POLITECNICO DI MILANO





Signal Recovery – 2023/2024

Introduction

Ivan Rech

Signal Recovery – Course staff

Instructor: **Prof. Ivan Rech**

- Office: 102, Building 24, Via Golgi 40
- Phone: 02- 2399 3700
- ivan.rech@polimi.it
- Office hours: on request by students (don't hesitate to contact me)

Tutor: **Dr. Giulia Acconcia**

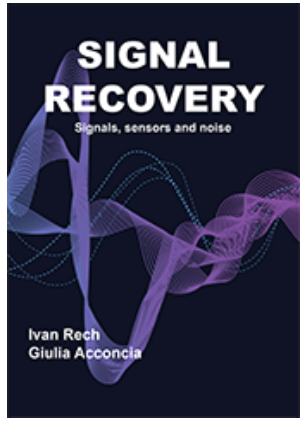
- Office: 105, Building 24, Via Golgi 40
- Phone: 02- 2399 4145
- giulia.acconcia@polimi.it
- Office hours: on request by students

"If you have any questions, please stop me during the lesson so it will be of help to everyone.
DON'T WAIT TO CLEAR YOUR DOUBTS"

Signal Recovery – Resources

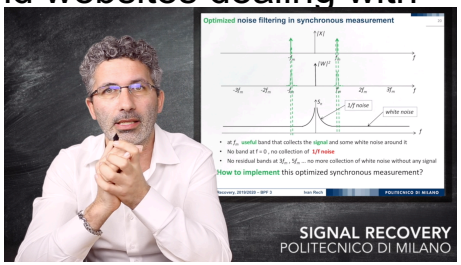
Course website

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



Bibliography

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



Video

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

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

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

- **Know-how in the foundations of electronic circuits**
- **Basic concepts on semiconductor devices**
- **Foundations of signals**
  - This aspect is very important. We will make one 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 just to solve some integral and use trigonometric expressions

