Electronics

Ist year LM, 10 credits

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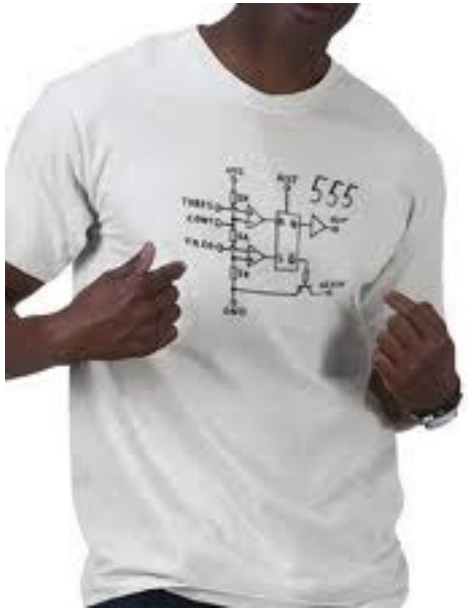
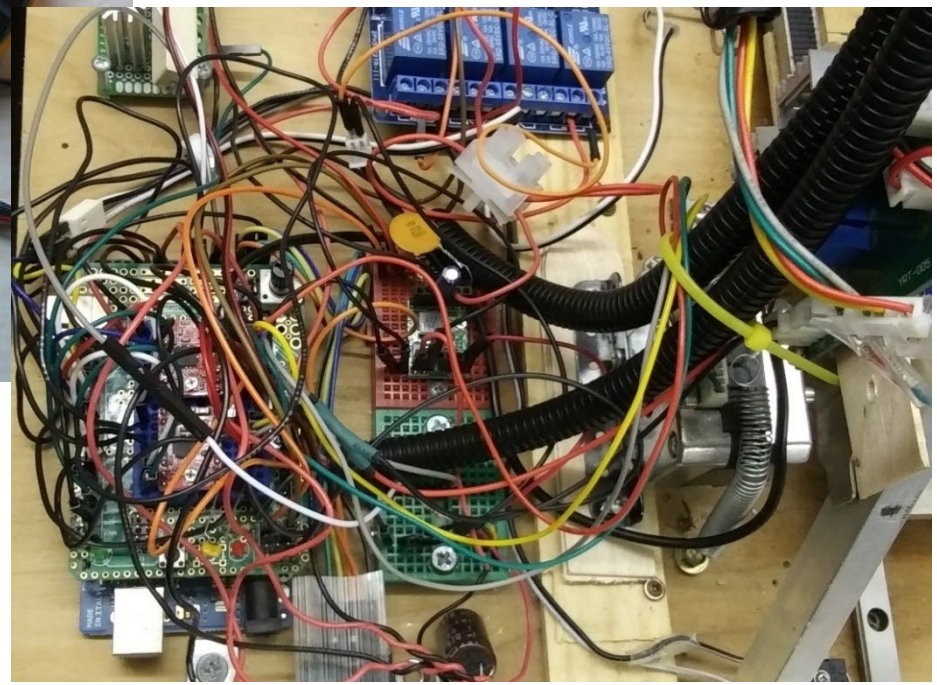
Outline

- Electronics in Engineering Physics
- What is all about?
- General information
- Final recommendation…

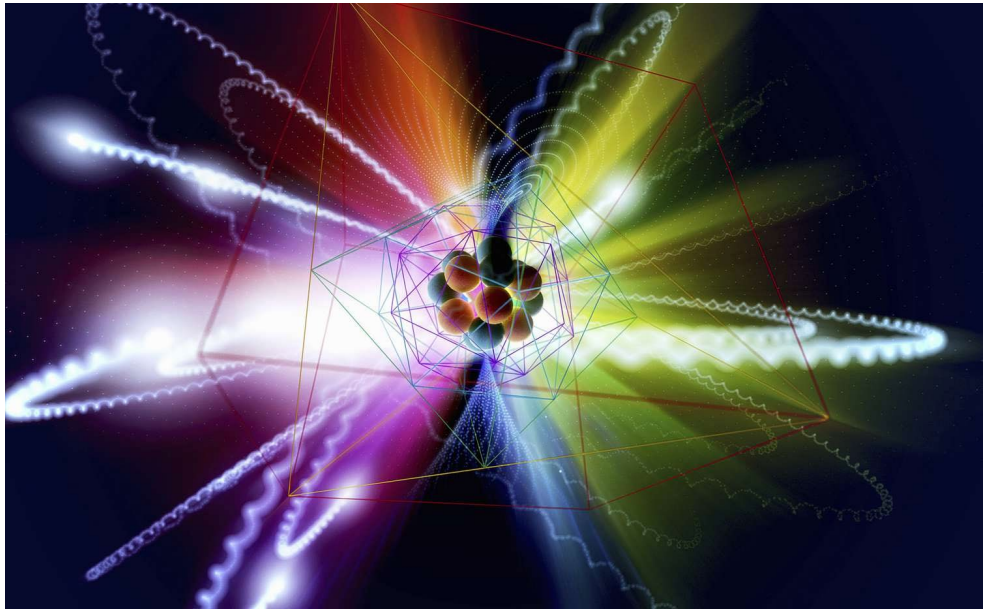

WHY?

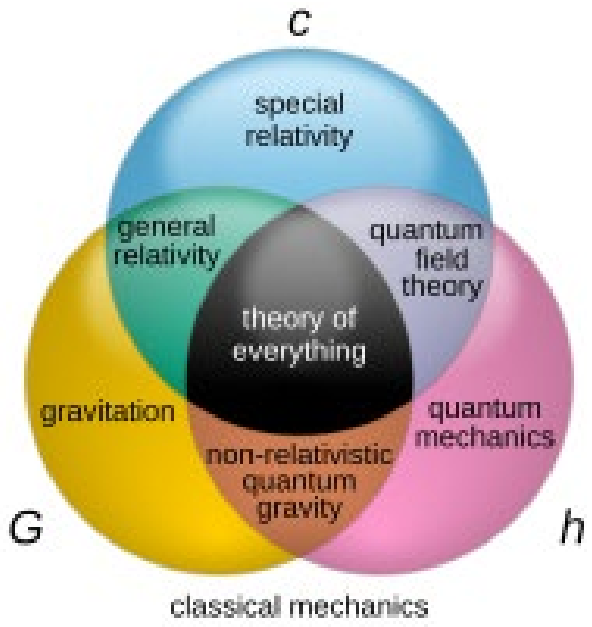
What does «Electronics» mean to you?

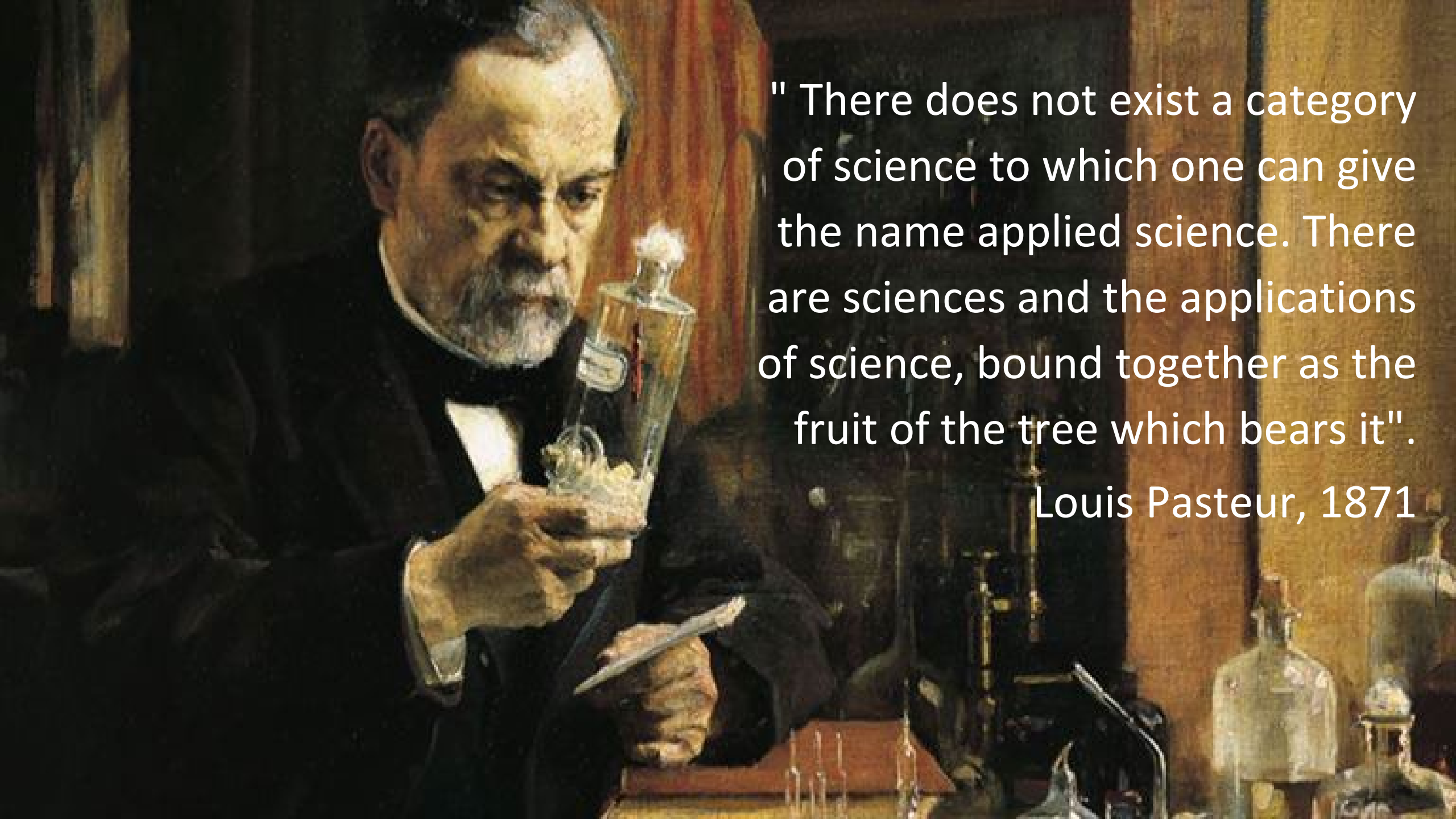


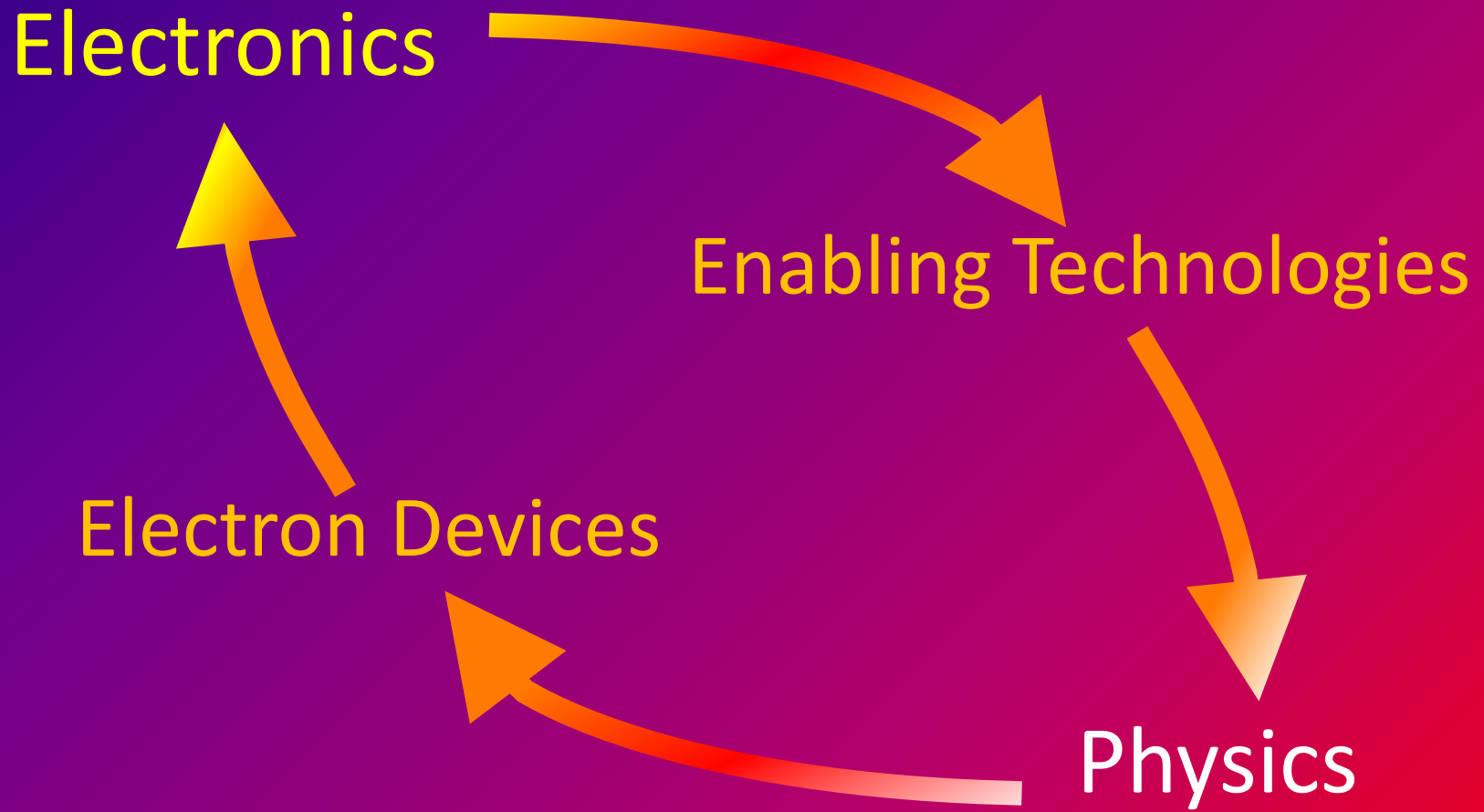


And what about «Physics»?

