Course objectives

Part I: Optical Communication Systems
- System components
- Theoretical considerations
- Networking

Part II: Optical Orthogonal Codes for Fiber
Optical Code Division Multiple Access (FO-CDMA)
- FO-CDMA – definitions and devices
- OOC constructions

Optical Orthogonal Codes for FO-CDMA
1. Code division multiple-access techniques in optical fiber networks
   - Fundamental principles
   - Systems performance analysis
2. Optical orthogonal codes: design, analysis and applications
3. Optical orthogonal codes - new bounds
4. Constructions for optimal optical orthogonal codes
5. Optical orthogonal codes with unequal auto- and cross-correlation constraints
6. Construction and performance analysis of a new family of optical orthogonal codes for CDMA fiber-optic networks

Optical Communication Systems
1. Light propagation in optical fibers and power loss mechanisms
2. Optical detection theory
3. Optical sources and transmitters
4. Optical detectors and receivers
5. Optical amplifiers
6. Fiber nonlinearities
7. Modulation formats for digital fiber transmission systems
8. Wavelength-division multiplexing (WDM)
9. Fiber optic communications networks

Optical Fibers
*A glass or plastic fiber that has the ability to guide light along its axis. The three parts of an optical fiber are the core, the cladding, and the coating or buffer.

- Core: The light-conducting central portion of an optical fiber, composed of material with a higher index of refraction than the cladding. The portion of the fiber that transmits light.
- Cladding: Material that surrounds the core of an optical fiber. Its lower index of refraction, compared to that of the core, causes the transmitted light to travel down the core.
- Coating: The material surrounding the cladding of a fiber. Generally a soft plastic material that protects the fiber from damage.
Light propagation in optical fibers
- Single mode fibers
  - Higher capacity
  - No dispersion
  - Low attenuation
  - Smaller core diameter causes coupling difficulties
  - The tolerances for single-mode connectors and splices are much more demanding

Light propagation in optical fibers
- Multimode Step-index Fiber
  - Pulse dispersion
  - High attenuation
  - Less coupling difficulties due to larger core diameter
  - The tolerances for single-mode connectors and splices are less demanding
  - Cheap to produce

Light propagation in optical fibers
- Multimode Graded-index Fiber
  - Less pulse dispersion
  - Less attenuation
  - Less coupling difficulties due to larger core diameter
  - The tolerances for single-mode connectors and splices are less demanding
  - Difficult and expensive to produce

Fiber loss mechanisms
- Attenuation is one of the most important factors that limit the performance
  - Fiber effects
    - Material absorption and scattering
    - Bending and microbending losses
    - Mode coupling radiation and leaky modes
  - System effects
    - Coupling losses between devices
    - Losses in fibre splices and connectors

Fiber Losses

The Electromagnetic Spectrum
Light propagation in optical fibers and power loss mechanisms - references

- Göran Einarsson, Principles of Lightwave Communications – chapters 2 (and 4)
- John Crisp, Introduction to Fiber Optics – chapters 2 through 7 (except 4)

Optical detection theory

- Photodetectors
- Modelling of the induced electric current as a Poisson process
- On-Off keying and photon-counting receiver
- Gaussian approximations for calculation of BER
- Optical Information Theory

Optical detection theory - reference

- Göran Einarsson, Principles of Lightwave Communications – chapter 5

Optical sources (LD)

- Laser Diode (LD): A semiconductor that emits coherent light when forward biased.

Optical sources (LED)

- Light-emitting Diode (LED): A semiconductor that emits incoherent light when forward biased. Two types of LED's include edge-emitting LED's and surface-emitting LED's

Optical transmitters

- Transmitter: A device that includes a source and driving electronics. It functions as an electrical-to-optical converter - A device that converts electrical signals to optical signals.
Photodetector: An optoelectronic transducer such as a PIN photodiode or avalanche photodiode. In the case of the PIN diode, it is so named because it is constructed from materials layered by their positive, intrinsic, and negative electron regions.

Receiver: A terminal device that includes a detector and signal processing electronics. It functions as an optical-to-electrical converter.

Optical detectors and receivers - references
- HANDBOOK OF FIBER OPTIC DATA COMMUNICATION
  - Chapter 3 Detectors for Fiber Optics
  - Chapter 6 Fiber Optic Transceivers
- OPTICAL FIBER TELECOMMUNICATIONS IIIB
  - Chapter 3 Transmitter and Receiver Design for Amplified Lightwave Systems
- OPTICAL FIBER TELECOMMUNICATIONS IVA
  - Chapter 16 High Bit-Rate Receivers, Transmitters, and Electronics
**Optical amplifiers**

- With the demand for longer transmission lengths, optical amplifiers have become an essential component in long-haul fiber optic systems.
  - Semiconductor optical amplifiers (SOAs)
  - Erbium doped fiber amplifiers (EDFAs)
  - Raman optical amplifiers
- Lessen the effects of dispersion and attenuation allowing improved performance of long-haul optical systems.

**Semiconductor optical amplifiers (SOA)**

A laser diode without end mirrors coupled to the fibers on both ends. Light coming in either fiber is amplified by a single pass through the laser diode.

**Erbium-doped Fiber Amplifier (EDFA)**

Optical fibers doped with the rare earth element, erbium (68), which can amplify light in the 1550 nm region when pumped by an external light source.