Schedule

Sessione d'esame	1 SEMESTRE				Sessione d'esame	2 SEMESTRE				Sessione d'esame		
agosto 2023	settembre 2023	ottobre 2023	novembre 2023	dicembre 2023	gennaio 2024	febbraio 2024	marzo 2024	aprile 2024	maggio 2024	giugno 2024	luglio 2024	agosto 2024
1 mar	1 ven	1 dom Fest. Ebr.	1 mer	1 ven	1 lun	1 gio	1 ven	1 lun Lunedì dell'Angelo	1 mer	1 sab	1 lun	1 gio
2 mer	2 sab	2 lun	2 gio	2 sab	2 mar	2 ven	2 sab	2 mar	2 gio	2 dom	2 mar	2 ven
3 gio	3 dom	3 mar	3 ven	3 dom	3 mer	3 sab	3 dom	3 mer	3 ven	3 lun	3 mer	3 sab
4 ven	4 lu	4 mer POLI	4 sab	4 lun	4 gio	4 dom	4 lun	4 gio	4 sab	4 mar	4 gio	4 dom
5 sab	5 mar	5 gio MI	5 dom	5 mar	5 ven	5 lun	5 mar	5 ven	5 dom	5 mer	5 ven	5 lun
6 dom	6 mer	6 ven Fest. Ebr.	6 lun	6 mer (patrono Lecco)	6 sab	6 mar	6 mer MI	6 sab	6 lun	6 gio	6 sab	6 mar
7 lun	7 gio	7 sab Fest. Ebr.	7 mar	7 gio	7 dom	7 mer	7 gio POLI	7 dom	7 mar	7 ven	7 dom	7 mer
8 mar	8 ven	8 dom	8 mer	8 ven	8 lun	8 gio	8 ven	8 lun	8 mer	8 sab	8 lun	8 gio
9 mer	9 sab	9 lun	9 gio	9 sab	9 mar	9 ven	9 sab	9 mar MI	9 gio	9 dom	9 mar	9 ven
10 gio	10 dom	10 mar	10 ven	10 dom	10 mer	10 sab	10 dom	10 mer POLI	10 ven	10 lun	10 mer	10 sab
11 ven	11 lun	11 mer	11 sab	11 lun	11 gio	11 dom	11 lun	11 gio	11 sab	11 mar	11 gio	11 dom
12 sab	12 mar	12 gio	12 dom	12 mar	12 ven	12 lun	12 mar	12 ven	12 dom	12 mer Fest. Ebr	12 ven	12 lun
13 dom	13 mer	13 ven	13 lun	13 mer	13 sab	13 mar	13 mer	13 sab	13 lun	13 gio Fest. Ebr	13 sab	13 mar
14 lun	14 gio	14 sab	14 mar	14 gio	14 dom	14 mer	14 gio	14 dom	14 mar	14 ven	14 dom	14 mer
15 mar	15 ven	15 dom	15 mer	15 ven	15 lun	15 gio	15 ven	15 lun	15 mer	15 sab	15 lun	15 gio
16 mer	16 sab Fest. Ebr.	16 lun	16 gio	16 sab	16 mar	16 ven	16 sab	16 mar	16 gio	16 dom	16 mar MI	16 ven
17 gio	17 dom Fest. Ebr.	17 mar	17 ven	17 dom	17 mer	17 sab	17 dom	17 mer	17 ven	17 lun	17 mer POLI	17 sab
18 ven	18 lun	18 mer	18 sab	18 lun	18 gio	18 dom	18 lun	18 gio	18 sab	18 mar	18 gio MI	18 dom
19 sab	19 mar	19 gio	19 dom	19 mar MI	19 ven	19 lun	19 mar	19 ven	19 dom	19 mer	19 ven POLI	19 lun
20 dom	20 mer	20 ven	20 lun	20 mer	20 sab	20 mar	20 mer	20 sab	20 lun	20 gio	20 sab	20 mar
21 lun	21 gio	21 sab	21 mar	21 gio POLI	21 dom	21 mer	21 gio	21 dom	21 mar	21 ven	21 dom	21 mer
22 mar	22 ven	22 dom	22 mer	22 ven	22 lun	22 gio	22 ven	22 lun	22 mer	22 sab	22 lun	22 gio
23 mer	23 sab	23 lun	23 gio	23 sab	23 mar	23 ven	23 sab	23 mar Fest. Ebr	23 gio	23 dom	23 mar	23 ven
24 gio	24 dom	24 mar	24 ven	24 dom	24 mer	24 sab	24 dom	24 mer Fest. Ebr	24 ven	24 lun	24 mer	24 sab
25 ven	25 lun Fest. Ebr.	25 mer	25 sab	25 lun	25 gio	25 dom	25 lun	25 gio	25 sab	25 mar	25 gio	25 dom
26 sab	26 mar	26 gio	26 dom	26 mar	26 ven	26 lun	26 mar	26 ven	26 dom	26 mer	26 ven	26 lun
27 dom	27 mer MI	27 ven	27 lun	27 mer	27 sab.	27 mar	27 mer	27 sab	27 lun	27 gio	27 sab	27 mar
28 lun	28 gio POLI	28 sab	28 mar	28 gio	28 dom	28 mer	28 gio	28 dom	28 mar	28 ven	28 dom	28 mer
29 mar	29 ven	29 dom	29 mer	29 ven	29 lun	29 gio	29 ven	29 lun Fest. Ebr	29 mer	29 sab	29 lun	29 gio
30 mer	30 sab Fest. Ebr.	30 lun	30 gio	30 sab	30 mar		30 sab	30 mar Fest. Ebr	30 gio	30 dom	30 mar	30 ven
31 gio		31 mar		31 dom	31 mer		31 dom Pasqua		31 ven		31 mer	31 sab

esami di profitto | lezione | festività | vacanze | lauree 1°livello | lauree Magistrali

prove in itinere | sabato | altre attività

15 weeks
101 hours

Tentative schedule: lessons, tutorial

Tools

2h Introduction 20/2 (2h)
3h Signals description 22/2 (3h)
2h Noise description part 1 23/2 (2h)
1,5h Noise description: part 2 23/2 (1h)+27/2 (0,5h)
1,5h Filtering signals 27/2 (1,5h)
3h Tutorial 29/2
1h Filtering noise 1/3(1h)

First Part – filtering

2h Low pass filter: part 1 1/3 (2h
1,5h Low pass filter: part 2 5/3 (1,5h)
2,5h Low pass filter: part 3 5/3 (0,5h)+8/3(2h) 3h Tutorial 7/3
1,5h Optimum filter: part 1 8/3 (1h)+12/3 (0,5h)
1,5h Optimum filter: part 2 12/3 (1,5h)
3h Tutorial 14/3
3h Tutorial 15/3
4h High pass filter: part 1 19/3 (2h)+21/3(2h)+QA
3h Tutorial 22/3
4h High pass filter: part 2 26/3(2h)+28/3(2h)+QA
3h Tutorial 4/4
3h Tutorial 5/4
——————— **MID TERM (11/4)** ———————
3h Band pass filter: part 1 16/4 (2h)+18/4 (1h)
2,5h Band pass filter: part 2 (IN VIDEO)+18/4 (0,5h Q/A)
SEMINAR ON A REAL APPLICATION 18/4 1,5h
3h Band pass filter: part 3 19/4 (3h)
2h Band pass filter: part 4 23/4 (2h)

