POLITECNICO DI MILANO

Signal Recovery – 2021/2022

Introduction

Ivan Rech

Signal Recovery – Course staff

Instructor: **Prof. Ivan Rech**

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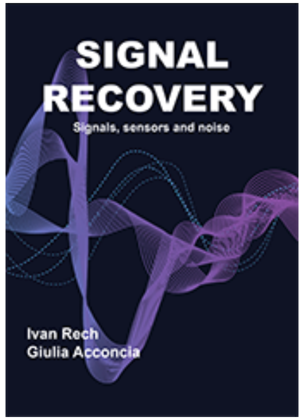
- Office hours: on request by students

"If you have any questions, please stop me during the lesson so it will be of help to everyone"

Signal Recovery – Resources

Course website

- http://home.deib.polimi.it/rech/Didattica.html

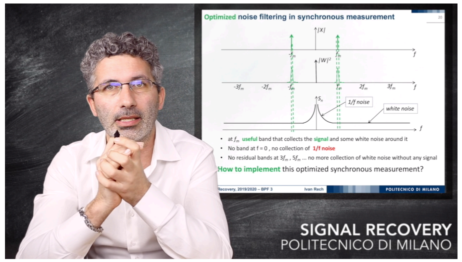


Bibliography

- Ivan Rech, Giulia Acconcia: "Signal Recovery" book, (**FREE PDF**)
- Complete set of slides employed in the lectures
- Text and explanation of problems given in the written tests carried out in previous years
- Papers, presentations, technical documentation, suggested references and websites dealing with signal recovery, sensors and measurement instrumentation

Complementary Bibliography

- Sergio Cova, Notes and Bibliography for the course “Signal recovery” Printer: Libreria Cortina, 2014.
- T.H. Wilmshurst, Signal recovery from noise in electronic instrumentation, 2nd edition, Printer: A. Hilger - IOP Publishing Ltd, edition year: 1990, ISBN: 0-7503-0058-2
- Silvano Donati, Photodetectors: Devices, Circuits and Applications, Printer: Prentice Hall, edition year: 2000, ISBN: 0130203378



Video

- Ad hoc videos for each lesson will be made available on Beep.

Teaching activities

Teaching activities will include

- Lectures (2 per week). Total lecture hours: 60 (tentative)+Q/A
- Tutorials (1 per week). Total tutorial hours: 40 (tentative)

Lectures are intended to introduce students to the concept and methods covered by the course.

Tutorial sessions are intended to present sample problems and solutions and to help students develop problem-solving strategies.

Required knowledge

- **Firm know-how in the foundations of electronic circuits**
- **Basic concepts on semiconductor devices**
- **Foundations of signals**
  - This aspect is very important. We will make 3h of tutorial to recap part of the knowledge. The first chapter of the book has the same goal. ***This could be not enough*** without a previous knowledge, please go back to the previous exams knowledge.
- **Basic knowledge of probability and statistics**
  - We will introduce all the basic concept we will need
- **General background in mathematics and physics**
  - We will have to solve some integral and use trigonometric expressions

Schedule

Sessione d'esame	1 SEMESTRE				Sessione d'esame		2 SEMESTRE			Sessione d'esame	
agosto 2021	settembre 2021	ottobre 2021	novembre 2021	dicembre 2021	gennaio 2022	febbraio 2022	marzo 2022	aprile 2022	maggio 2022	giugno 2022	luglio 2022
1 dom	1 mer	1 ven	1 lun	1 mer	1 sab	1 mar	1 mar	1 ven	1 dom	1 mer	1 ven
2 lun	2 gio	2 sab	2 mar	2 gio	2 dom	2 mer	2 mer	2 sab	2 lun	2 gio	2 sab
3 mar	3 ven	3 dom	3 mer	3 ven	3 lun	3 gio	3 gio	3 dom	3 mar	3 ven	3 dom
4 mer	4 sab	4 lun	4 gio	4 sab	4 mar	4 ven	4 ven	4 lun	4 mer	4 sab	4 lun
5 gio	5 dom	5 mar	5 ven	5 dom	5 mer	5 sab	5 sab	5 mar	5 gio	5 dom	5 mar
6 ven	6 lun	6 mer	6 sab	6 lun	6 gio	6 dom	6 dom	6 mer	6 ven	6 lun	6 mer
7 sab	7 mar	7 gio	7 dom	7 mar	7 ven	7 lun	7 lun	7 gio	7 sab	7 mar	7 gio
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15 weeks

104 hours

33h Lessons (55%) and 23h Tutorial (58%) before the midterm exam

Tentative schedule: lessons(L), tutorial(T)