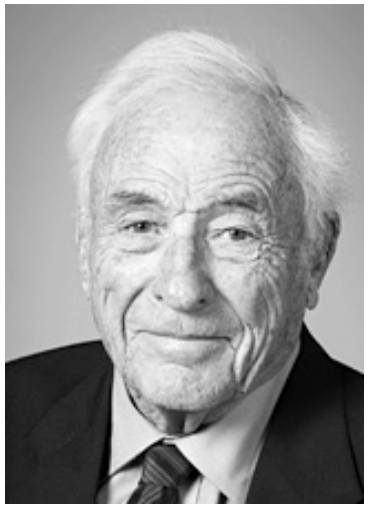





" There does not exist a category of science to which one can give the name applied science. There are sciences and the applications of science, bound together as the fruit of the tree which bears it".
Louis Pasteur, 1871


Electronics
Enabling Technologies
Physics
Electron Devices

Who are they?



A. Fert, P. Grünberg

Nobel 2007 in physics
“for the discovery of Giant Magnetoresistance”

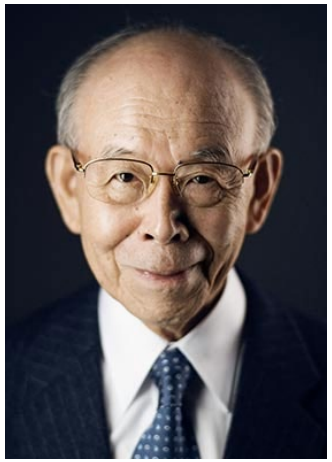
W. S. Boyle, G. E. Smith

Nobel 2009 in physics
“for the invention of an imaging semiconductor circuit – the CCD sensor”

And besides…


A. Geim, K. Novoselov

Nobel 2010 in physics
"for experiments regarding the two-dimensional material graphene"

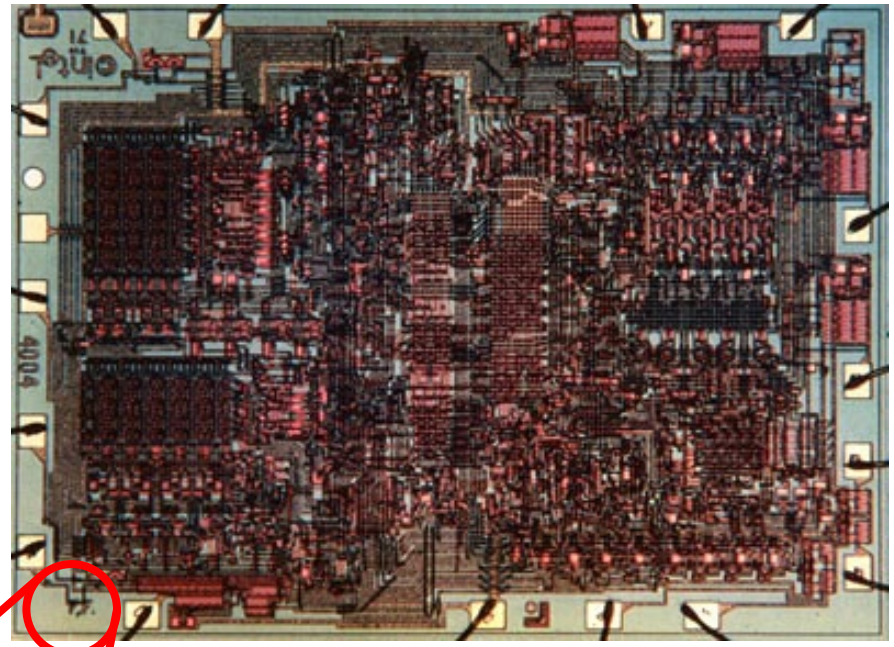


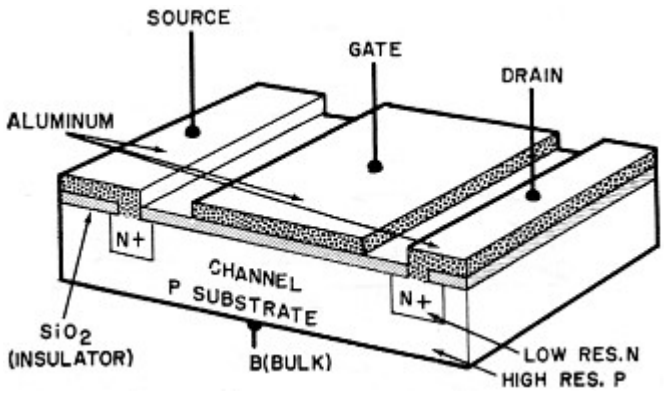
I. Akasaki, H. Amano, S. Nakamura

Nobel 2014 in physics
"for invention of blue light-emitting diodes"

Bell Labs, december 1947

Intel 4004 (1971)





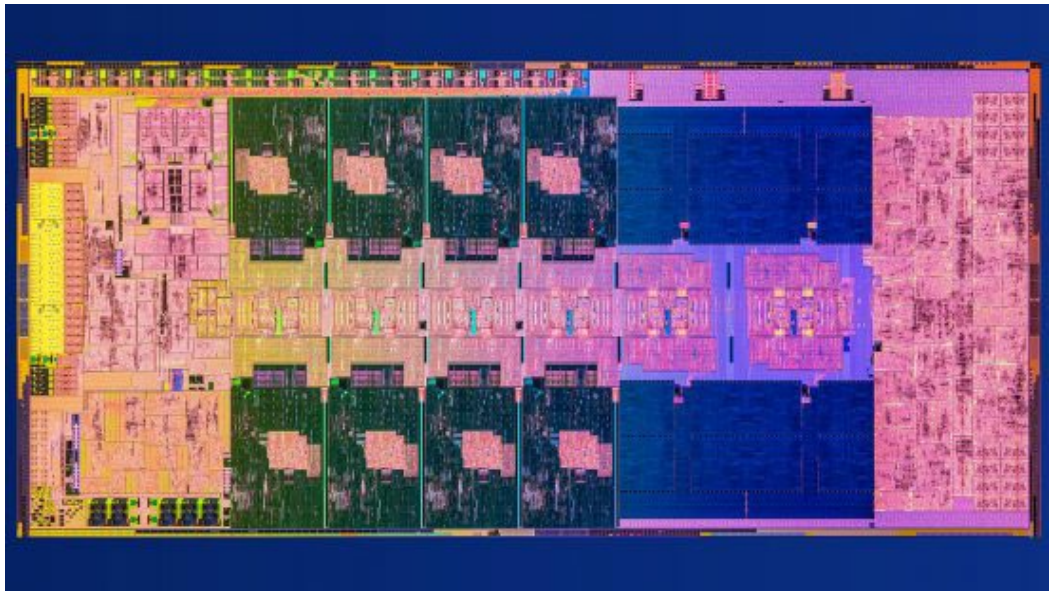
Technology: 10 µm

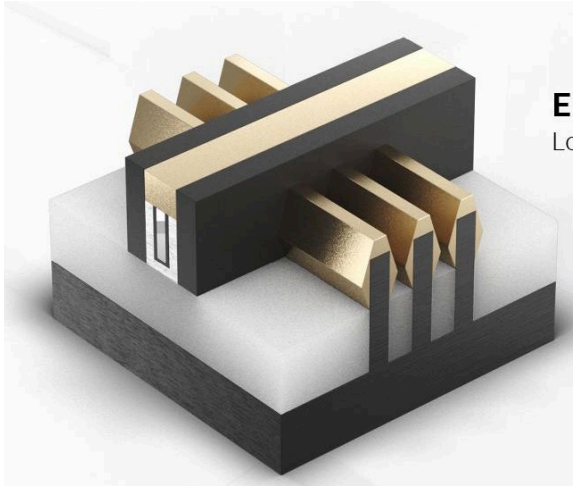
Transistor count: 2300

Size: 12 mm^2

Frequency: 740 kHz

Intel Raptor Lake (2022)





Technology: 10 nm FinFET

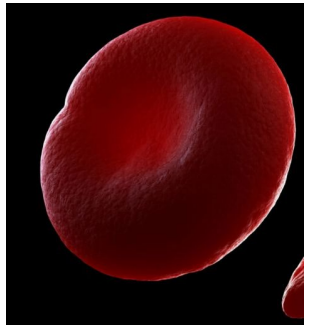
Transistor count: ≈ 26 billion

Chip size: 257 mm^2 (8P+16E cores)

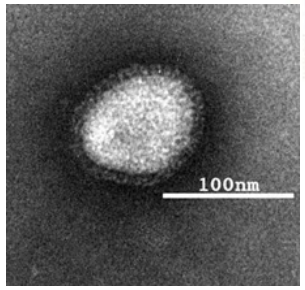
Max. frequency: ≈ 5 GHz

Moore law: scaling

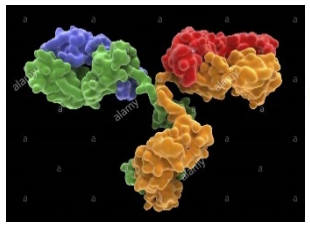
Red blood cell
(7.5 µm)

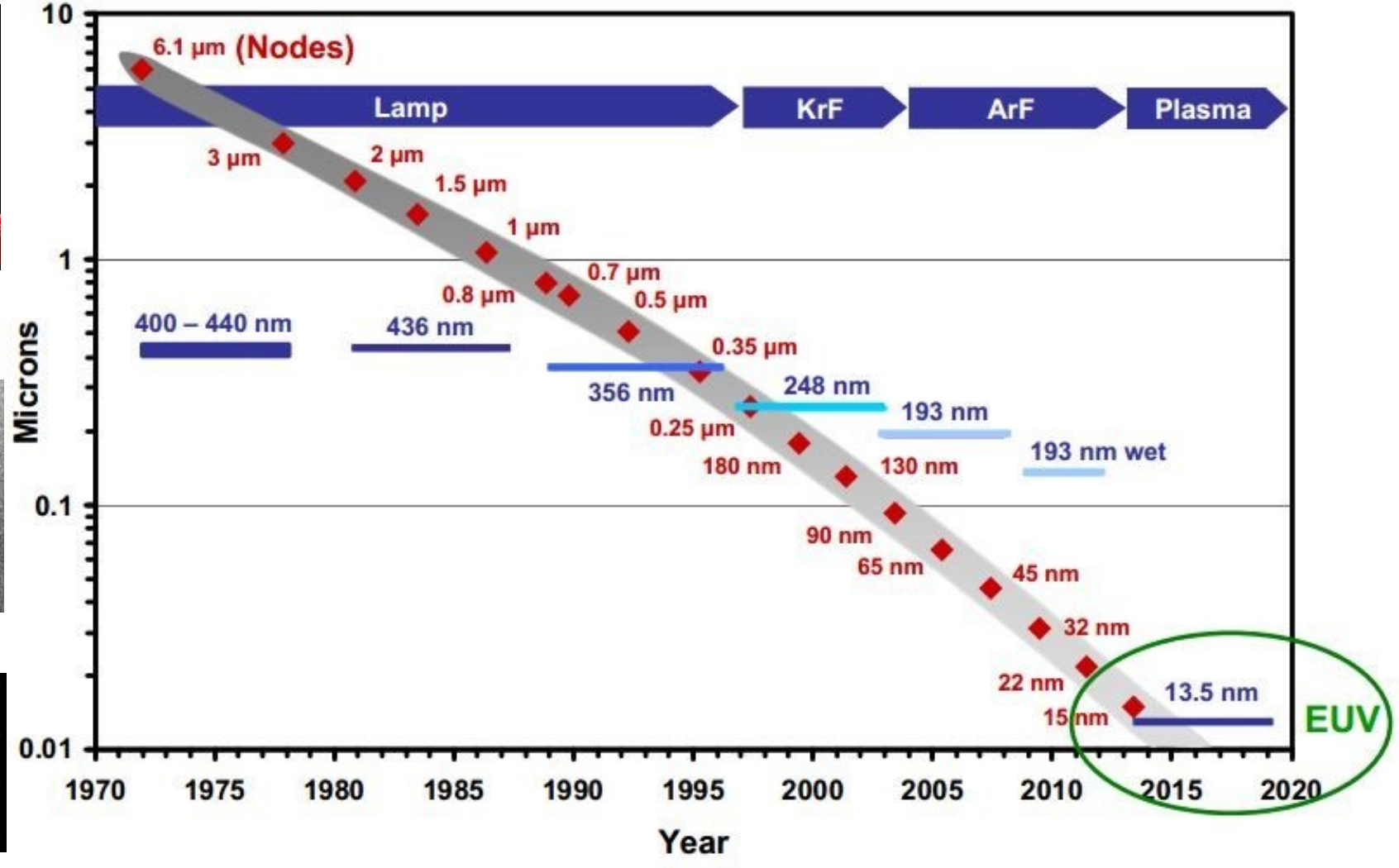


Flu Virus
(0.1 µm)



