POLITECNICO DI MILANO





Signal Recovery – 2022/2023

Introduction

Ivan Rech

Signal Recovery – Course staff

Instructor: **Prof. Ivan Rech**

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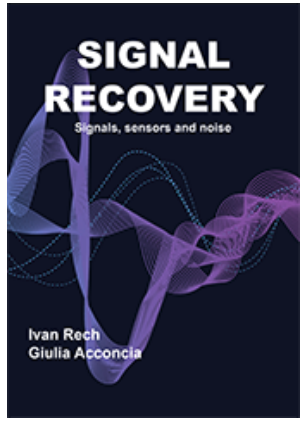
- Office hours: on request by students

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

Signal Recovery – Resources

Course website



- https://rech.faculty.polimi.it/

Bibliography

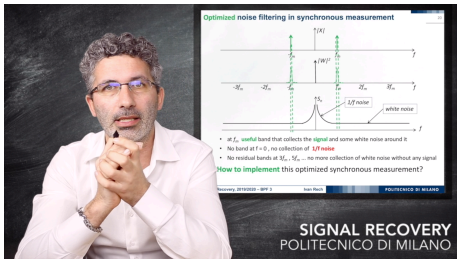
- Ivan Rech, Giulia Acconcia: "Signal Recovery" book, (**FREE PDF**)
- Complete set of slides employed in the lectures
- Text and explanation of problems given in the written tests carried out in previous years
- Papers, presentations, technical documentation, suggested references and websites dealing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

Calendario accademico 2022/2023

Sessione d'esame	1 SEMESTRE				Sessione d'esame	2 SEMESTRE				Sessione d'esame	
agosto 2022	settembre 2022	ottobre 2022	novembre 2022	dicembre 2022	gennaio 2023	febbraio 2023	marzo 2023	aprile 2023	maggio 2023	giugno 2023	luglio 2023
1 lun	1 gio	1 sab	1 mar	1 gio	1 dom	1 mer	1 mer	1 sab	1 lun	1 gio	1 sab
2 mar	2 ven	2 dom	2 mer	2 ven	2 lun	2 gio	2 gio	2 dom	2 mar	2 ven	2 dom
3 mer	3 sab	3 lun	3 gio	3 sab	3 mar	3 ven	3 ven	3 lun	3 mer	3 sab	3 lun
4 gio	4 dom	4 mar	4 ven	4 dom	4 mer	4 sab	4 sab	4 mar	4 gio	4 dom	4 mar
5 ven	5 lun	5 mer	5 sab	5 lun	5 gio	5 dom	5 dom	5 mer	5 ven	5 lun	5 mer
6 sab	6 mar	6 gio	6 dom	6 mar	6 ven	6 lun	6 lun	6 gio	6 sab	6 mar	6 gio
7 dom	7 mer	7 ven	7 lun	7 mer	7 sab	7 mar	7 mar	7 ven	7 dom	7 mer	7 ven
8 lun	8 gio	8 sab	8 mar	8 gio	8 dom	8 mer	8 mer MI	8 sab	8 lun	8 gio	8 sab
9 mar	9 ven	9 dom	9 mer	9 ven	9 lun	9 gio	9 gio POLI	9 dom Pasqua	9 mar	9 ven	9 dom
10 mer	10 sab	10 lun	10 gio	10 sab	10 mar	10 ven	10 ven	10 lun Lunedì dell'Angelo	10 mer	10 sab	10 lun
11 gio	11 dom	11 mar	11 ven	11 dom	11 mer	11 sab	11 sab	11 mar	11 gio	11 dom	11 mar
12 ven	12 lun	12 mer	12 sab	12 lun	12 gio	12 dom	12 dom	12 mer	12 ven	12 lun	12 mer
13 sab	13 mar	13 gio	13 dom	13 mar	13 ven	13 lun	13 lun	13 gio	13 sab	13 mar	13 gio
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16 mar	16 ven	16 dom	16 mer	16 ven	16 lun	16 gio	16 gio	16 dom	16 mar	16 ven	16 dom
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18 gio	18 dom	18 mar	18 ven	18 dom	18 mer	18 sab	18 sab	18 mar	18 gio	18 dom	18 mar
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21 dom	21 mer	21 ven	21 lun	21 mer	21 sab	21 mar	21 mar	21 ven	21 dom	21 mer	21 ven
22 lun	22 gio	22 sab	22 mr	22 gio	22 dom	22 mer	22 mer	22 sab	22 lun	22 gio	22 sab
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24 mer	24 sab	24 lun	24 gio	24 sab	24 mar	24 ven	24 ven	24 lun	24 mer	24 sab	24 lun
25 gio	25 dom	25 mar	25 ven	25 dom	25 mer	25 sab	25 sab	25 mar	25 gio	25 dom	25 mar
26 ven	26 lun	26 mer	26 sab	26 lun	26 gio	26 dom	26 dom	26 mer	26 ven	26 lun	26 mer
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28 dom	28 mer	28 ven	28 lun	28 mer	28 sab	28 mar	28 mar	28 ven	28 dom	28 mer	28 ven
29 lun	29 gio	29 sab	29 mar	29 gio	29 dom		29 mer	29 sab	29 lun	29 gio	29 sab
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31 mer		31 lun		31 sab	31 mar		31 ven		31 mer		31 lun

