Fall Quarter

0.1 Communication systems and DSP

Module: 0.1
Period: Fall Quarter

Responsible: Roberto Garello (Politecnico di Torino - DET)

Credits: 6
Total hours: ~60

Course Objectives

The course is focused on the basics of signal processing in the time and frequency domain(Part 1), digital signal processing (Part 2), and digital communication systems (Part 3).

Course Syllabus

Part 1.Spectral Analysis and estimation theory

- Introduction to Signal Processing. The Fourier Transform
- Introduction to linear systems
- Sampling theorem
- Introduction to random processes

Part 2. Digital processing

- Introduction to digital signal processing
  - z-transform
  - DTFT
  - “digital” frequency
  - linear systems
- Digital filters theory
  - FIR and IIR filters
  - main filter structures
  - basics of filter design
  - filter design demo

Part 3.Communication systems

- Introduction to digital transmission systems:
  - System model

- Fundamental quantities (data rate, bandwidth, power, error probability, complexity)

- Constellations, labelling, and transmitted waveforms
- Signal space. Vector representation. Energy.
- Decision theory
- Receiver structures
- Intro to Error probability – asymptotic performance – constellation gain.
- Intro to spectrum. Intro to ISI.
- m-PAM
- 2-PSK and 4-PSK
- Intro to m-PSK and m-QAM

0.3 Basics on geomatics and satellite orbits

Module: 0.3
Period: Fall Quarter

Responsible: Marco Roggero (Politecnico di Torino - Dept. of Architecture and Design)

Credits: 4
Total hours: ~40

Course Objectives

Lessons aim to provide basics of orbits mechanics, and on the functional principles of navigation systems.

Course Syllabus

Part 1.

- Principles of Geodesy Reference Systems and Frames
- Inertial and terrestrial reference systems
- Geocentric coordinates
- WGS84 and ITRF
- Datum change

Part 2.

- Earth potential
- The ellipsoid and geographic coordinates
- The geoid and vertical reference frames
- Definition of height
- Coordinates transformation
- Global and regional datum

Part 3.

- Principles of cartography
- Cartographic projections
- Map transformation
- The Gauss projection and UTM
- Basics on GIS
- Numeral cartography and DEMs

Part 4.

- Two body orbital mechanics
  - Basic laws
  - The two body problem
  - Constants of motion
  - The trajectory equation
  - The elliptical orbit
  - The circular orbit
  - The parabolic orbit
  - The hyperbolic orbit
- Space mission geometry
- Orbit determination
  - Classical orbital elements
  - Perturbations
- Specialized Orbits
- Orbit Transfer
- Ground Tracks and Earth Coverage
- Orbit Design Process
- Satellites Constellations
  - Exercise: GALILEO

1.1 GNSS Introduction

Module: 1.1
Period: Fall Quarter

Responsible: Adjunct professor

Credits: 5
Total hours: ~50

Course Objectives

Lessons aim to provide basic elements for the understanding of Global Navigation Satellite Systems. The topics addressed in the course focus on the functional principles of navigation systems. Furthermore, the existing global and regional satellite-based navigation systems are described. The architecture of the space segment, the ground segment and the user segment are addressed.

Course Syllabus

Part 1. Fundamentals on satellite navigation systems

- Introduction to navigation principles
- Functional principles
- PVT computation
  - Position estimation with pseudoranges
- Dilution of precision
- Error sources in pseudorange computation
  - Ionospheric effects
  - Tropospheric effects
  - Other error sources
- The navigation message

Part 2. Basics on Timing in navigation systems

- Functional principles of atomic clocks, time scales, dissemination and synchronization.
- Interpretation of GNSS architecture from the "time" perspective;
- Importance of atomic clocks in GNSS;
- Importance of the "System Time Scale" in GNSS";
- Timekeeping with GNSS: time scales dissemination;
- Timekeeping with GNSS: synchronization of ground atomic clocks and time scales.
- Atomic clocks and GNSS systems

- Basics in Quantum Mechanics - An Hystorical Approach
- Fundamental concepts in Atomic clocks: block schemes, quantum spectroscopy, accuracy, stability, quality factor;
- Atomic clocks involved in GNSS: clocks based on Cs beam, Rb cell and H-Maser.

Part 3. Satellite navigation systems description

- A brief history of satellite navigation systems development: from TRANSIT to GPS
- GPS
  - Objectives, Status, and Policies
  - System architecture
  - Signals (structure, power)
  - Modernization Plans
- Galileo
  - Objectives, Status and Policies
  - Services
  - System Development
  - Signals and Data
  - GPS Interoperability
- GLONASS overview
- Beidou overview
- Regional Navigation Satellite Systems overview

Part 4. Fundamentals of Kalman filter

- The concept of state
- The concept of prediction
- The iterative algorithm
- An example

2.3 Front-End Technologies and Antennas

Module: 2.3
Period: Fall Quarter

Responsible: Marina Mondin (Politecnico di Torino - DET)

Credits: 3
Total hours: ~30

Course Objectives

The course aims to provide basic elements on the software receivers techniques. The analog-to-digital conversion problem is firstly addressed as starting point to enter the world of digital signals. Afterwards, techniques and problems related to the design of analog front-ends, digital front-ends and filtering are analyzed. Laboratories on the topics addressed within the course are proposed to students. Furthermore models for the receiving antenna will be analyzed.

Course Syllabus

Part 1. Techniques for software receivers

- **Sampling and quantization**
  - Introduction
  - Sampling and Reconstruction
  - Quantization
  - Analog-to-Digital Converters
  - Demodulation by sub-sampling
  - Matlab demo on sampling

- **Analog front-end structures**
  - Super heterodyne
  - Zero-IF
  - RF sampling
  - Single down-conversion

- **Filtering**
  - The simulation theorem
  - IIR design and linear phase FIR design
  - Frequency Sampling design
  - Matlab lab on FIR design and signal reconstruction

- **Digital front-end and channelization**
  - Digital front-end structures
  - Generation of numerical sinusoids
  - Polyphase filters
  - DFT and FFT based channelization
  - Decimation and sample-rate conversion

Part 2. Overview on antennas

- General properties of the EM field
- Qualitative discussion on polarization (linear) and its use in communication systems
- Review of link budget
- Antenna pattern; example: Galileo navigation antenna pattern
- Noise temperature and its impact
- Antenna radiation parameters: directivity, gain, aperture; gain normalization, examples (ideal axial beam)
- Examples of commercial receiving antennas (ground segment and user)
- Polarization
  - Polarization of vector fields, TX/RX properties of eEM field; polarization in the Friis formula
  - Polarization issues in GNSS
  - Polarization losses for linear and circular polarized receiving antennas
- The impedance bandwidth issue for antennas
- The “50Ohm paradigm” for interface specs
- Return loss and VSWR as quality factors to measure impedance mismatch
- Phase center stability issue in GNSS
- Examples of antennas and their potential use for GNSS receivers: dipole, patch; dual-pol/CP: turnstile, CP patch (dual-probe configuration)