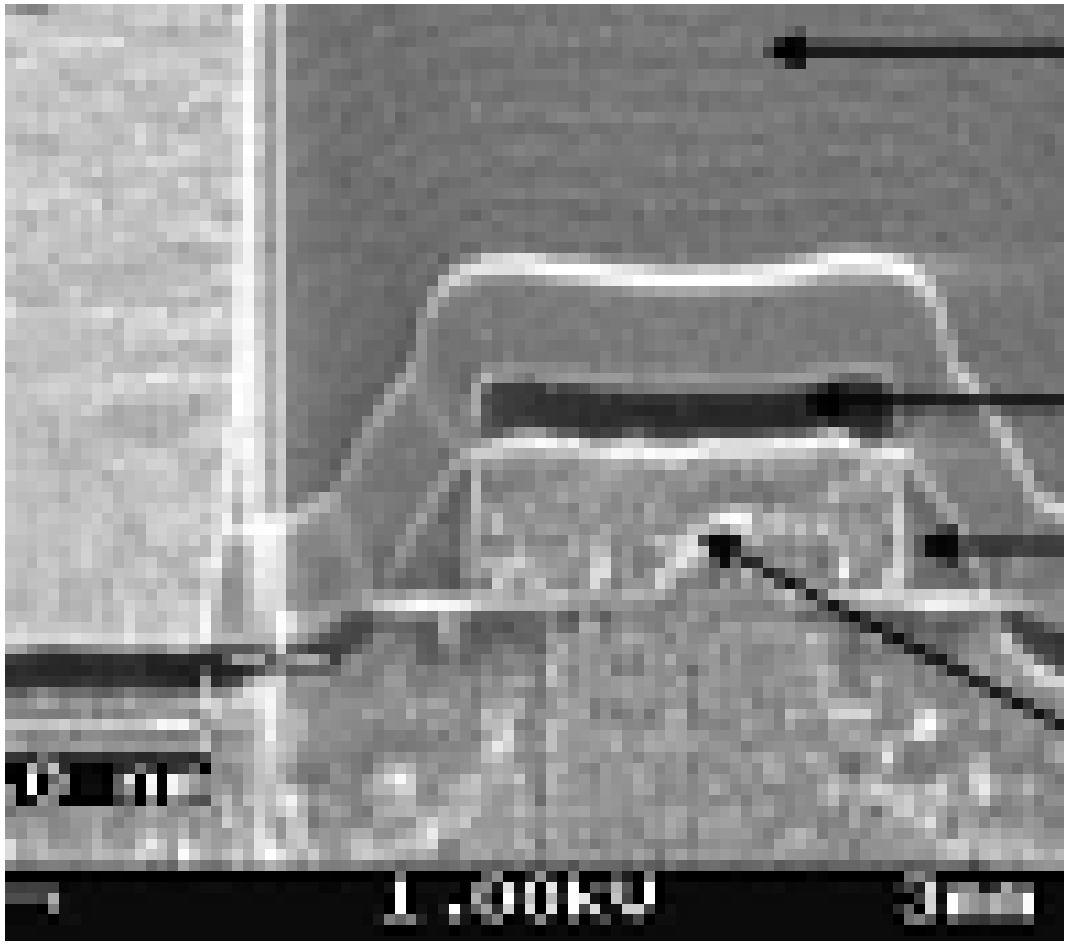
Immunoglobulin
(10 nm)



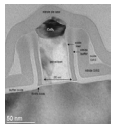


Scaling

1 µm – 1990



90 nm – 2003



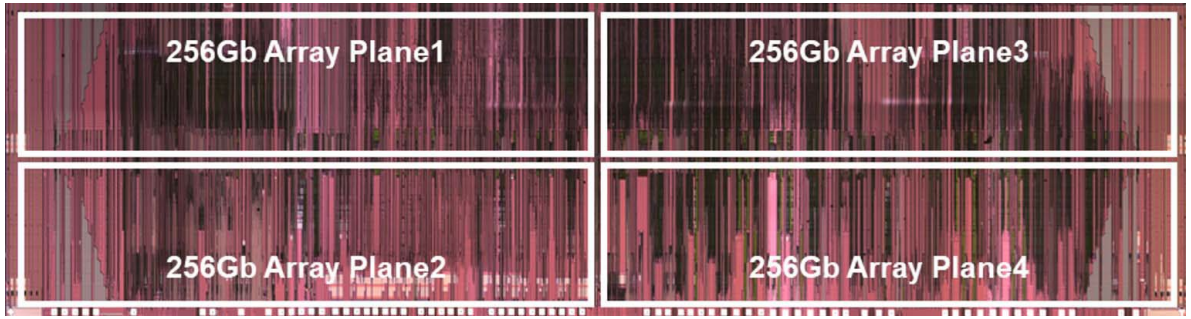
16 nm – 2014

Scaling limit?

What comes next?

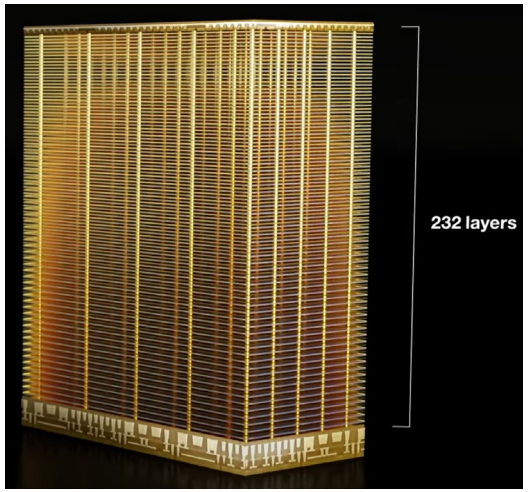
- Scaling is challenged by many factors
  - Physical, technological, economical,…
  - Gate length has already stopped scaling
  - 3D integration is already providing an alternative to conventional scaling
- Many proposals for a post-silicon era
  - Quantum computing, spintronic, DNA computing,… but we are still relying on silicon!
- Exciting field for doing work/research/thesis

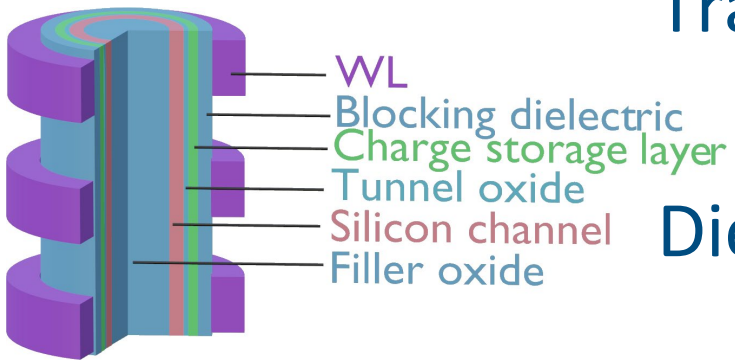
3D NAND (2024)



Technology: 3D (280 layers)

Capacity: 1 Tb (128 GB)



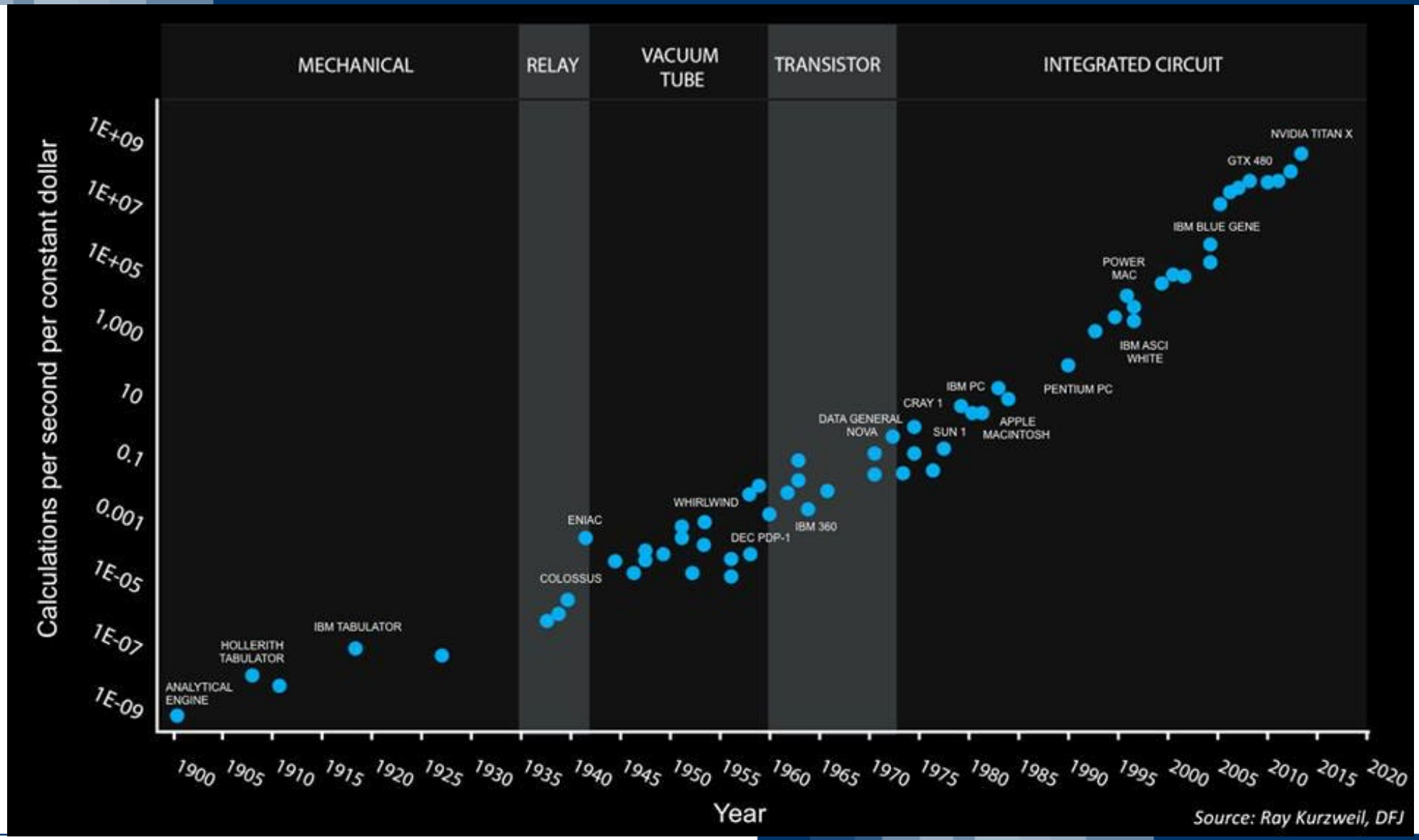


Transistor count: > 300 billion

Die size: ≈ 60 mm^2

Density: ≈ 28 Gb/mm^2

Moore law: performance



A path for you!

