Preface

Optical interference plays a prominent role in scientific discovery and modern technology. Historically, optical interference was instrumental in establishing the wave nature of light. Nowadays, optical interference continues to be of great importance in areas such as spectroscopy and metrology. Thus far, the physical optics literature has discussed the interference of optical waves with the same single frequency (i.e., homodyne interference) and the interference of optical waves with two different frequencies (i.e., heterodyne interference), but it hardly ever deals with the interference of optical waves whose frequencies are continuously modulated (i.e., frequency-modulated continuous-wave interference).

Frequency-modulated continuous-wave (FMCW) interference, which was originally investigated in radar in the 1950s, has been recently introduced in optics. The study of optical FMCW interference not only updates our knowledge about the nature of light but also creates a new advanced technology for precision measurements.

This book introduces the principles, applications, and signal processing of optical FMCW interference. The layout of this book is straightforward. Chapter 1 gives a short introduction to optical FMCW interferometry by considering the historical development, general concepts, and major advantages provided by this new technology. Chapter 2 focuses on the principles of optical FMCW interference. Three different versions of optical FMCW interference—sawtooth-wave optical FMCW interference, triangular-wave optical FMCW interference, and sinusoidal-wave optical FMCW interference—are discussed in detail. Moreover, multiple-beam optical FMCW interference and multiple-wavelength optical FMCW interference are also discussed by this chapter.

Chapter 3 introduces the optical sources for optical FMCW interference. Since, in practice, only lasers can be frequency-modulated optical sources, and the most frequently used ones are semiconductor lasers, this chapter first introduces the general principles of lasers, including the concepts of stimulated emission, population inversion, optical resonators, laser modes, and frequency modulation, and then discusses the characteristic features of semiconductor lasers. Chapter 4 introduces the optical detectors for optical FMCW interference. The operating principles of the commonly used semiconductor photodiodes, including PN photodiodes, PIN photodiodes, and avalanche photodiodes, and related issues, such as photodiode biasing, photocurrent amplification, and noise sources, are discussed in detail.

Chapter 5 discusses the coherence theory of optical FMCW interference, including the effects of the frequency bandwidth of optical sources, coherence of optical FMCW waves, and influence of the phase noise of optical sources. Chapter 6 first indicates the fundamental requirements and techniques for constructing optical FMCW interferometers and then gives some examples of optical FMCW interferometers, which are modified from the classical homodyne interferometers such as the Michelson interferometer, the Mach-Zehnder interferometer, and the Fabry-Perot interferometer.

Chapters 7, 8, and 9 deal with fiber-optic FMCW interferometers and fiber-optic FMCW interferometric sensors. Optical fibers are cylindrical dielectric optical waveguides and have been widely used in the fields of image transmission and optical communication, providing a low-noise, low-attenuation, low-cost, long-distance, and flexible light-propagation medium. The application of optical fibers and fiber-optic components to optical interferometers can make the interferometers compact, reliable, flexible, and more accurate. Moreover, with optical-fiber technology, more advanced detection techniques, more sophisticated interferometers, even “solid” interferometers (i.e., all-fiber interferometers) can be developed.

Chapter 7 first briefly introduces optical fibers and fiber-optic components and then presents some typical fiber-optic FMCW interferometers, including fiber-optic Michelson FMCW interferometers, fiber-optic Mach-Zehnder FMCW interferometers, and fiber-optic Fabry-Perot FMCW interferometers. Chapter 8 discusses the multiplexing technologies of fiber-optic FMCW interferometers. Four important multiplexing methods (frequency-division, time-division, time-frequency-division and coherence-division) and the related multiplexed fiber-optic FMCW interferometers are discussed in detail. Chapter 9 presents a number of advanced fiber-optic sensors based on optical FMCW interference, including fiber-optic FMCW interferometric displacement sensors, fiber-optic FMCW interferometric strain sensors, fiber-optic FMCW interferometric stress sensors, fiber-optic FMCW interferometric temperature sensors, and fiber-optic FMCW interferometric rotation sensors (i.e., fiber-optic FMCW gyroscopes).

Chapter 10 discusses the signal processing of optical FMCW interference. Three different methods for both frequency measurement and phase measurement are discussed in detail.

This book is based on the author’s twenty-year research experience in this field. The author has tried his best to make this book clear, concise, and correct. All the contributors to optical FMCW interferometry involved in this book are given credit; however, inventors in other related fields are not always acknowledged.

This book is intended for scientists, engineers, and researchers in both academia and industry. It is especially suited to professionals who are working in the field of measurement instruments. It can also be used as a textbook of modern optical interferometry for senior undergraduate or graduate students.

I would like to express special gratitude to Dr. Hans Koelsch of Springer-Verlag New York for his great help in creating this project. Thanks also to my son, Jack, for his valuable help in the preparation of this manuscript. Finally, I would like to dedicate this book to my wife, Nancy, for her constant encouragement and support.

Vancouver, 2004 Jesse Zheng