**Optical amplifiers - references**

- [Optical Fiber Telecommunications IIIB](#)
  - Chapter 2 Erbium-Doped Fiber Amplifiers for Optical Communications
- [Optical Fiber Telecommunications IVA](#)
  - Chapter 14 Semiconductor Optical Amplifiers

**Fiber nonlinearities**

- Nonlinearity effects arise as optical fiber data rates, transmission lengths, number of wavelengths, and optical power levels increased.
- In the early days - fiber attenuation and fiber dispersion these issues are easily dealt with using a variety of dispersion avoidance and cancellation techniques.
- Fiber nonlinearities present a new realm of obstacle that must be overcome.

**Fiber nonlinearities**

- Nonlinearities that need special attention when designing state-of-the-art fiber optic systems include
  - stimulated Brillouin scattering (SBS)
  - stimulated Raman scattering (SRS)
  - four wave mixing (FWM)
  - self-phase modulation (SPM)
  - cross-phase modulation (XPM)
  - intermodulation (mixing)
Fiber nonlinearities - references

- OPTICAL FIBER TELECOMMUNICATIONS
  - IIIA
    - Chapter 8 Fiber Nonlinearities and Their Impact on Transmission Systems
  - IVB
    - Chapter 13 Nonlinear Optical Effects in WDM Transmission

Frequency Modulation (FM)

Optical systems employing FM encoding refer to the technique as pulse-frequency modulation (PFM). This simply means that the FM signal is limited (converted to digital 0’s and 1’s) before it is transmitted over the fiber.

Digital Modulation (PCM)

Once the analog information has been put into a digital form, the digital channels are time-division multiplexed (TDM) and sent to the laser transmitter. The digital signal is converted into light pulses; the laser is on for a “1” and off for a “0”. Time-division multiplexing is used by digital systems to either combine multiple video signals on to one fiber or to create subchannels for digitized audio and/or data signals. TDM allows signals to be added to or removed from a system without system degradation.
When data rates were in the low gigabit range and transmission distances were less than 100 km or so, most fiber optic transmitters used directly modulated lasers. However, as data rates and span lengths grew, waveguide chirp, caused by turning a laser on and off, limited data rates. Dispersion problems resulted when the wavelength chirp widened the effective spectral width of the laser. A laser source with no wavelength chirp and a narrow linewidth provide one solution to the problem. This solution took the form of external modulation which allows the laser to be turned on continuously; the modulation is accomplished outside of the laser cavity.

### Wavelength-division multiplexing

The fiber optic industry first deployed single wavelength transmission links. As requirements changed, the industry responded with wavelength-division multiplexing (WDM), which sends two distinct signals per fiber, doubling transmission capacity.

Two important considerations in a WDM device:
- Crosstalk
- Channel separation.

### Coarse wavelength-division multiplexing

With a capacity greater than WDM and smaller than DWDM, CWDM allows a modest number of channels, typically eight or less, to be stacked in the 1550 nm region of the fiber called the C-Band. To dramatically reduce cost, CWDMs use uncooled lasers with a relaxed tolerance of ± 3 nm. Whereas DWDM systems use channel spacing as close to 0.4 nm, CWDM uses a spacing of 20 nm.

Important components for a DWDM systems are:
- transmitters
- receivers
- fiber amplifiers
- DWDM multiplexers
- DWDM demultiplexers

### Dense wavelength-division multiplexing (WDM) - references

Some Internet resources
Fiber optic communications networks - overview

- All networks involve the same basic principle: information can be sent to, shared with, passed on, or bypassed within a number of computer stations (nodes) and a master computer (server). In addition to various topologies for networks, a number of standards and protocols have been developed, each with their own advantages, topologies, and medium requirements.

- Standards and protocols
  - Asynchronous Transfer Mode (ATM)
  - Ethernet, Fast Ethernet, Gigabit Ethernet
  - Fiber Distributed Data Interface (FDDI)
  - Fibre Channel
  - Integrated Services Digital Network (ISDN)
  - Synchronous Optical Network (SONET)

Fiber optic communications networks - ATM

- ATM: A transmission standard widely used by the telecom industry. A digital transmission switching format with cells containing 5 bytes of header information followed by 48 data bytes. Part of the B-ISDN standard.
- ATM organizes different types of data into separate cells, allowing network users and the network itself to determine how bandwidth is allocated. This approach works especially well with networks handling burst data transmissions. Data streams are then multiplexed and transmitted between end user and network server and between network switches. These data streams can be transmitted to many different destinations, reducing the requirement for network interfaces and network facilities, and ultimately, overall cost of the network itself.

Fiber optic communications networks - Ethernet

- Ethernet: A standard protocol (IEEE 802.3) for a 10-Mb/s baseband local area network (LAN) bus using carrier sense multiple access with collision detection (CSMA/CD) as the access method. Ethernet is a standard for using various transmission media, such as coaxial cables, unshielded twisted pairs, and optical fibers.

Fiber optic communications networks - FDDI & ISDN

- FDDI: A dual counter-rotating ring local area network.
- ISDN: An integrated digital network in which the same time-division switches and digital transmission paths are used to establish connections for services such as telephone, data, electronic mail and facsimile. How a connection is accomplished is often specified as a switched connection, non-switched connection, exchange connection, ISDN connection, etc.

Fiber optic communications networks – SONET

- SONET: Abbreviation for synchronous optical network transport system. An interface standard widely used by the telecom industry where OC-3 is the lowest current rate (155.5 Mb/s), and OC-768 is the highest rate being contemplated (39,808 Gb/s). Valid rates increase by a factor of four from the OC-3 rate up to OC-768.