Tools

1h Introduction 22/2 (1h)
3h Signals description 22/2 (1h)+24/2 (2h)
2h Noise description: part 1 24/2 (1h)+25/2(1h)
2h Noise description: part 2 25/2 (2h)
2h Noise description: part 3 1/3 (2h)
3h Tutorial 3/3
2h Filtering signals 4/3 (2h)
2h Filtering noise 4/3(1h)+8/3 (1h)

First Part – filtering

2h Low pass filter: part 1 8/3 (1h)+10/3(1h)
2h Low pass filter: part 2 10/3 (2h)
3h Low pass filter: part 3 11/3 (3h)
2h Tutorial 15/3
2h Optimum filter: part 1 17/3 (2h)
1h Tutorial 17/3
3h Tutorial 18/3
2h Optimum filter part 2 22/3 (2h)
4h High pass filter: part 1 24/3 (3h)+29/3 (1h)
3h Tutorial 25/3
1h Q&A on high pass filter 29/3(1h)
3h Tutorial 31/3
3h High pass filter: part 2 1/4 (3h)
2h Tutorial 5/4
3h Tutorial 7/4
3h Tutorial 8/4
2h Band pass filter: part 1 21/4 (2h)
2h Band pass filter: part 2 (VIDEO) +21/4 (1h Q&A)
3h Band pass filter: part 3 22/4 (3h)
2h Band pass filter: part 4 26/4 (2h)
3h Tutorial 29/4

Second Part - sensors

3h Photodetector: part 1 3/5 (2h) + 5/5 (1h)
2h Photodetector: part 2 5/5 (2h)
3h Photodetector: part 3 6/5 (3h)
2h Tutorial 10/5
3h Photodetector: part 4 12/5 (3h)
3h Tutorial 13/ 5
2h Photodetector: part 5 17/5 (2h)
3h Tutorial 19/5
2h Photodetector: part 6 20/5 (2h)
1,5h Temperature sensor 20/5(1h)+24/5 (0.5h)
1,5h Strain Gauges 24/5(1.5h)
3h Tutorial 26/5
3h Tutorial 27/5
2h Q&A 31/5

This is only an indicative schedule, any important changes will be communicated via WEBEEP

At the end of each part you will be asked for optional feedback in order to improve the course

33h Lesson, 23h Tutorial (41%): before 14/4
60h Lesson, 40h Tutorial (40%):Total

Signal Recovery – Assessment

- One **midterms**, 14 April: 1.1h exam equal to ½ normal exam (1 exercise)
  During the first exam in June it would be possible to make only the second exercise (1.1h) completing the exam (if the score of the midterm was>=17) or make the full normal exam (2.2h).

- 100% of the grade will be determined by the final exam: 2.2h written exam, **closed book,** 2 theoretical/numerical problems (ANY topic of the slides could be used for theoretical questions)

- weighing: 50% 50% (normally 3 question for each problems, with same weight)

- pass boundary set at 60% (maximum). Pass boundary is equated to adjust for varying difficulty levels across different exams

- 5 exam dates set by the School of Industrial and Information Engineering

- Students who pass the written exam with a score **≥27** may take an *optional* oral exam. The oral exam could be request, in any case, from the professor

- Oral exam adjustment range: $-\infty$ to +3/30

PLEASE: download an read the notice for the exam

ATTENTION

The exam is based on open questions. There is therefore no unique way to respond to the request.

With the same question it is possible to answer correctly with **different degrees of detail**. Responses will be evaluated accordingly.

Trivial example: Given a signal with a certain shape and a 10Hz band immersed in a noise with a 1GHz band, you are asked to improve the signal to noise ratio:

- You decide to reduce the noise band from 1GHz to 999MHz. The filter improves the S/N and it is correct but it is definitely not what is expected
- You decide to reduce the noise band to 1MHz. The filter improves the S/N, it is correct and better than the previous one but still it is not what we will learn to be the best we can do
- You Optimize the filter according to the shape and band of the signal.

These three answers are ALL correct but of course, as with your future job, they will have three different ratings. During the course and in the exercises we will practice on real exam topics to understand how to take the exam correctly.

Signal Recovery – The Goal

Signal Recovery deals with electronic techniques for recovering sensor signals from noise

main goal

not just to know and properly describe *techniques and instruments*

but rather

to gain a good insight *in the problems and in the approaches developed.*

We wish to **evaluate the solutions and understand the reasons of choices and decisions,** critically highlighted by

a) the physics of phenomena involved

b) the principles of signal and noise processing

c) the actual performance of the available devices.

Signal Recovery – The Goal

- We have to clearly distinguish intrinsic limitations and contingent limitations:
  intrinsic *limitations* are set by laws of nature and **cannot be overcome**
  contingent *limitations* are due to the state of the art and **can be overcome** by the technological progress.