- Every major company/research center works on such issues
- This is all but a niche topic $\Rightarrow$ the semiconductor industry has changed the world more than any other
- If interested, get in touch and earn a laurea thesis (and maybe a Ph.D. degree) in a related topic
- More on this at the end of the class

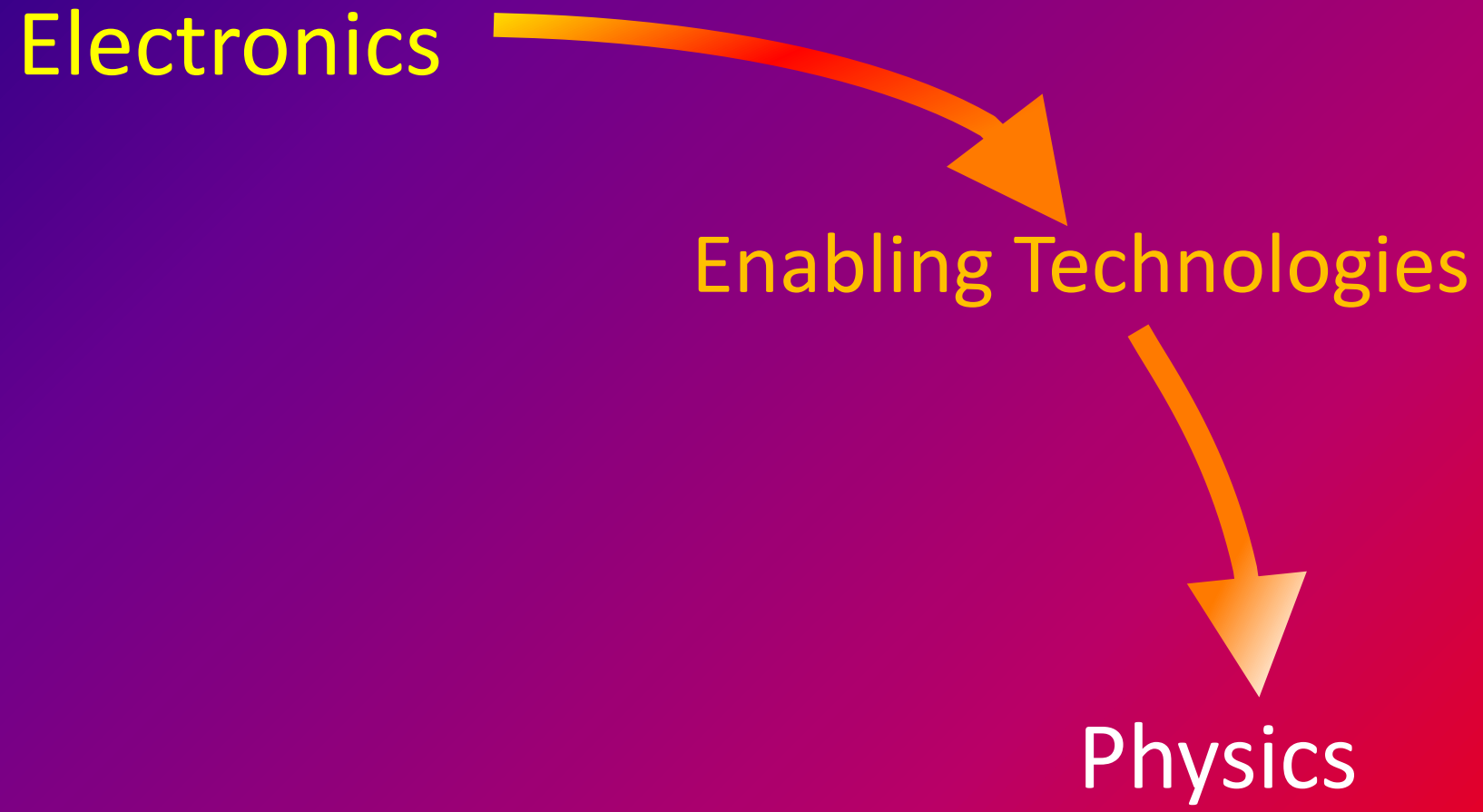
Further insight

Electron devices class

1st semester LM

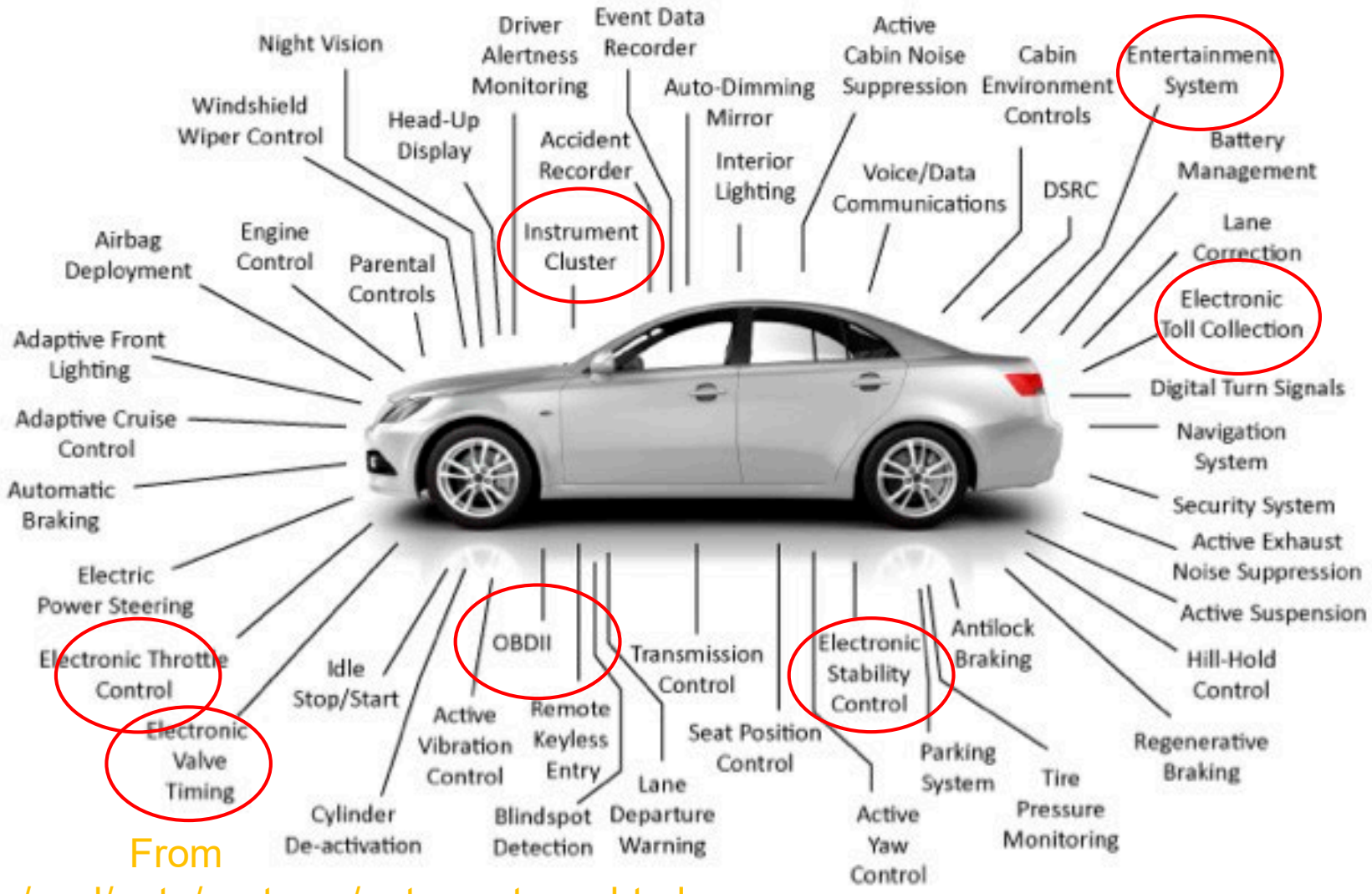
Available in the TABLE 1 group (for EP)

Instructor: Prof. C. Monzio Compagnoni


Electronics
Enabling Technologies
Physics

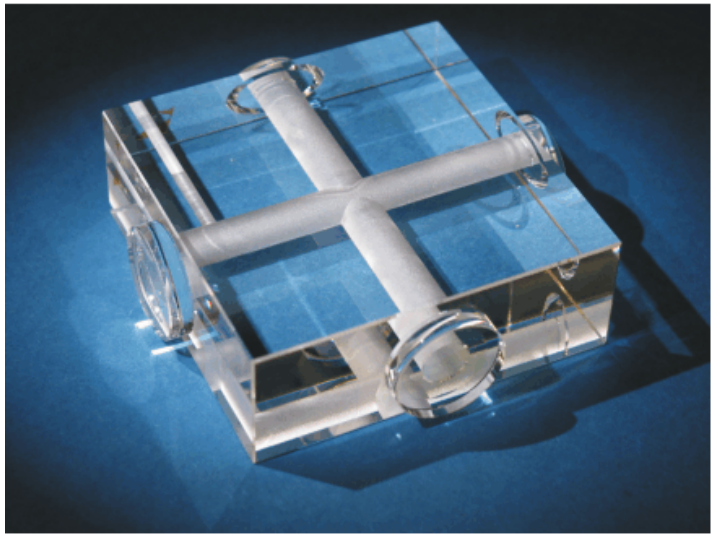
Enabling technologies: medicine/surgery

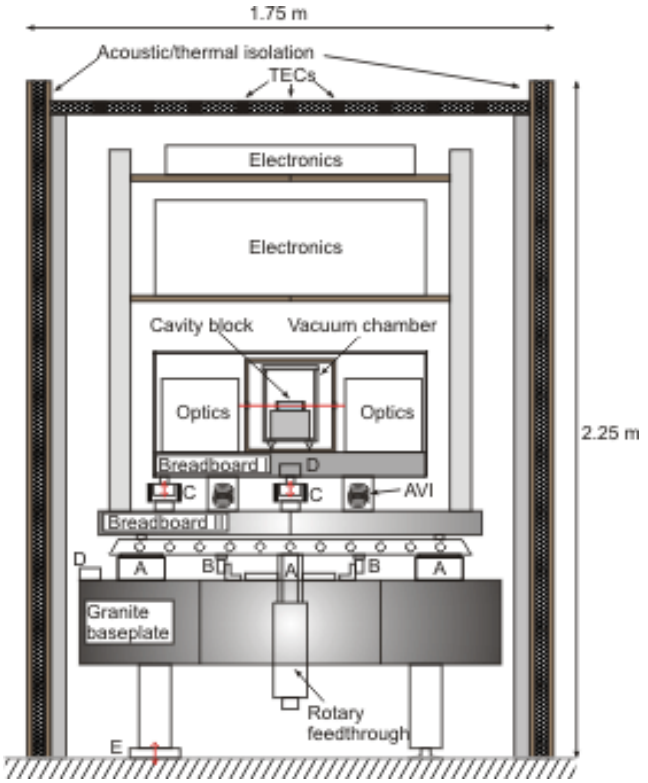
Enabling technologies: automotive



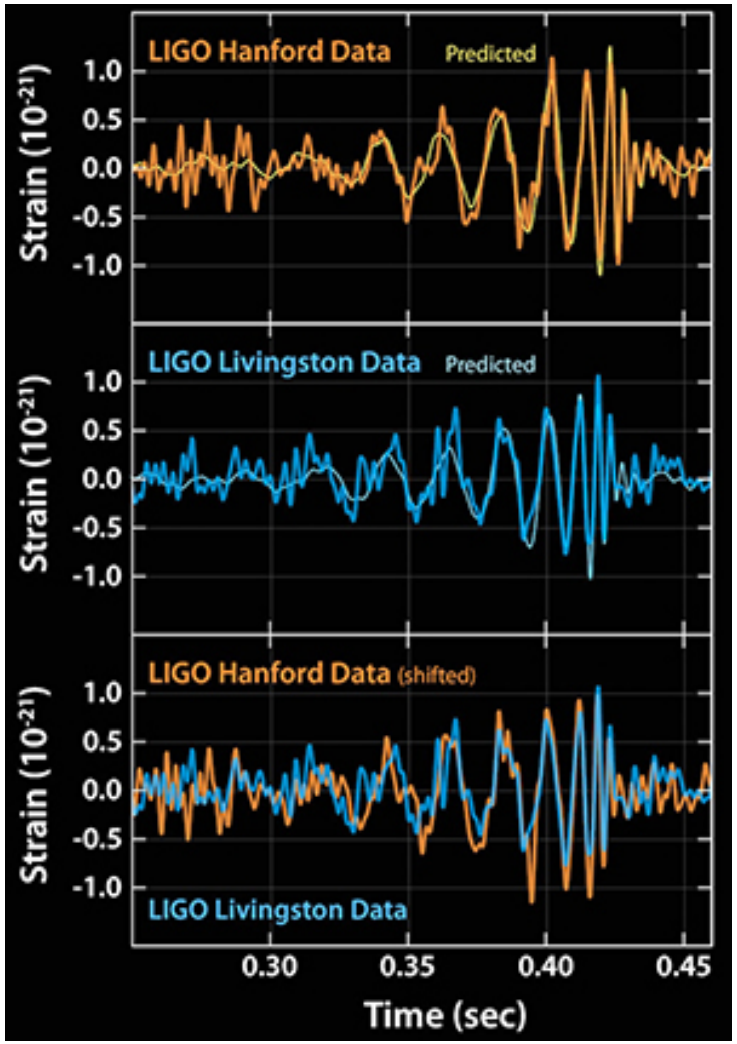
From cecas.clemson.edu/cvel/auto/systems/auto-systems.html

Enabling technologies: physics





Example: GW detection (2015)