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prove in itinere | sabato | altre attività

15 weeks
101 hours

Tentative schedule: lessons, tutorial

Tools

1h Introduction 21/2 (1h)
3h Signals description 21/2(1h)+23/2 (2h)
2h Noise description part 1 23/2 (1h)+24/2(1h)
2h Noise description part 2 24/2 (2h)
2h Filtering signals 28/2 (2h)
3h Tutorial 2/3
2h Filtering noise 3/3(2h)

First Part – filtering

2h Low pass filter part 1 3/3 (1h) + 7/3 (1h)
2h Low pass filter part 2 7/3 (1h) + 9/3(1h)
3h Low pass filter part 3 9/3 (2h) +10/3(1h)
2h Tutorial 10/3
2h Optimum filter part 1 14/3 (2h)
3h Tutorial 16/3
2h Optimum filter part 2 17/3 (2h)
4h High pass filter part 1 17/3 (1h) + 23/3(3h)
2h Tutorial 21/3
3h Tutorial 24/3
3h High pass filter part 2 28/3(2h)+4/4(1h)
3h Tutorial 30/3
3h Tutorial 31/3
1h Q/A on HPF 4/4 (1h)
2h Band pass filter part 1 6/4 (2h)
2h Band pass filter part 2 (VIDEO)+6/4 (1h Q/A)
3h Band pass filter part 3 13/4 (3h)
3h Tutorial 14/4
2h Band pass filter part 4 18/4 (2h)

Second Part - sensors

3h Photodetector part 1 27/4 (3h)
2h Photodetector part 2 28/4 (2h)
3h Photodetector part 3 28/4 (1h)+9/5 (2h)
2h Tutorial 2/5
3h Tutorial 5/5
3h Photodetecto part 4 11/5 (3h)
3h Tutorial 12/5
2h Photodetector part 5 16/5 (2h)
3h Tutorial 18/5
2h Photodetector part 6 19/5 (2h)
1,5h Temperature sensor 19/5 (1h)+23/5(0,5h)
1,5h Strain Gauges 23/5(1,5h)
3h Tutorial 25/5
3h Tutorial 26/5
2h Tutorial 30/5
2h Q/A 1/6

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

Signal Recovery – Assessment

- 100% of the grade will be determined by the final exam: 2h 15min 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

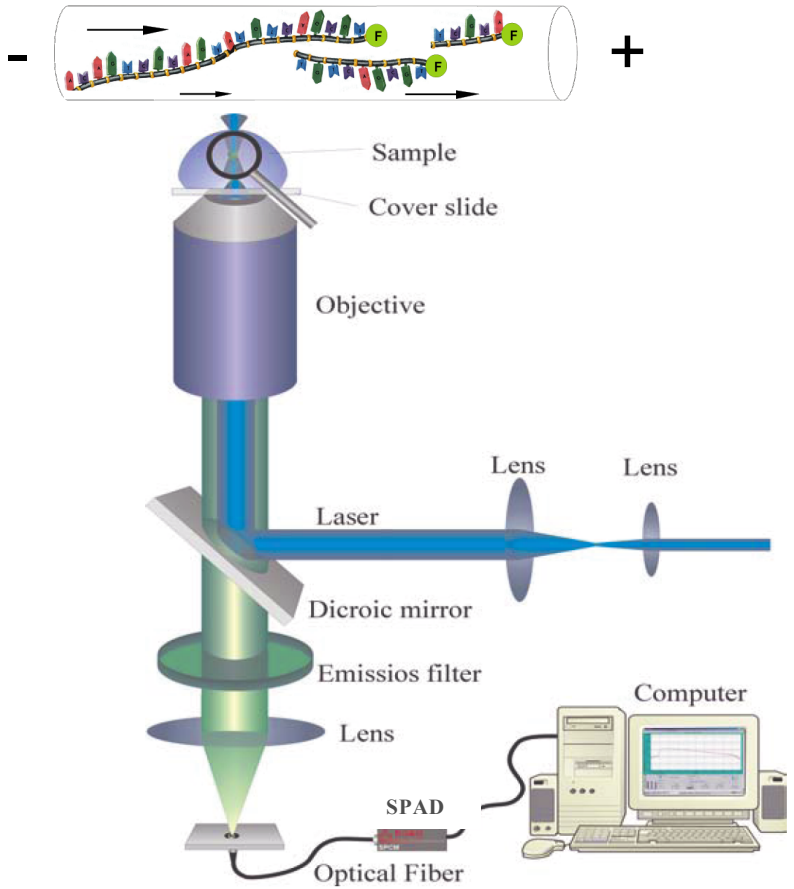
$$\lim_{x \to 5} \frac{1}{x-5} \to \; 5$$