2h Tutorial by Professor 30/4 (2h)
3h Tutorial 2/5

Second Part - sensors

2,5h Photodetector: part 1 3/5 (2,5h)
2h Photodetector: part 2 3/5 (0,5h)+7/5 (1,5)+Q/A
2h Photodetector: part 3 9/5 (2h)
3h Photodetector: part 4 9/5 (1h)+14/5 (2h)
3h Tutorial 10/5
2h Photodetector: part 5 16/5 (2h)
2h Photodetector: part 6 16/5 (1h)+21/5 (1h)
3h Tutorial 17/5
1,5h Temperature sensor 21/5 (1h)+23/5(0,5h)
2h Strain Gauges 23/5+Q/A (2h)
3h Tutorial 24/5
2h Theory Q/A 28/5
3h Tutorial 30/5
3h Tutorial 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

EXTRA hours for Q&A on theory

I reserved the Beta classroom (Building 24) for this 3 dates:

- **13 March 14.30-15:30**
- **3 April 14.30-15:30**
- **8 May 14.30-15:30**

for **optional Q&A** related to the theory lessons to help students experiencing difficulties on theory topics.

In these dates, no new topic will be discussed, nor any exercise will be solved.

ATTENTION: since it is optional, if no students shows up at the beginning of the time slot (within 10 minutes) the date is automatically cancelled

Signal Recovery – Assessment

- 2024 Exam duration: **2h 45min**. (pre-covid the duration was 3h but with 8 questions, in the 2020-2023 it was shortened to 2h 15min but with six questions).
- weighing: six questions with same weight
- pass boundary set at 60% (**18/30**). 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
- A midterm with just 1 problem (3 questions). To be defined if online or in classroom depending on the classroom availability. If you pass the midterm exam you can just make only the second problem at one of the exams in the June-July session.
- 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 can increase or decrease the final grade

PLEASE: download an read the complete notice for the exam

Signal Recovery – Assessment

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 to better understand the connections with the different aspects of a complex problem and find the better solution
-
- **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 (the exam is based ONLY on the material illustrated in the slides during the lessions).

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

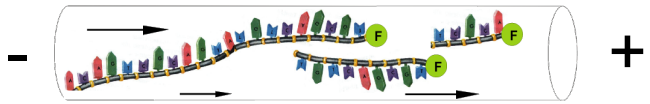
$$\lim_{x \to 5} \frac{1}{x-5} \to \; 5$$

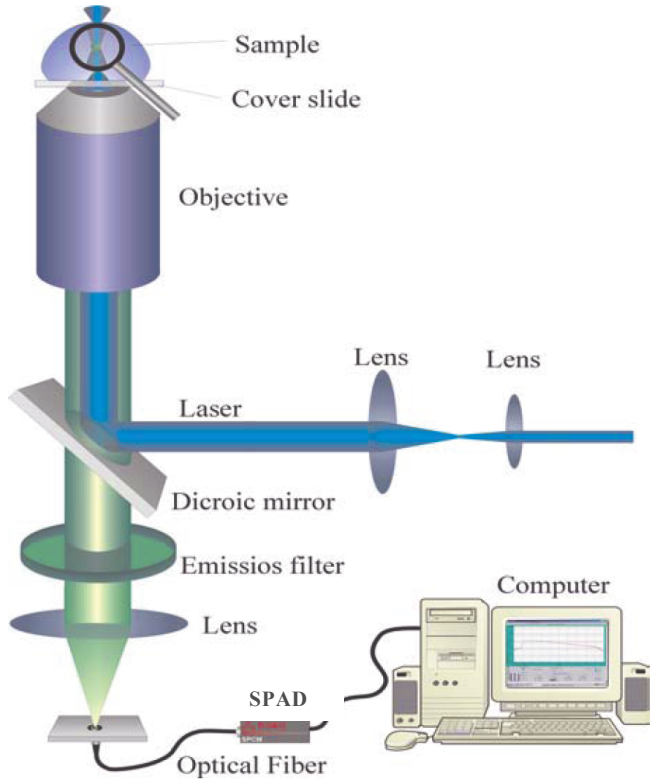
Well, this is just a joke, not observed in reality ...
... but examples similar to this occur in real courses !