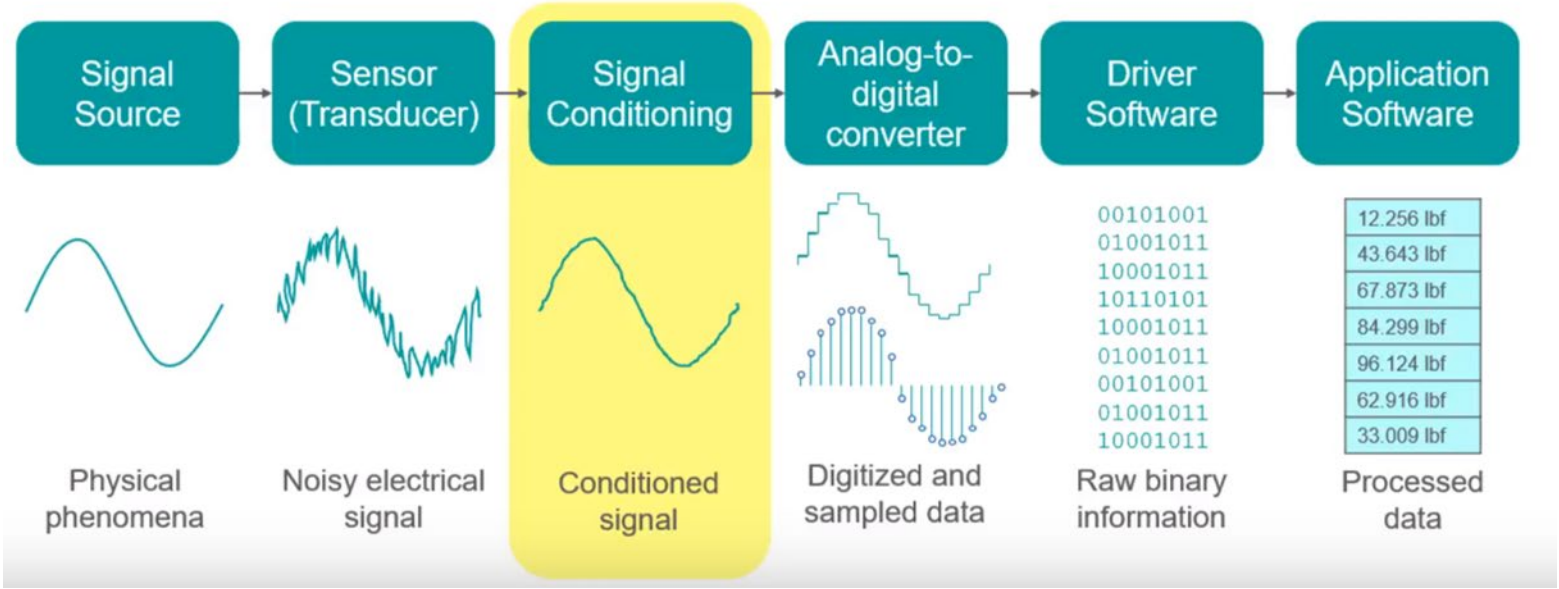
- GW signal shifted arms length by a fraction of the diameter of a proton
- Detectors pick up noise from earthquakes, trucks, ocean waves, bicycle riding,…
- How do you do it?

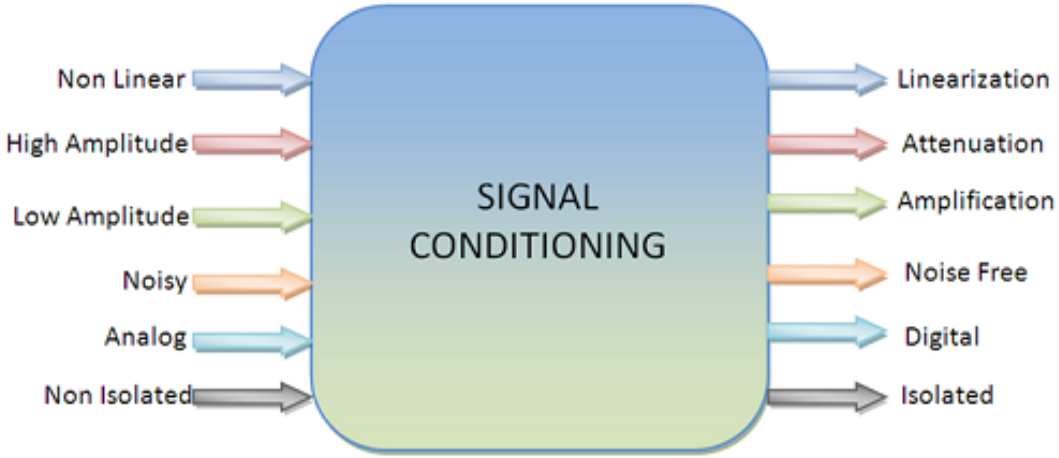
More mundane examples

- Have you ever experienced being in a lab (e.g., during your BSc thesis), working on an experiment right before a deadline, and not measuring anything at all? Just noise and no signal?

- Have you ever connected an earphone/loudspeaker/musical instrument and did not get the sound quality you wanted?

Signal conditioning





Motivation for this class

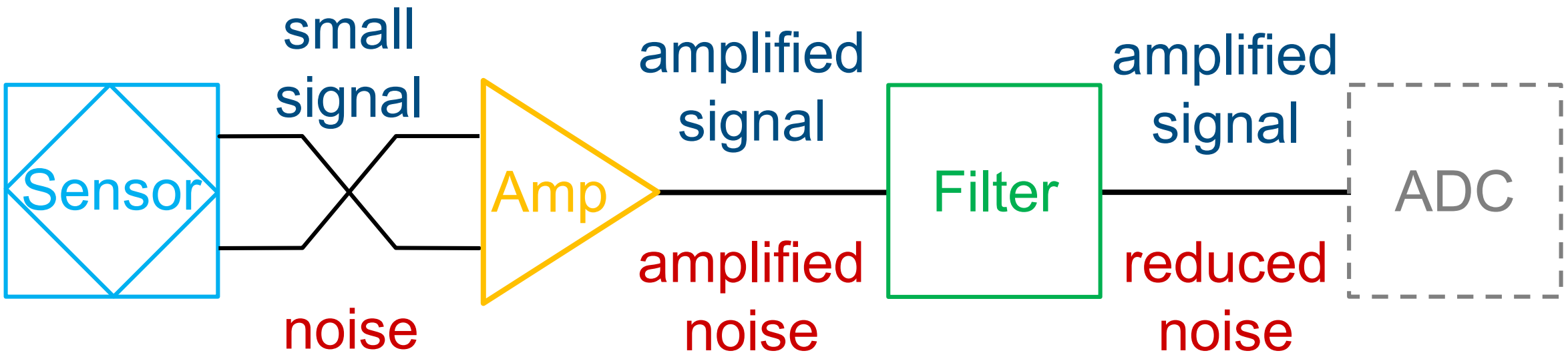
- You already had many classes in physics and possess a knowldedge of the different experimental techniques there used
- Experiment outputs are plagued by noise that can prevent the achievement of a meaningful result
- Here we complete your knowledge by looking at the techniques for noise reduction in data acquisition

For the Telecom Eng. students

- Links between telecom and electronics are countless; however…
- This course is not about telecom circuit design (others take care of that)
- This course deals with signal recovery. We use the same techniques employed at the receiver side of a transmission channel, but for signals coming from sensors
  - Your background should facilitate you in the second part


What's
GOING ON ?

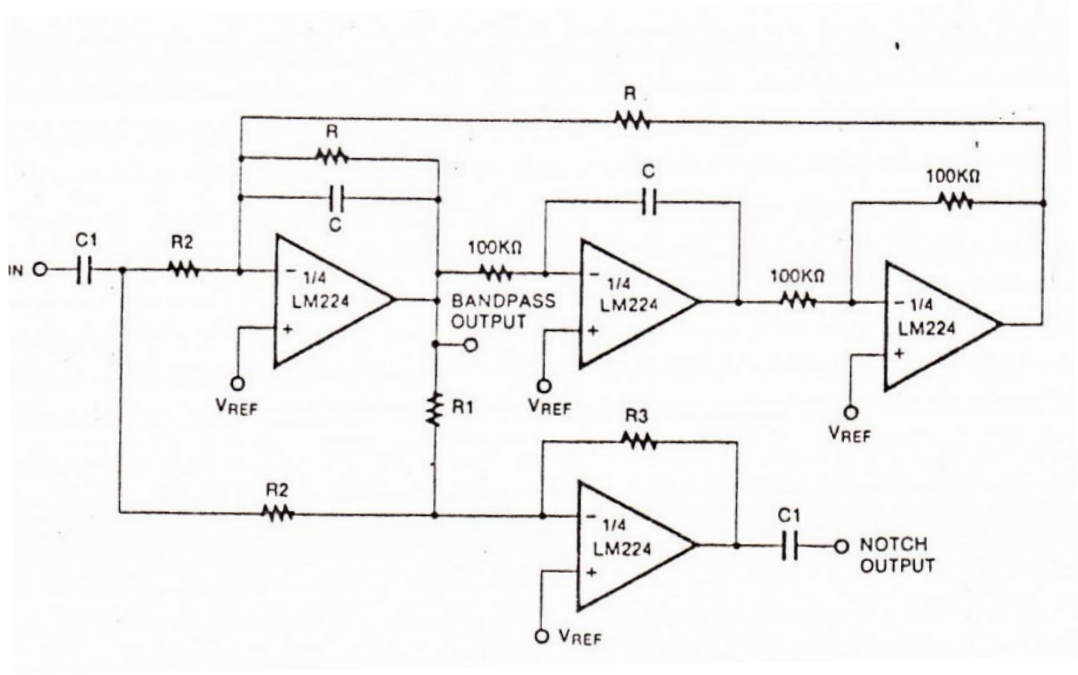
Signal acquisition chain

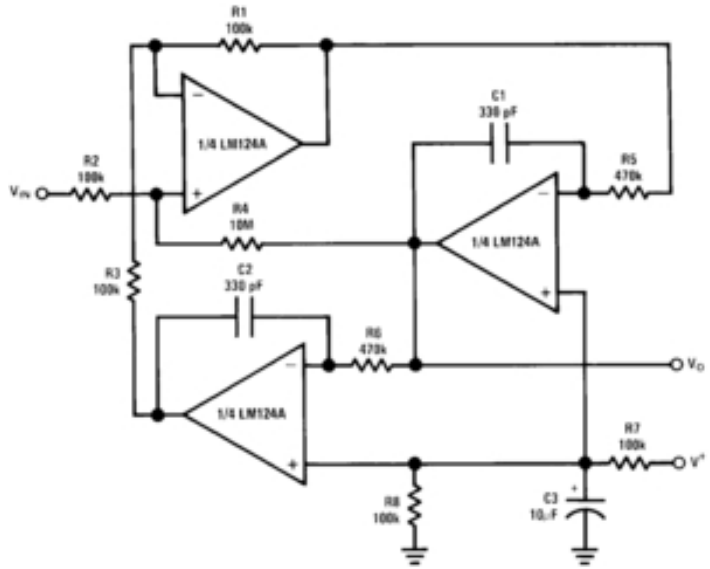


Course sections

- OA Circuits (20h)
  - Feedback, impedances, parameters,…
  - Linear applications and instrumentation amps
  - Frequency response, stability and compensation
- Sensors (5h)
  - Wheatstone bridge and connections
- Noise (8h)
  - Noise and random processes
  - Noise calculations in circuits
- Signal recovery from noise (25h)
  - Filtering techniques for white noise
  - Filtering techniques for low-frequency noise

Operational amplifiers





- Analysis and design of simple circuits
- Emphasis on application to data acquisition

Stability

Real OA: parameters

ANALOG DEVICES

Low Noise, Precisio
Operational Amplifie
OP2

FEATURES

Low noise: 80 nV p-p (0.1 Hz to 10 Hz), 3 nV/√Hz
Low drift: 0.2 μV/°C
High speed: 2.8 V/μs slew rate, 8 MHz gain bandwidth
Low V_{OS}: 10 μV
Excellent CMRR: 126 dB at VCM of ±11 V
High open-loop gain: 1.8 million
Fits OP07, 5534A sockets
Available in die form

GENERAL DESCRIPTION

The OP27 precision operational amplifier combines the low offset and drift of the OP07 with both high speed and low noise. Offsets down to 25 μV and maximum drift of 0.6 μV/°C make the OP27 ideal for precision instrumentation applications. Exceptional low noise, e_n = 3.5 nV/√Hz, at 10 Hz, a low 1/f noise corner frequency of 2.7 Hz and high gain (1.8 million), allow accurate high-gain amplification of low-level signals. A gain-bandwidth product of 8 MHz and a 2.8 V/μs slew rate provide excellent dynamic accuracy in high speed, data-acquisition systems.

A low input bias current of ±10 nA is achieved by use of a bias current cancellation circuit. Over the military temperature range this circuit typically holds I_B and I_{OS} to ±20 nA and 15 nA, respectively.

The output stage has good load driving capability. A guaranteed swing of ±10 V into 600 Ω and low output distortion make the OP27 an excellent choice for professional audio applications.

(Continued on Page 3)

PIN CONFIGURATIONS

Figure 1. 8-Lead TO-99 (J-Suffix)

Figure 2. 8-Lead CERDIP—Glass Hermetic Seal (Z-Suffix), 8-Lead PDIP (P-Suffix), 8-Lead SOI (S-Suffix)

FUNCTIONAL BLOCK DIAGRAM

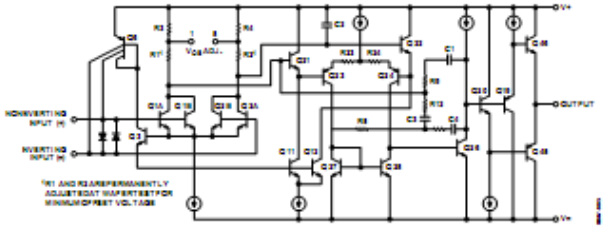


Figure 3.

Rev. F

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SPECIFICATIONS

ELECTRICAL CHARACTERISTICS

V_S = ±15 V, T_A = 25°C, unless otherwise noted.

Table 1.

