

Optics 505 - Diffraction and Interferometry

1.0 Introduction

Diffraction and interferometry involve wave combination. In this class, we study the basics of electromagnetic wave combination. Although many of the same concepts apply to compression waves, like sound, our interest is in optical phenomena. Many beautiful and useful effects are explained through the theory discussed in this course.

The difference between diffraction and interferometry is that interferometry involves combining a small number of waves, and diffraction involves combining many waves in a continuous fashion. A strong understanding of interferometry provides a basis for understanding diffraction, so we first discuss combining a small number of waves and instrumentation associated with the effects. Then, we expand the discussion to combining an infinite number of waves within the context of diffraction.

1.1 A short historical review

The foundation of interferometry started with the observation of Newton's rings in the mid 17th century. Actually, Newton's rings were described in terms of waves by Hooke and Boyle, not Newton. At the time, Newton opposed the wave theory of light. As a result, the correct superposition theory of Huygens was not accepted until nearly a hundred and fifty years later. In 1801, Sir Thomas Young demonstrated that combination of two light rays could give rise to darkness, which started to break down barriers to acceptance of the principle of interference. The turning point to acceptance of wave theory came in 1818, with Fresnel's brilliant memoir on diffraction. About forty years later, James Clark Maxwell started publishing the set of equations that fully describe electromagnetic effects. Even though the theory was nearly complete, many leading scientists believed that light propagated through the ether, which was thought to be an elastic solid pervading all matter. Fizeau's famous experiment in 1851 involving an interferometer seemed to verify the ether theory. However, it was the null result from Michelson's famous interferometer in 1882 that led to rejection of the ether theory. Since that time, many scientists, inventors and engineers have contributed to the rich discipline of wave optics. Today, wave optics is an extremely important discipline for research, industry and for the consumer. From ultra-precise measurement of submicrometer distances, to measurement of star separation, to formation of bright spots with laser pointers, wave optics continues to be an important and interesting subject for the student of optics.

1.2 Basic philosophy of interference

Interference involves the study of waves and wavefronts. Electromagnetic waves are temporally harmonic oscillations that propagate in a direction normal to the electric vector in homogeneous media. Wavefronts are three-dimensional surfaces defined by a constant temporal phase of the electromagnetic field. Since phase is directly proportional to the optical path length (OPL) traversed by the wave, wavefronts are also defined by surfaces of constant OPL.

Interference involves the combination of at least two waves. The waves can emanate from a coherent source, like a laser, or an incoherent source, like a light bulb filament. A simple way to formulate solutions for problems in interference is to imagine that the source exists in its own space, called the *source space*. The optical system consisting of lenses, mirrors and beam splitters forms multiple images of the source that exist in the *observation space*. Wavefronts propagating from the multiple images lead to interference effects.

Production of multiple beams in observation space is usually classified either as *division of amplitude* or *division of wavefront*. Division of amplitude can be achieved from a simple beamsplitter, where the complete wavefront from S_0 is split into two parts S_1 and S_2 , as shown in Fig. 1.1(a). Division of amplitude results in multiple images of the source in observation space. Division of wavefront is achieved by sampling the source wavefront S_0 to create two new wavefronts S_1 and S_2 that may or may not resemble S_0 . For the example shown in Fig. 1.1(b), two pinholes are used to sample source wavefront S_0 . If the pinholes are small enough, S_1 and S_2 resemble waves from point sources, regardless of the form of S_0 .

Whatever method is used to generate the observation-space wavefronts, a critical factor in determining interference is the optical path difference OPD from the sources to the detector, as shown in Fig. 1.2. For example, the optical path length OPL_1 from S_1 to the observation point is length r_1 multiplied by the refractive index n of the observation space at the detector. OPL_1 is directly proportional to the time it takes light to travel from S_1 to the observation point. OPL_2 is defined in a similar way with respect to S_2 . OPD is simply $OPL_1 - OPL_2$, which is a measure of the time difference between points on the source images to the observation point. A basic postulate of interference is that, for OPD equal to an integer number of wavelengths, the constructive nature of waves leads to a bright observation point. For OPD equal to an odd number of half wavelengths, a dark observation occurs.

1.3 Basic philosophy of diffraction

The Huygens theory of diffraction is illustrated in Fig. 1.3, where a source point S_0 illuminates an opaque screen with a clear central aperture. Inside the aperture, the wavefront consists of a continuum of individual secondary source points. Each secondary source point S_j emits its own wavefront that reaches the detector. Observation at the detector is due to a summation of wavefronts from individual secondary source points. The contribution from each S_j depends on OPL_i , the amplitude and phase of the source $A_i \exp(j\phi_i)$, and the relative positions of S_j and the observation point.





1.4 Abbreviated historical time line

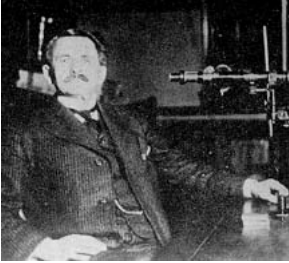

references:

<http://history.hyperjeff.net/electromagnetism.html>

<http://members.aol.com/WSRNet/D1/hist.htm>

1452-1519	Leonardo Da Vinci, from <u>Codex Atlanticus</u> - <i>Thus every body placed in the luminous air spreads out in circles and fills the surrounding space with infinite likeness of itself and appears all in all and all in every part.</i>
1664	Robert Hooke - wave theory of light

1675	<p>Robert Boyle - wave theory of light</p> 
1677	<p>Christian Huyghens - Treatise on Light</p> 
1704	<p>Issac Newton – <u>Optics</u></p> 
1801	<p>Thomas Young - interference and polarization</p>  <p>Thomas Young (1773-1829)</p>
1814	<p>Augustin Jean Fresnel - wave theory</p>

1855-1868	James Clark Maxwell - field equations
1882	Albert A. Michelson - Michelson interferometer 
1882	Gustav R. Kirchoff - solid mathematical foundation for diffraction phenomena 
1890	O. Weiner - observation of standing wave patterns
1899	Lord Rayleigh - Explains blue color of sky and red sunsets
1899	Marie P. A. C. Fabry and Jean B. G. G. A. Perot - Fabry-Perot Interferometer