A lecture-by-lecture Description of a
Course on Digital Communication
based on the book
A. Lapidoth, *A Foundation in Digital Communication*,
second edition, Cambridge University Press, 2017

- Lecture 1
  - Topics:
    - Course information.
    - Block diagram of a point-to-point digital communication system.
    - Review of signals: The energy in a signal (why we call it energy), the inner product (complex integral), and orthogonality (why mathematicians object).
    - Review of the Fourier Transform and Inverse Fourier Transform. Emphasize the 2π's etc.
    - Parseval's Theorem.
    - Real signals have conjugate-symmetric Fourier Transforms, hence the dashed lines in the figures.
    - Sinc and brickwall.
    - The definition of bandwidth.
  - Sections: 2.3, 3.1, 3.2, 4.1, 4.2, 6.1, 6.2.1–6.2.2.
  - Assignment: Read Chapter 4. Review your Fourier Transform!
- Lecture 2
  - Topics:
    - Baseband representation of passband signals.
    - Bandwidth in baseband and passband.
    - Inner product in passband and baseband.
    - The baseband representation of the convolution of two passband signals.
    - The baseband representation of a filtered passband signal.
  - Sections: 7.1–7.8 (without all the mathematical technicalities).
  - Assignment: Be sure you can justify all the entries in Table 7.1.
- Lecture 3
  - Topics:
    - Finite dimensional linear subspaces of L_2 (bases, dimension, orthonormal bases, Gram-Schmidt procedure—just a reminder!).

    * Expressing a signal in terms of a given orthonormal basis.
    * Projection of an arbitrary energy limited function onto a finite dimensional subspace (definition, uniqueness and computation using an orthonormal basis).
    * Projections and closest element in the subspace.
    * Complete Orthonormal Systems (CONS).
    * Implication of Fourier and Parseval (CONS in time if, and only if, CONS in frequency).
    * The Sampling Theorem as an orthonormal expansion.
  - Sections: 8.1–8.4.
  - Assignment: Review Chapter 7.

- Lecture 4
  - Topics:
    * Sampling real passband signals. Emphasize complex vs. real samples and the implementation of complex computations using real circuitry.
    * Linear Modulation.
    * Orthogonal Linear Modulation (noiseless demodulation using the inner product).
    * Implementing the inner product using a matched filter.
    * What is a stochastic process?
    * Why is the result of modulating random bits a stochastic process?
  - Sections: 9.1–9.3, 10.1–10.6, 5.8.
  - Assignment: Read Chapter 12.

- Lecture 5
  - Topics:
    * The definition of PAM, the pulse shape, and the baud period.
    * Rate calculations in bits-per-symbol and bits-per-second. Examples of the rate being higher than 1, equal to 1, or lower than 1 bit per symbol.
    * One matched filter for all the inner products: sample the matched filter at different times.
    * Necessary and sufficient condition for $\boldsymbol{\phi}$ and its time shifts by integer multiples of T to be orthonormal, i.e., that its self-similarity function be a Nyquist pulse.
    * Excess bandwidth.
    * Band-edge symmetry.
    * Raised Cosine.

  - Sections: 10.7, 11.1–11.3.
  - Assignment: Read Sections 10.8–10.10

- Lecture 6

  - Topics

    * Energy and Expected Energy in PAM.
    * Why the transmitted signals are typically centered.
    * Power in PAM signals makes only sense when sending infinitely many bits. Bi-infinite block-mode is the most interesting case.
    * Power in PAM when symbols form a centered WSS discrete-time stochastic process.

  - Sections: 14.1–14.4, 14.5.1.
  - Assignment: Read Sections 14.5.2 and 14.5.3 (without proof).

- Lecture 7

  - Topics:

    * Power Spectral Density: motivation and definition of operational PSD.
    * The symmetry requirement and why the operational PSD is otherwise not unique.
    * Computation of the operational PSD for PAM signals.

  - Sections: 15.1–15.3, 15.4.1, 15.4.2.
  - Assignment: Read Section 15.4.3.

- Lecture 8

  - Topics:

    * Derivation of QAM: getting the right number of dimensions per second per Hz.
    * Emphasize that W Hz in passband are "just as good" as W in baseband.
    * Emphasize that two real passband signals are orthogonal if, and only if, the inner product between their baseband representations is imaginary; it need not be zero.
    * Counting bits per *complex* symbols.
    * Decoding: Converting to baseband and matched filtering.
    * Energy in QAM—only expectation of products of the form $\mathsf{E}\left[C_\ell C^*_{\ell+m}\right]$ appear. Products of the form $\mathsf{E}\left[C_\ell C_{\ell+m}\right]$ never show up.

  - Sections: 16.1–16.7, 16.8.1, 18.1, 18.2.
  - Assignment: Read Sections 19.1–19.7.

- Lecture 9
  - Topics:
    - The power in QAM. Emphasize Equations (18.26) & (18.27) without a proof of the latter (Theorem 18.5.2).
    - The power in QAM.
    - The operational PSD of QAM.
    - Introduction to hypothesis testing.
    - Guessing in the absence of observables.
    - The joint law of the hypothesis and the observable.
  - Sections: 18.3, 18.4 (without 18.4.2), 20.1–20.4.
  - Assignment: Read Sections 18.3.2 and 18.3.3 without proofs.
- Lecture 10
  - Topics:
    - Guessing with observables.
    - Randomized decision rules are no better.
    - The MAP and ML rules.
    - The Bhattacharyya Bound.
    - Testing for the mean of a Gaussian.
    - Processing prior to deciding.
  - Sections: 20.5–20.11.
  - Assignment: Read Section 20.15.
- Lecture 11
  - Topics:
    - Sufficient statistics.
    - Consequences of optimality.
    - Multi-dimensional binary Gaussian hypothesis testing.
    - Multi-hypothesis testing.
    - 8-PSK example.
    - Union Bound in general and for the 8-PSK problem.
    - Sufficient Statistics in multi-hypothesis testing.
    - Pairwise sufficiency and sufficiency.
  - Sections: 20.12–20.14, 21.1–21.6, 22.3.2 (proof when densities are strictly positive).
  - Assignment: Read Section 21.6.

- Lecture 12
  - Topics:
    - The Multivariate Gaussian distribution.
  - Sections: 23.1–23.7.
- Lecture 13
  - Topics:
    - The FDDs.
    - Weak and Strong sense stationarity.
    - The PSD.
    - Gaussian Stochastic Processes: wide sense stationarity and strict sense stationarity; the FDDs are determined by the autocovariance function and the mean.
    - Linear functionals of Gaussian Processes are Gaussian.
    - Any set of linear functions of Gaussian Processes results in a multivariate Gaussian vector.
    - White Gaussian noise with respect to a given bandwidth.
  - Sections: 25.1–25.7, 25.9–25.12, 25.15.
  - Assignment: Read Sections 25.13–25.14.
- Lecture 14
  - Topics:
    - From a stochastic process to a random vector.
    - The random vector of inner products: reduction to the multi-dimensional multi-hypothesis Gaussian problem.
    - Optimal guessing rule and performance analysis.
    - Example of antipodal signaling.
  - Sections: 26.1–26.6, 26.8.
  - Assignment: Read Section 26.9.