Parameter	Symbol	Conditions	OP27A/E			OP27G			Unit
			Min	Typ	Max	Min	Typ	Max	
INPUT OFFSET VOLTAGE[1]	V_{OS}			10	25		30	100	μV
LONG-TERM V_{OS} STABILITY[2, 3]	V_{OS}/Time			0.2	1.0		0.4	2.0	μV/Mo
INPUT OFFSET CURRENT	I_{OS}			7	35		12	75	nA
INPUT BIAS CURRENT	I_B			±10	±40		±15	±80	nA
INPUT NOISE VOLTAGE[4]	$e_{n\ p\text{-}p}$	0.1 Hz to 10 Hz		0.08	0.18		0.09	0.25	μV p-p
INPUT NOISE VOLTAGE DENSITY[3]	e_n	f_O = 10 Hz		3.5	5.5		3.8	8.0	nV/√Hz
		f_O = 30 Hz		3.1	4.5		3.3	5.6	nV/√Hz
		f_O = 1000 Hz		3.0	3.8		3.2	4.5	nV/√Hz
INPUT NOISE CURRENT DENSITY[4]	i_n	f_O = 10 Hz		1.7	4.0		1.7		pA/√Hz
		f_O = 30 Hz		1.0	2.3		1.0		pA/√Hz
		f_O = 1000 Hz		0.4	0.6		0.4	0.6	pA/√Hz
INPUT RESISTANCE									
Differential Mode[5]	R_{IN}		1.5	6		0.7	4		MΩ
Common Mode	R_{INCM}			3			2		GΩ
INPUT VOLTAGE RANGE	IVR		±11.0	±12.3		±11.0	±12.3		V
COMMON-MODE REJECTION RATIO	CMRR	V_{CM} = ±11 V	114	126		100	120		dB
POWER SUPPLY REJECTION RATIO	PSRR	V_S = ±4 V to ±18 V		1	10		2	20	μV/V
LARGE SIGNAL VOLTAGE GAIN	A_{VO}	R_L ≥ 2 kΩ, V_O = ±10 V	1000	1800		700	1500		V/mV
		R_L ≥ 600 Ω, V_O = ±10 V	800	1500		600	1500		V/mV
OUTPUT VOLTAGE SWING	V_O	R_L ≥ 2 kΩ	±12.0	±13.8		±11.5	±13.5		V
		R_L ≥ 600 Ω	±10.0	±11.5		±10.0	±11.5		V
SLEW RATE[6]	SR	R_L ≥ 2 kΩ	1.7	2.8		1.7	2.8		V/μs
GAIN BANDWIDTH PRODUCT[6]	GBW		5.0	8.0		5.0	8.0		MHz
OPEN-LOOP OUTPUT RESISTANCE	R_O	V_O = 0, I_O = 0		70			70		Ω
POWER CONSUMPTION	P_d	V_O		90	140		100	170	mW
OFFSET ADJUSTMENT RANGE		R_P = 10 kΩ		±40			±40		mV

[1] Input offset voltage measurements are performed approximately 0.5 second after application of power. A/E grades guaranteed fully warmed up.
[2] Long-term input offset voltage stability refers to the average trend line of V_{OS} vs. time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 days are typically 2.5 μV. Refer to the Typical Performance Characteristics section.
[3] Sample tested.
[4] See voltage noise test circuit (Figure 21).
[5] Guaranteed by input bias current.
[6] Guaranteed by design.

TYPICAL PERFORMANCE CHARACTERISTICS

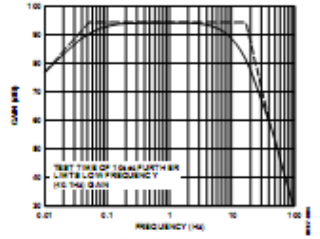


Figure 4. 0.1 Hz to 10 Hz p-p Noise Tester Frequency Response

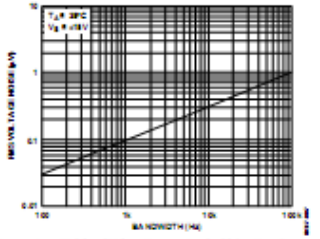


Figure 7. Input Wideband Voltage Noise vs. Bandwidth (0.1 Hz to Frequency in Indicated)

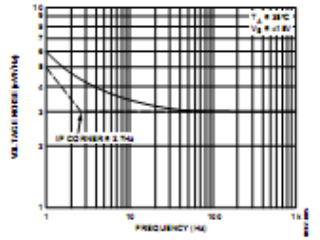


Figure 5. Voltage Noise Density vs. Frequency

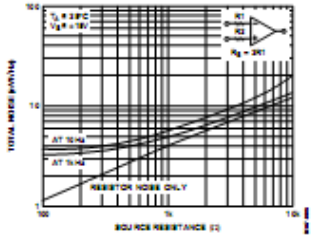


Figure 8. Total Noise vs. Source Resistance

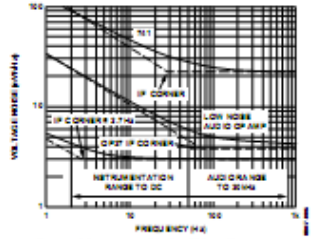


Figure 6. A Comparison of Op Amp Voltage Noise Spectra

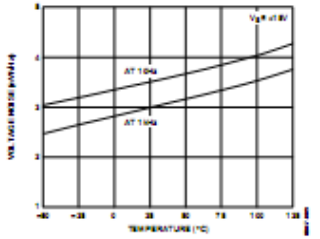
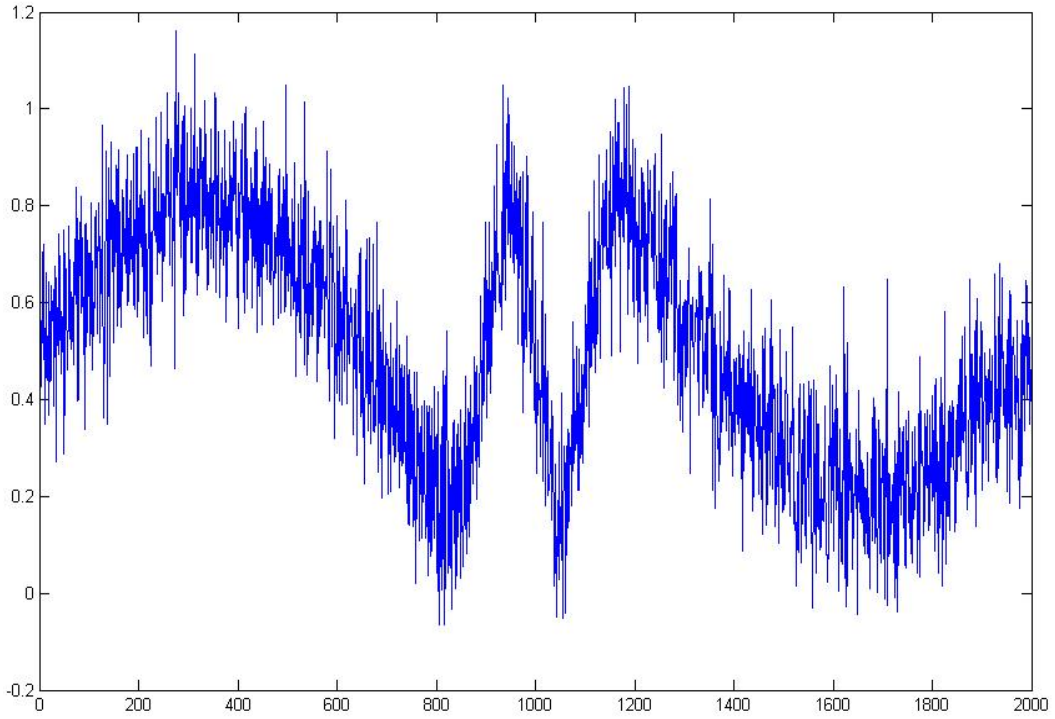
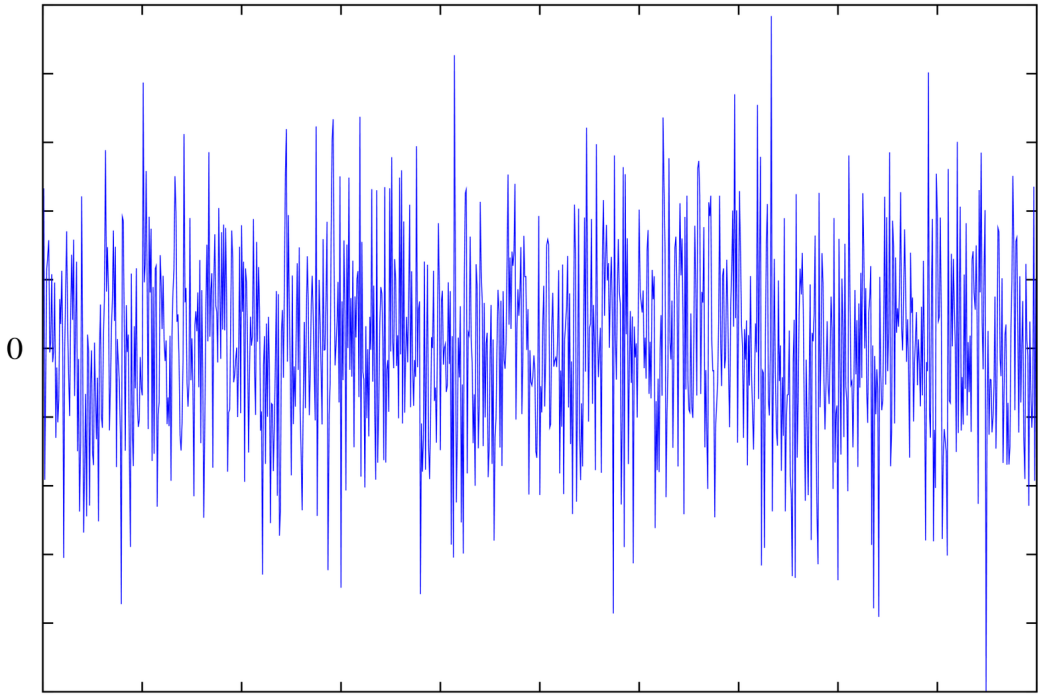


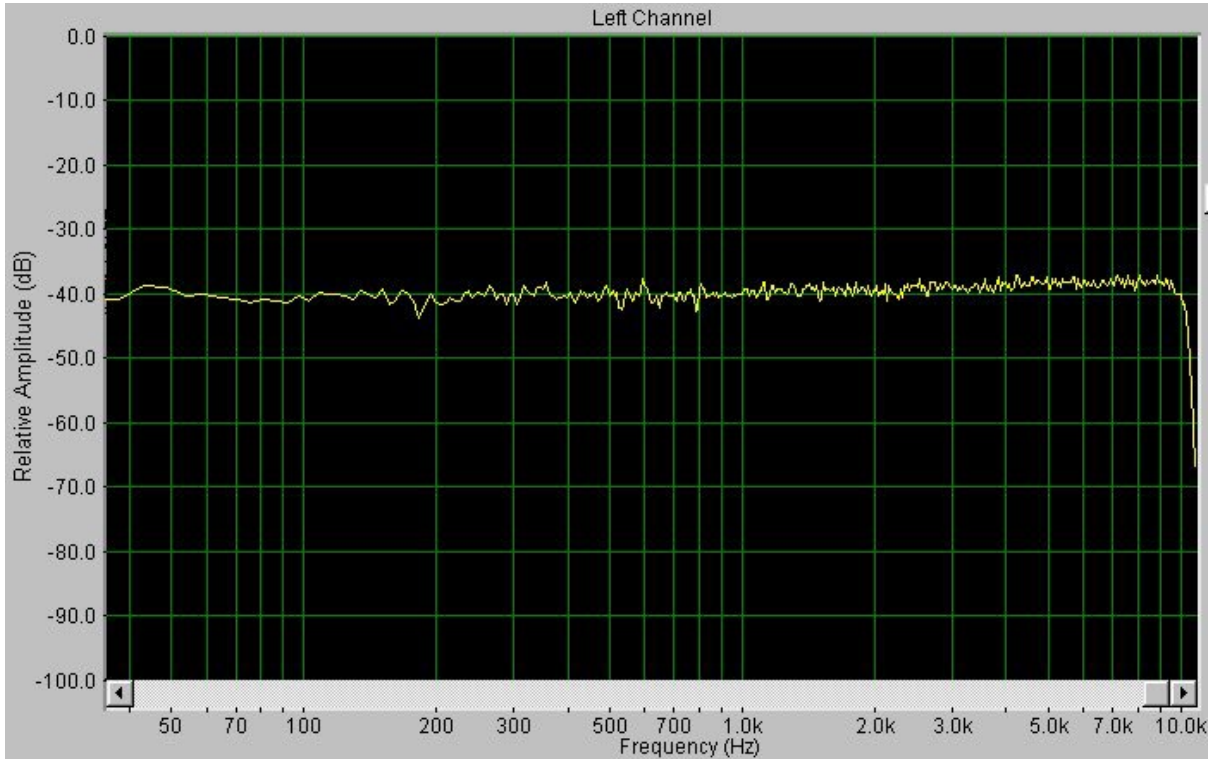
Figure 9. Voltage Noise Density vs. Temperature