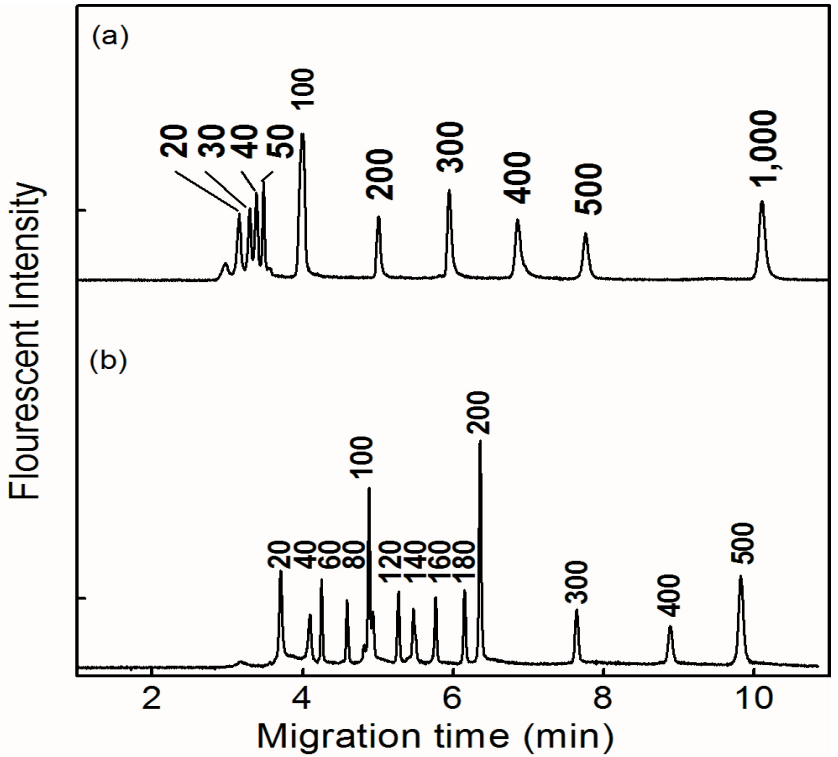
Well, this is just a joke, not observed in reality ...
... but examples similar to this occur in real courses !

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



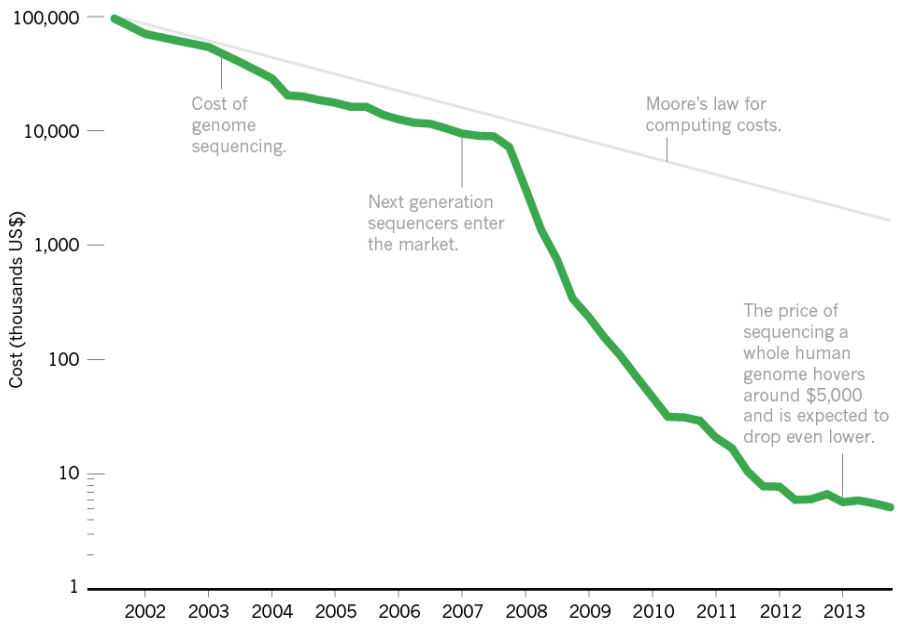


Signal Recovery – real application

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.