of the second source, as shown on the right,

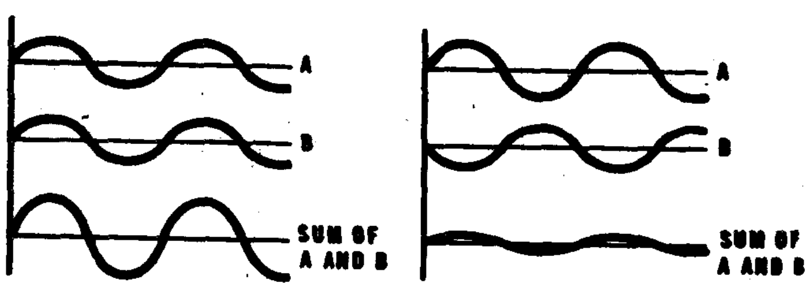

FIGURE 1.2. Two waves of the same wavelength add (at the left) if their crests and troughs coincide, and subtract (at the right) if the crest of one coincides with the trough of the other.