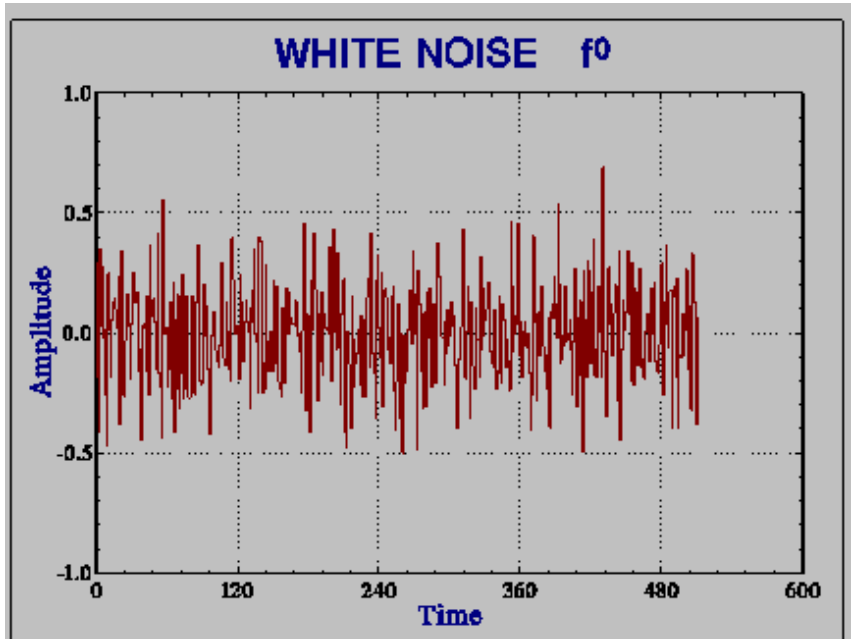
Signal and noise



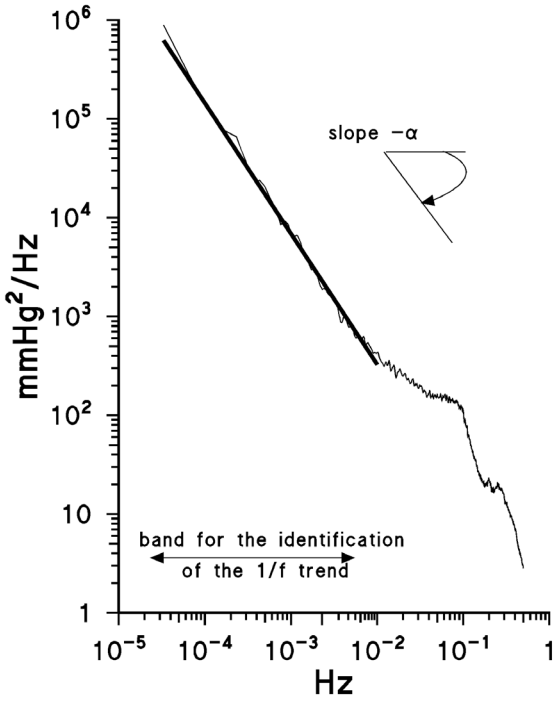


White noise

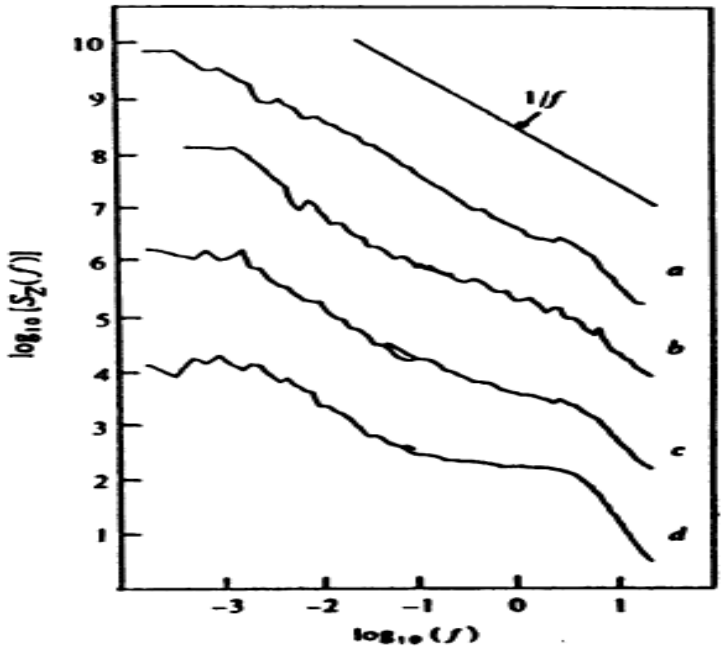

Left Channel
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
Relative Amplitude (dB)
50
70
100
200
300
500
700
1.0k
2.0k
3.0k
5.0k
7.0k
10.0k
Frequency (Hz)


WHITE NOISE f0
1.0
0.5
0.0
-0.5
-1.0
Amplitude
0
120
240
360
480
600
Time

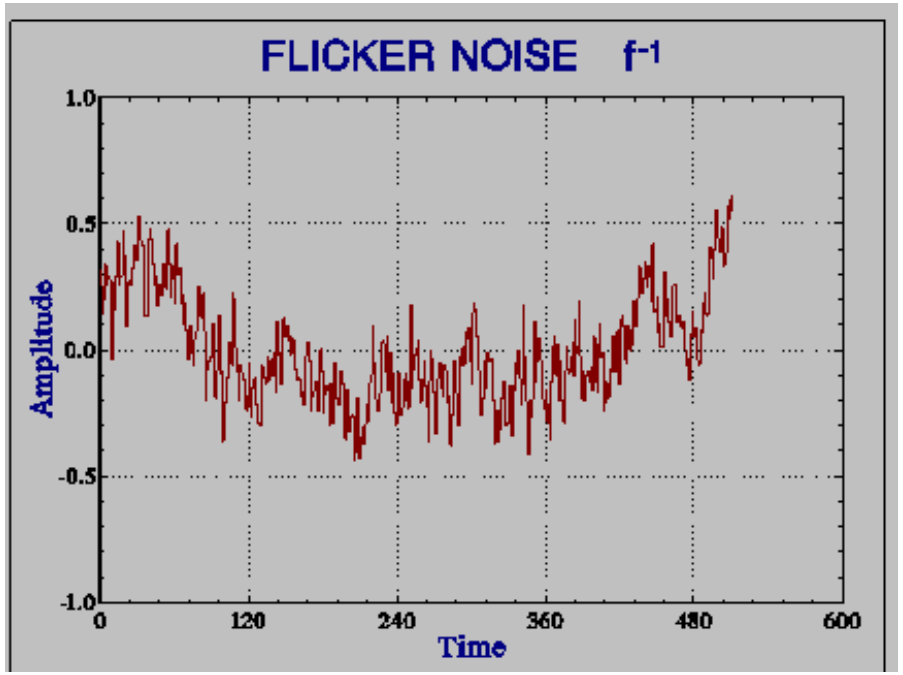
Flicker (1/f) noise



Systolic blood pressure



Radio signal for different kinds of music



What you learn

- To analyze and design simple circuits using OAs
- To understand and solve simple problems in data acquisition, involving
  - Sensor arrangement
  - Preamplification
  - Noise filtering

- Overall, an “engineering” approach to simple yet realistic problems


info

Timetable

	Mon	Tue	Wed
8.15 – 9.15			
9.15 – 10.15		10.30	
10.15 – 11.15		E.P.6	
11.15 – 12.15		E.P.6	
12.15 – 13.15			
13.15 – 14.15		14.30	
14.15 – 15.15	T.0.1 (ex.)		21.S.2
15.15 – 16.15	T.0.1 (ex.)		21.S.2
16.15 – 17.15	T.0.1 (ex.)		21.S.2

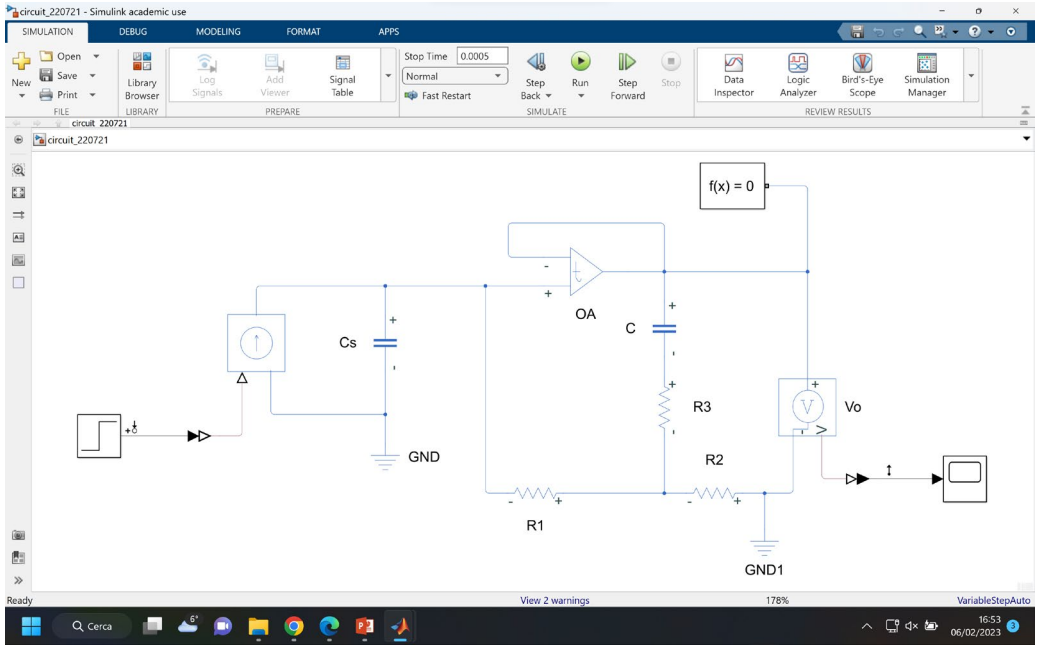
- As usual, the calendar is very tight ⇒ we will probably need to have lesson during the partials break
- All lessons, drills, and tutorage will be streamed, recorded and made available ASAP

Structure

- Lessons
  - Theory and basic concepts
  - Few numerical examples
- Drills (Dr. Davide Resnati, Micron Tech., and myself (first 5 drills))
  - Numerical examples (10)
  - Exam test solution (3)
- Tutorage (David Refaldi, Ph.D. student)
- Office hours: always (just send me an email)
- Your opinion IS important ⇒ please, give feedback

Circuit simulation

- Matlab Simulink files with exam circuits are also available
- You can use them to verify your results as well as study the approximation validity, make changes and play around…
- A short overview of the tool will be provided



Lecture slides

- Available on class website: spinelli.faculty.polimi.it ⇒ Teaching ⇒ Electronics
- (Very) useful for schemes, equations, figures,…
- Hint: print them ahead of time and take (plenty of) notes alongside
- Slides cannot contain everything ⇒ never forget to read/study on the textbooks!
- Lesson recordings will be available as soon as they are ready

Drill slides

- Slides for the first ten drills are available
- Later, we will pick examples from past exam tests, so no slides should be necessary
- Drills are meant to understand how to approach the problems. Exam test solutions are also needed to finalize your preparation to the exam
- Drill recordings will be available as soon as they are ready

Tutorage

- A student tutorage (20h) has been set up for this class
- Tutorage is made of 7 slots of Q&A focused on different parts of the program ⇒ attend, be proactive and ask questions to clarify your doubts

- Starts usually around April (I will keep you updated)

Students' requests

- Shortening of the program
  - Over the years I got rid of:
    - OA active filters
    - Reflections on transmission lines
    - Sensors: basic concepts
    - Deformation and temperature sensors
    - Interferences and shielding
    - S&H amplifiers and ADCs
    - Ratemeter filter
- Extra drill hours
  - Sure! We'll discuss this at the end of the class

Textbooks

- Operational Amplifiers
  - S. Franco, “Design with OAs and analog ICs”, 4th ed., McGraw Hill, 2015
- Signals, noise and filtering
  - I. Rech, G. Acconcia, “Signal recovery”, available at rech.faculty.polimi.it/wp-content/uploads/SignalRecoveryBook-1.pdf
- Other specific online books/chapters are listed on the class website