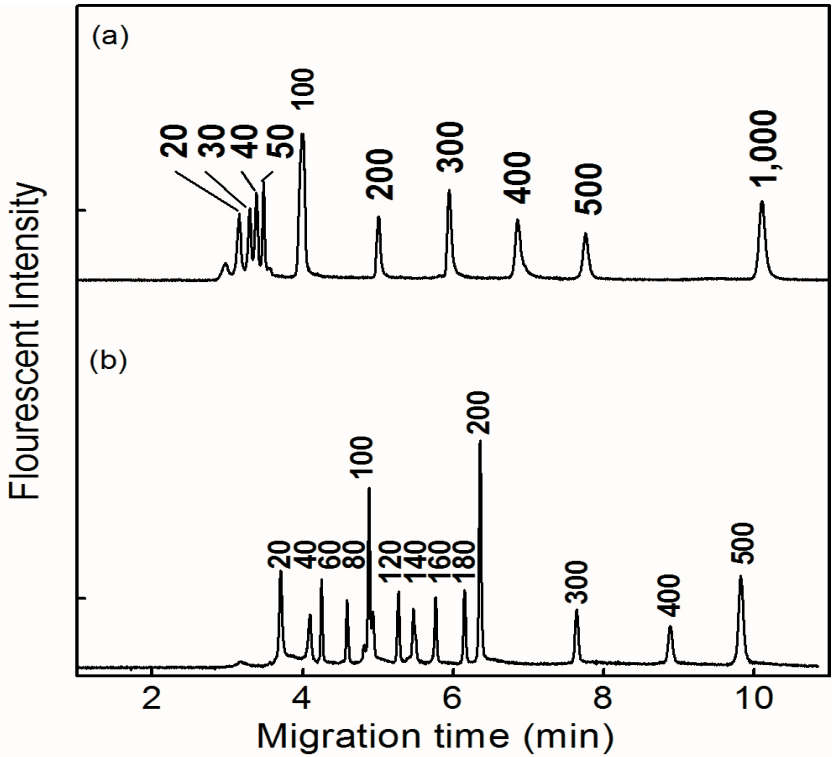
Signal Recovery – real application

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





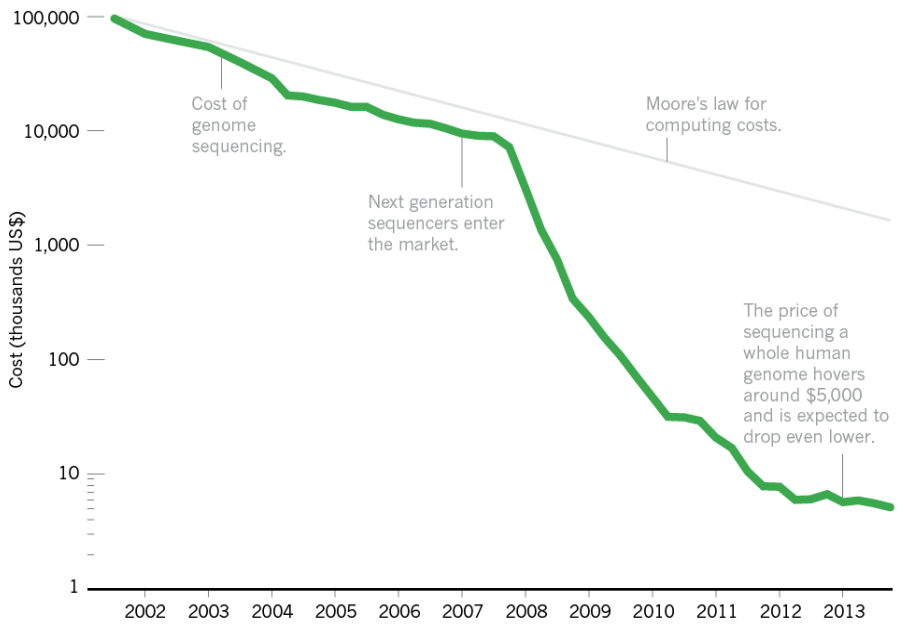


Signal Recovery – real application

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.