

**Course Title:**       **Optical Signal Processing and Interferometry for Quantum Applications**

**Credits Hrs:**       3

**Prerequisites:**

1. Basic Optics (waves, interference, diffraction)
2. Basic quantum mechanics (wavefunctions, operators)
3. Linear algebra and Fourier transforms

**Course Description**

This course provides a comprehensive treatment of optical signal processing and interferometry, spanning from classical Fourier optics to advanced applications in quantum optics and quantum information technology. Students will explore the theoretical foundations of optical coherence, modulation, and detection, while also gaining hands-on experience with interferometric techniques in laboratory settings. Emphasis is placed on understanding both classical and quantum aspects of interferometry, including photon statistics, squeezed states, and quantum-enhanced measurement techniques. Applications to optical communications, quantum sensing, quantum key distribution (QKD), and precision metrology are highlighted throughout the course.

**Course Objectives**

The main objectives of this course are to:

- Introduce the principles of optical signal processing using Fourier optics and filtering methods.
- Develop a clear understanding of classical interferometry (Michelson, Mach–Zehnder, Fabry–Perot, fiber interferometers).
- Build the mathematical and conceptual foundation of optical coherence theory.
- Introduce quantum states of light and their applications in interferometry.
- Demonstrate how interferometric methods are applied in quantum technologies, including sensing, communication, and metrology.
- Equip students with practical experience through laboratory experiments in optical signal processing and interferometry.
- Encourage research-oriented thinking by connecting theoretical knowledge to emerging trends in quantum photonics.

## Course Learning Outcomes (CLOs)

By the end of this course, students will be able to:

1. Explain principles of optical signal processing (Fourier optics, filtering, modulation).
2. Analyze and design interferometric systems (Michelson, Mach–Zehnder, Fabry–Perot, fiber-based).
3. Apply coherence theory to classical and quantum interferometry.
4. Understand quantum states of light and their role in interferometry.
5. Apply optical and quantum interferometric principles to quantum information and metrology.
6. Perform lab experiments in signal processing and interferometry, both classical and quantum regimes (once lab is established).

## Course Contents:

<b>Week</b>	<b>Contents</b>
1	Introduction, review of wave optics, Scalar diffraction theory, Fourier transforms
2	Fourier Optics & Spatial Filtering, Fourier transforming property of lenses, Optical correlators, matched filtering
3	Temporal and Spatial Coherence, Coherence theory, coherence time & length, Applications in interferometry
4	Optical Modulation & Detection, Amplitude, phase, frequency modulation, Photodetection and signal-to-noise ratio
5	Signal Processing with Interferometers, Basics of Michelson, Mach–Zehnder, Fabry–Perot, Filtering and modulation with interferometers
6	Michelson and Fabry–Perot Interferometers, Resolution, fringe visibility, finesse, Applications in metrology
7	Mach–Zehnder Interferometer, Phase modulation, switching, quantum beam splitting, Signal processing applications
8	<u>Mid Term</u>
9	Fiber-Optic Interferometers, Sagnac, Mach–Zehnder, Michelson,

- Interferometers in fiber optics, Applications: sensors, gyroscopes
- 10 Quantum States of Light, Fock states, coherent states, squeezed states, Photon detection, quantum noise
  - 11 Quantum Interferometry, Hong–Ou–Mandel effect, Quantum-enhanced interferometry (squeezed light)
  - 12 Quantum Optical Signal Processing, Quantum Fourier transform with optics, Quantum optical filtering & holography
  - 13 Interferometry in Quantum Information, Role in quantum communication & sensing, Applications in QKD, super-resolution imaging
  - 14 Optical Signal Processing in Quantum Metrology, Phase estimation, shot noise limit, Heisenberg limit, Precision measurements with interferometers
  - 15 Emerging Research Directions, Integrated photonic circuits for quantum, interferometry, Hybrid quantum–classical signal processing, Student seminar presentations
  - 16 Final Exam

**Textbooks/ References:**

- Saleh & Teich – *Fundamentals of Photonics* (2nd/3rd Ed., Wiley)
- Gerry & Knight – *Introductory Quantum Optics*

**Reference Books**

3. Hecht – *Optics* (5th Ed., Pearson) – for classical interferometry basics
4. Loudon – *The Quantum Theory of Light*
5. Yariv & Yeh – *Photonics: Optical Electronics in Modern Communications* (6th Ed.)
6. Mandel & Wolf – *Optical Coherence and Quantum Optics*

**Assessment:**

- Assignments: 10%
- Quizzes: 10%
- Midterm Exam: 30%
- Final Exam: 50%