- Be aware that **different technological implementations** may rely on the **same idea** and that the **evolution in technology** unceasingly stimulates **new ideas**

- To gain insight means to move at the pace of progress in science and technology and be able to contribute to it.

"To obtain this result we have to understand the physics of phenomena involved and to go insight the formalism and the mathematical approach"

Signal Recovery – The Goal

ATTENTION:

- Within this course we will use a lot of math.
- We need math to create a MODEL that allows us to understand/describe the physical phenomenon.
- **We are interested** in an intuitive understanding of the individual forumules.
- **We are NOT interested** (and therefore will not be asked for the exam) in the single mathematical steps that lead us from the model to the final finite formula.
- *However, these steps are almost always simple integral that an engineering student should be able to do easily.*

At the exam you will be asked only the degree of detail seen and explained in the classroom.

Formalism and insight

In a Math class, the Professor showed that:

$$\lim_{x\to 8} \frac{1}{x-8} \to \infty$$

Then he picked a student that followed with attention and asked

$$\lim_{x\to 5} \frac{1}{x-5} \to ?$$

and the answer was

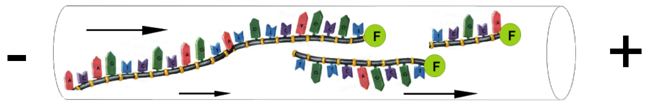
$$\lim_{x\to 5} \frac{1}{x-5} \to \rotatebox{90}{5}$$

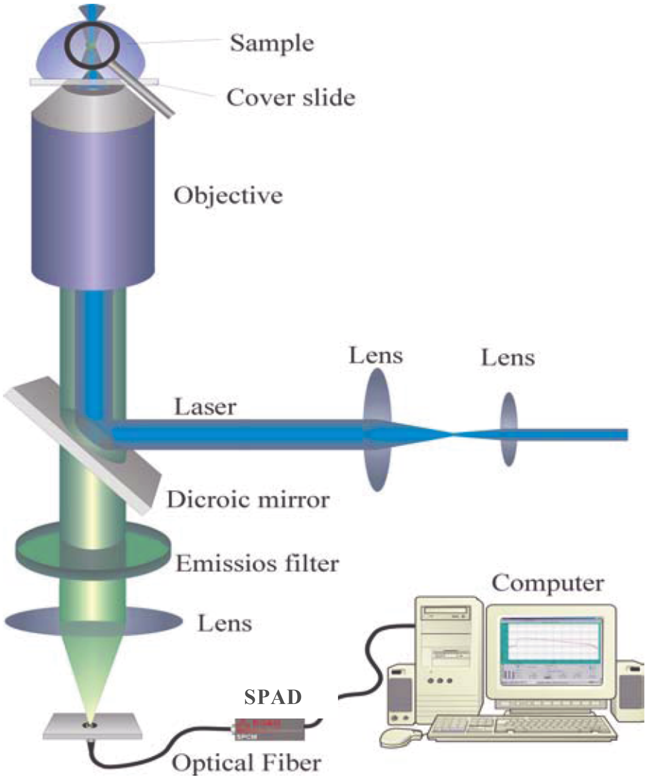
Well, this is just a joke, not observed in reality ...
... but examples similar to this occur in real courses !