Exercise books

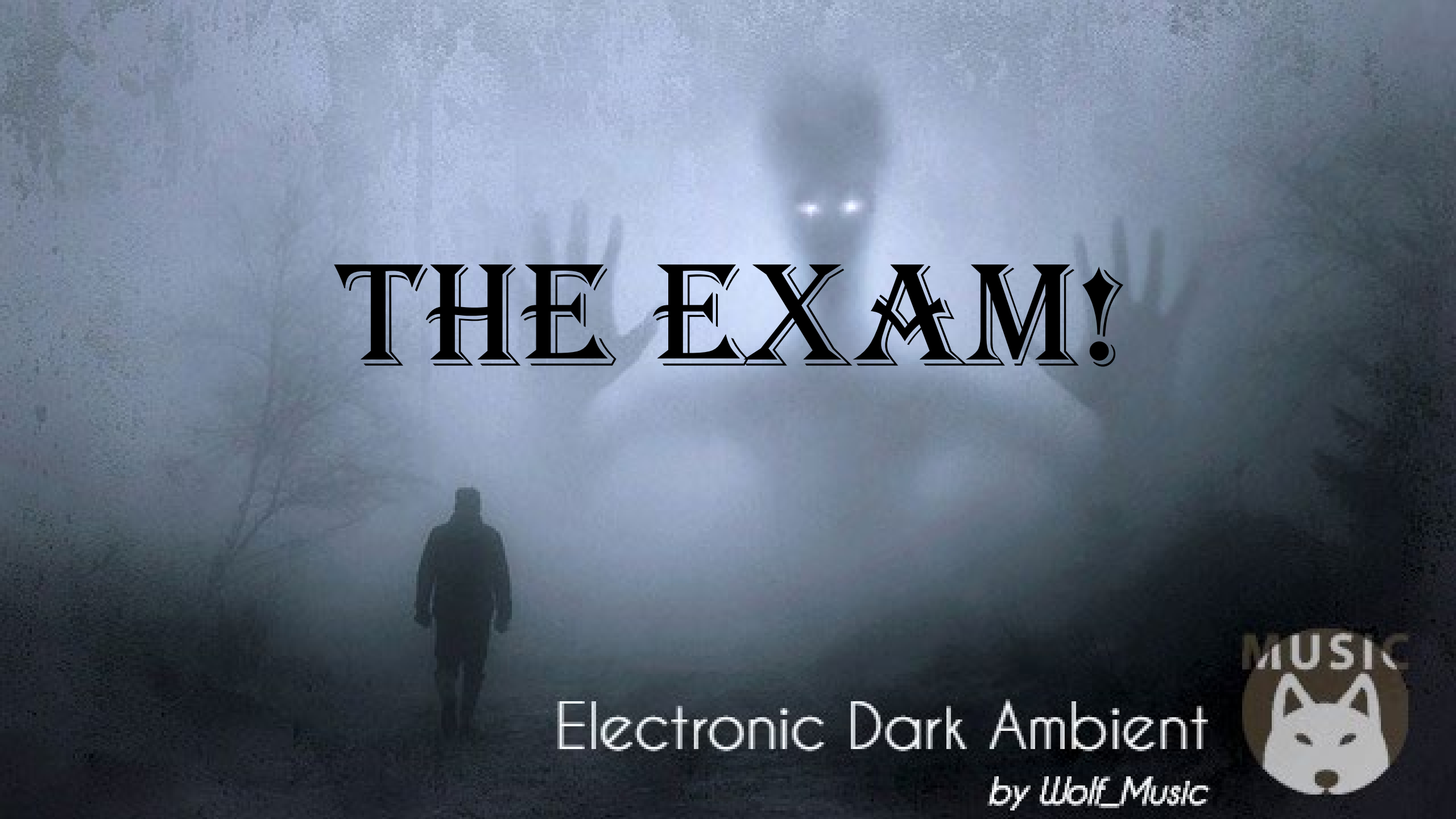
- Exam solutions for the last ten years (400 questions) are available on the class website
- No specific English book available (some problems can be found in textbooks)
- Introductory (italian) books on OAs are
  - A. Bonfanti, A. Lacaita, «L'amplificatore operazionale», Esculapio, 2005
  - A. Tosi, «Esercizi di elettronica», Esculapio, 2011 (85 pages on OAs)

Student-provided material

- Transcription of lessons and exercises given in AY 2016/17 (available on the course website)
  - Collected by Dr. Giacomo Inzani in 2018 (thanks!)
  - A bit outdated
  - I haven't had the time to proofcheck them
- If there's anything you would like to share, just get in touch and send it to me. It will be useful for others!

Prerequisites

- Linear networks (Kirchhoff, Thevenin and Norton theorems, superposition principle, impedance calculations,…)
- Fourier and Laplace transforms and linear systems (incl. Bode plot)
- A review of these concepts will be given in the first drill
- You should get familiar with these basic concepts as soon as possible (a few links are provided on the homepage, check whatever text you like)


THE EXAM!
Electronic Dark Ambient
by Wolf_Music
MUSIC

Final written examination

- Two parts (4 questions each)
  - OAs and noise
  - Filtering and signal conditioning
- To get 30/30 you need to correctly solve 6 points
- The numerical results, not just the method, matter
- Since 2018 the exam is open-book
  - You can bring any printed book or notes you like
  - You can bring a tablet if you took notes on it. No online stuff, please!
- Use either English or Italian

Tentative exam days

- June 18
- July 21
- September 10

- At: 11:30
- Span: 2 hours 45 minutes
- Dates may change due to conflicts/overlaps

Recommendations

The «please» list

- Old-fashioned non-symbolic calculators are fine and more than enough. Please, turn mobile phones & other devices off
- The exam is written only
  - Please, do not ask for oral, project or any other way of bypassing it
- You are welcome to come anytime to view and discuss your test result (send me an email; look at exam solution first)
  - Please, be fair and do not ask for a vote rise on the basis of anything (personal reasons, graduation mark,…) except your test

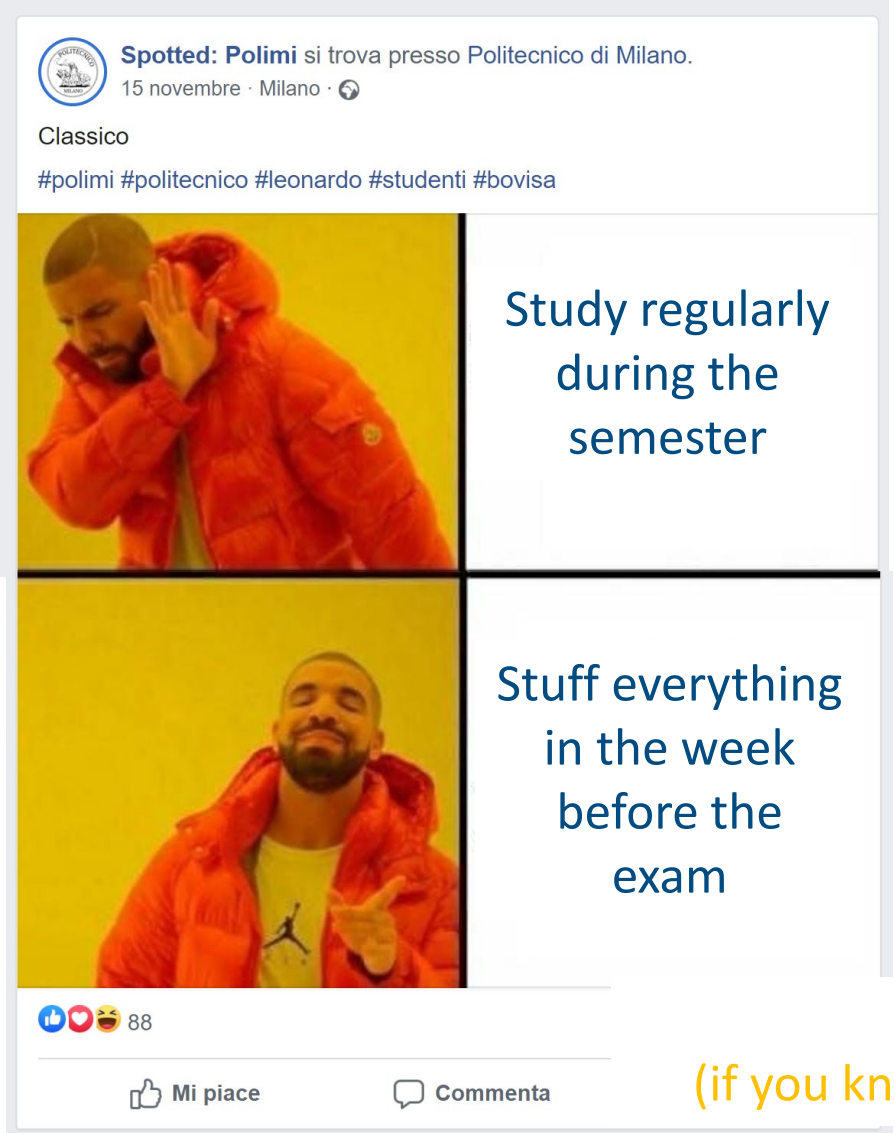
Myth debunking…

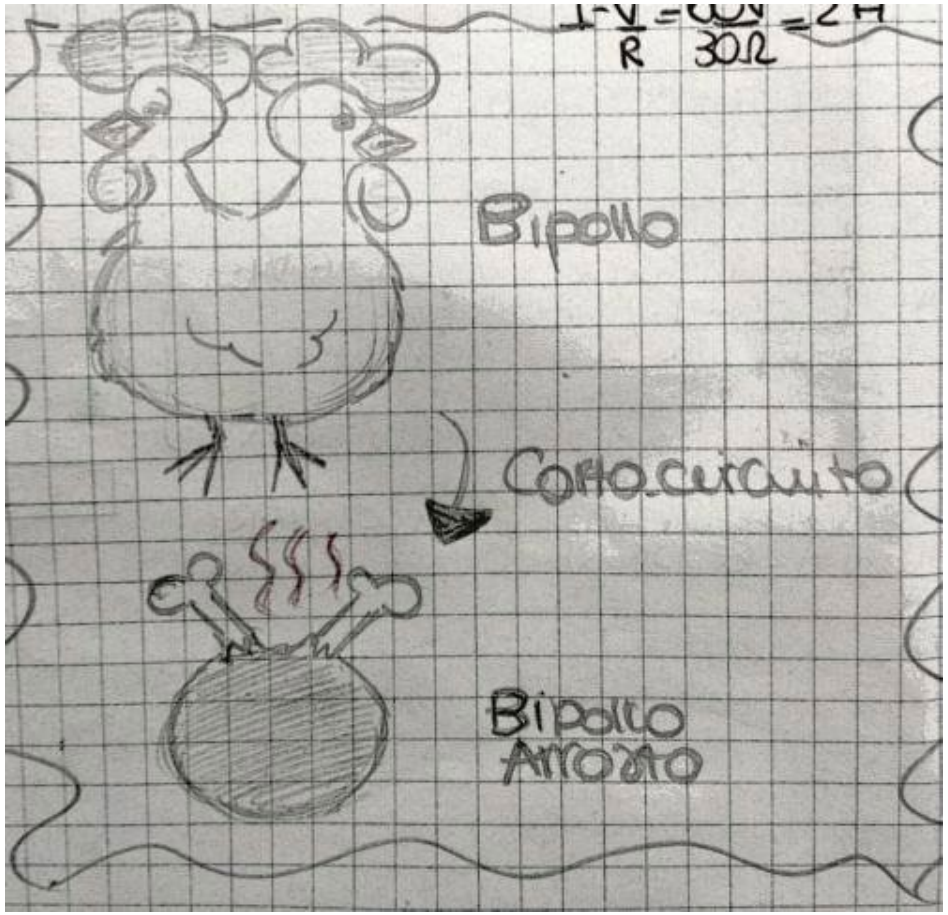
- The exam IS NOT difficult
  - Way more than 50% of attendees pass it
- It is (perhaps) a bit different from what you are used
  - You must solve simple problems, not just say how you would
  - It is designed to test your reasoning more than your recall
  - I ask you to show your understanding of the topic, not to learn everything by heart

Hints – 1

- Do make use of instructors office hours to ask questions
- Do NOT learn 10^n exam tests by heart hoping to find a similar one. First, make sure you understand the theory; then, move to exercises. Not the other way around!!
- Do NOT thrive on last-minute cramming. Learning requires time; there is no shortcut (unfortunately)!
  - Think of gym training: do you train regularly or just the day before the race?

Bad habits… and not-so-good results!





From Spotted: Polimi

(if you know the author of this, let me know, so I can acknowledge the joke)

Hints – 2

1. If you want a high mark, don't just "give it a try"; you are probably wasting your time
2. Be conscious about your true preparation

3. Please, please, please… DO NOT leave this exam last

The unlikely event of troubles

- If you experience trouble with the exam, get in touch, so we can work on what is wrong ⇒ show commitment to improve your understanding
- Please, do NOT pop up out of the blue handing me a blank sheet and telling that you have completed all the other exams plus thesis, plus Ph.D. enrolling, plus whatever… and now you “must” pass this exam ⇒ this is unethical and unfair (and pretty upsetting)

Final suggestions

- If you don’t understand something during the lesson, just ask!
  - You are welcome to use English or Italian
- Don’t be shy: your questions are important for others, too
  - Let’s try to have some interaction during the lessons and not all the questions at the end
- Try to get the most out of your staying in the class

Your instructor

- MS in Electronics Eng., 1992
- Ph.D. in Electronics Eng., 1995
- Visiting Scholar (UTSI, TN, USA), 1995
- Consultant for STMicroelectronics, 1996
- Teaching Assist. at Politecnico di Milano, 1997
- Associate Prof. at Univ. of Como, 1998
- Visiting Professor (ENSERG, France), 2001
- Transfer to Politecnico di Milano, 2004
- Full Prof. at Politecnico di Milano, 2006
- Research activity: nano-electronic memories, polymeric devices for galvanic isolation

The ascent begins!

Tomorrow:
negative feedback and amplifiers