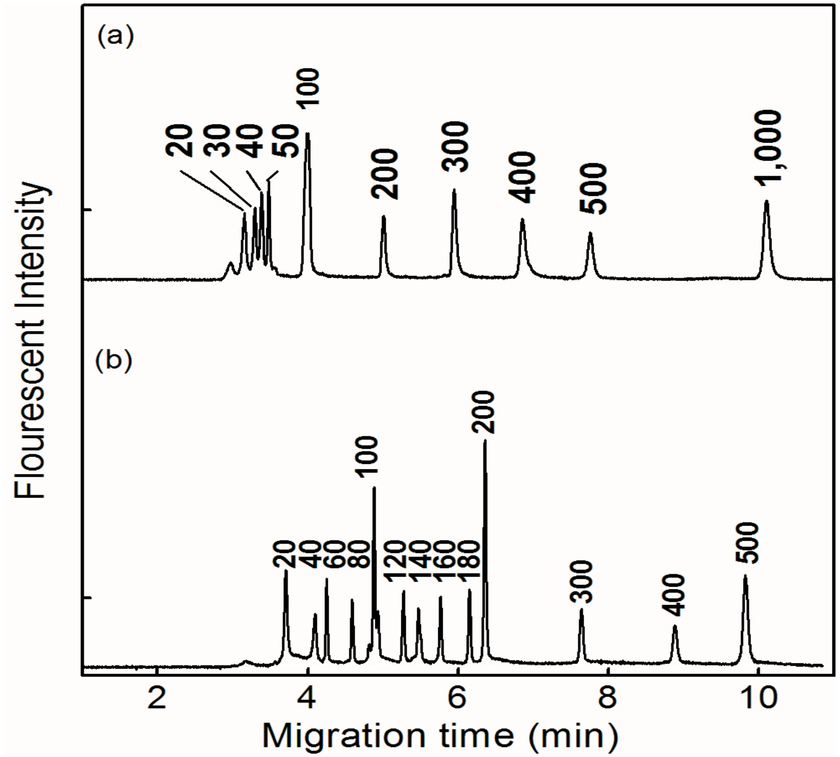
Signal Recovery – real application

GOAL: DNA separation of fragments of different lenghts

- Excited molecules in the focal volume give rise to a fluorescent signal
- Fragments with different length move with different speed
- Fragments reach the focal point with different delays





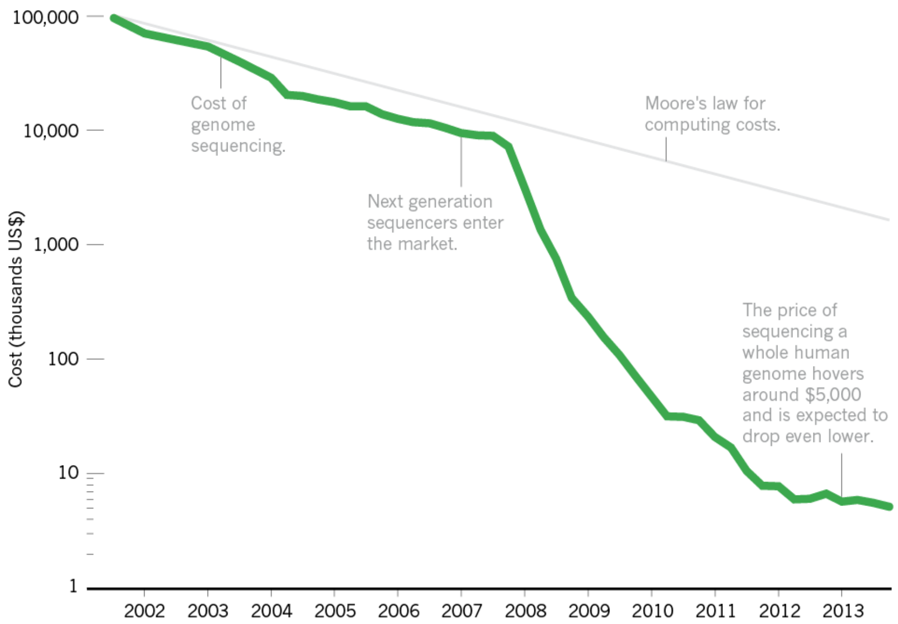


Signal Recovery – real application

In the first few years at the end of the ***Human Genome Project***, the cost of genome sequencing roughly followed Moore’s law, which predicts exponential declines in computing costs. After 2007. sequencing costs dropped precipitously.

Next generation sequencer enter the market

Higher sensitivity



Topics covered in this course

Signals and noise. Introduction to measurements, errors and statistical distributions. Mathematical treatment of signals and noise in the time and in the frequency domain. Signal-to-Noise ratio (S/N). Autocorrelation functions, energy and power spectra. Noise sources in electronic circuits and sensors. Main types of noise spectra. Noise interpretation and modeling with statistical pulse sequences.

Extracting signals from noise. Linear filters with constant parameters and with time-variant parameters, action on signals and noise and resultant S/N. Pulse-signals and constant-parameter low-pass filters; Gated Integrator (GI); Boxcar Integrator (BI); Sample-and-Hold (S&H) and fast samplers; discrete filtering by sampling and weighted average of samples. Optimum filtering for pulse-amplitude measurements, significance and practical usefulness. Noise with 1/f spectrum: characteristic features and ensuing problems, filtering approach. Constant-parameter high-pass filters; correlated double sampling (CDS) and further developments; Baseline Restorer (BLR). Periodic signals and constant-parameter resonant filters; modulation of signals and noise; Lock-in Amplifier (LIA), analog and digital implementations of LIAs.

Sensors are treated by discussing the physical principles of their operation; the device structure and technology; characteristic features and electrical parameters; output signals and information content; equivalent electric circuit; internal noise. Photodetectors: vacuum tube and semiconductor photodiodes; photoconductors; Photomultiplier tubes (PMT), avalanche photodiodes (APD) and single-photon avalanche diodes (SPAD); analog and digital detection, single-photon counting (SPC) and ***time-correlated single- photon counting (TCSPC) (not included in the exam)***. Temperature Sensors: thermo resistances. Strain and Force Sensors: strain gauges sensors.