Linköping University

Reinventing research and education

Analog Design, second course (ANDA)
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Electronics Systems
Department of Electrical Engineering

LiU EXPANDING REALITY

Lecture 1, ANDA

Course introduction, CMOS basics

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Analog design, second course (ANDA)

What is "analog"?

What are integrated circuits?

What is "second" course?

What is "board level", "circuit level"?

Web resources

WWW: http://www.es.isy.liu.se/courses/ANDA

WP: http://mixedsignal.wordpress.com

FB: http://www.facebook.com/mixedsignal

Twitter: @jjwikner

Studiehandboken 1

Prel. scheduled hours: 48
Rec. self-study hours: 112

Area of Education: Technology

Main field of studies: Electrical Engineering

Advancement level (G1, G2, A): G2

Aim:
The purpose is to give

- basic knowledge in analysis and design of analog and discrete-time circuits connected on a circuit board
- to give knowledge about different types of A/D- and D/A-converters and their usage
- to give knowledge about interconnects, termination of wires and load, dimensioning of circuits
- to give knowledge about noise and distortion

After the student has passed the course the student should be able to:

- Describe CMOS-transistors in different operation modes
- Describe the relationship between different design parameters and performance metrics
- Analyze amplifiers from small- and large-signal points of view
- Determine different types of performance measures for analog circuits

Studiehandboken 2

- Describe different methods for terminating wires/connecting chips
- Describe different types of noise and distortion, and also determine different type of noise- and distortion metrics.

Prerequisites: (valid for students admitted to programmes within which the course is offered)
Knowledge of basics in circuit theory, linear systems, and electronics.

Note: Admission requirements for non-programme students usually also include admission requirements for the programme and threshhold requirements for progression within the programme, or corresponding.

Organisation:
The course has lectures, lessons, and computer-based group exercises.

Course contents:
Introduction to CMOS technology: Integrated circuit components, such as PMOS and NMOS transistors, capacitors. Analyze one-stage amplifiers and operational amplifiers from a small

Studiehandboken 3

Course contents:

Introduction to CMOS technology: Integrated circuit components, such as PMOS and NMOS transistors, capacitors. Analyze one-stage amplifiers and operational amplifiers from a small signal point of view as well as from a large signal point of view. Determine different types of performance measures for differential amplifiers. D/A-converters: Different types, transfer functions, determine of output signal, offset errors. A/D-converters: Different types, quantization errors, comparators, resolution. Termination of wires: different techniques, high frequency systems, reflection. Noise: Different types, spectral density, noise bandwidth, models and metrics of noise, noise in devices. Distortion: Quantization, aliasing, bandwidth, and harmonic distortion.

Course literature:

For the first lectures material will be distributed and in addition, the literature will be given on the course homepage before start.

Examination:

A written examination	4,5 ECTS
Laboratory work	1,5 ECTS

Written exam (TEN1) During the lectures five quizzes will be handed out. The answers will be returned during the same lecture. Out of five quizzes one can maximally obtain three points. These points can be accounted for in the written exam. The written exams contains of five exercises totalling 25 points. With correct quizzes, the student can obtain a total of 28 points. The grading is: 10p: 3, 15p: 4, 20p: 5.

A brief history of time 1

Course has been around since the 1980's

- Constantly evolving (you are the guinea pigs)

New for this year

- Updated lessons material
- Established quizzes in studiehandboken
- Back to transmission line theory
- More oriented towards PCB-related issues

Analog design, advanced course

J Jacob Wikner (Lectures, Lesson, Labs, Miniproject)

Ph.D. Linköping University, 2001
Ericsson, Infineon, Sicon, Anacatum, Cognicatus, IVP, LiU

Mohammed Reza Sadeghifar (Lessons ANDA)

Ph.D. student
Master Science, LiU

What is "analog" (bar voltage/current)?

A large amount of trade-offs

Design targets not as "orthogonal" as in digital design.

There are no good tools to support these trade-offs

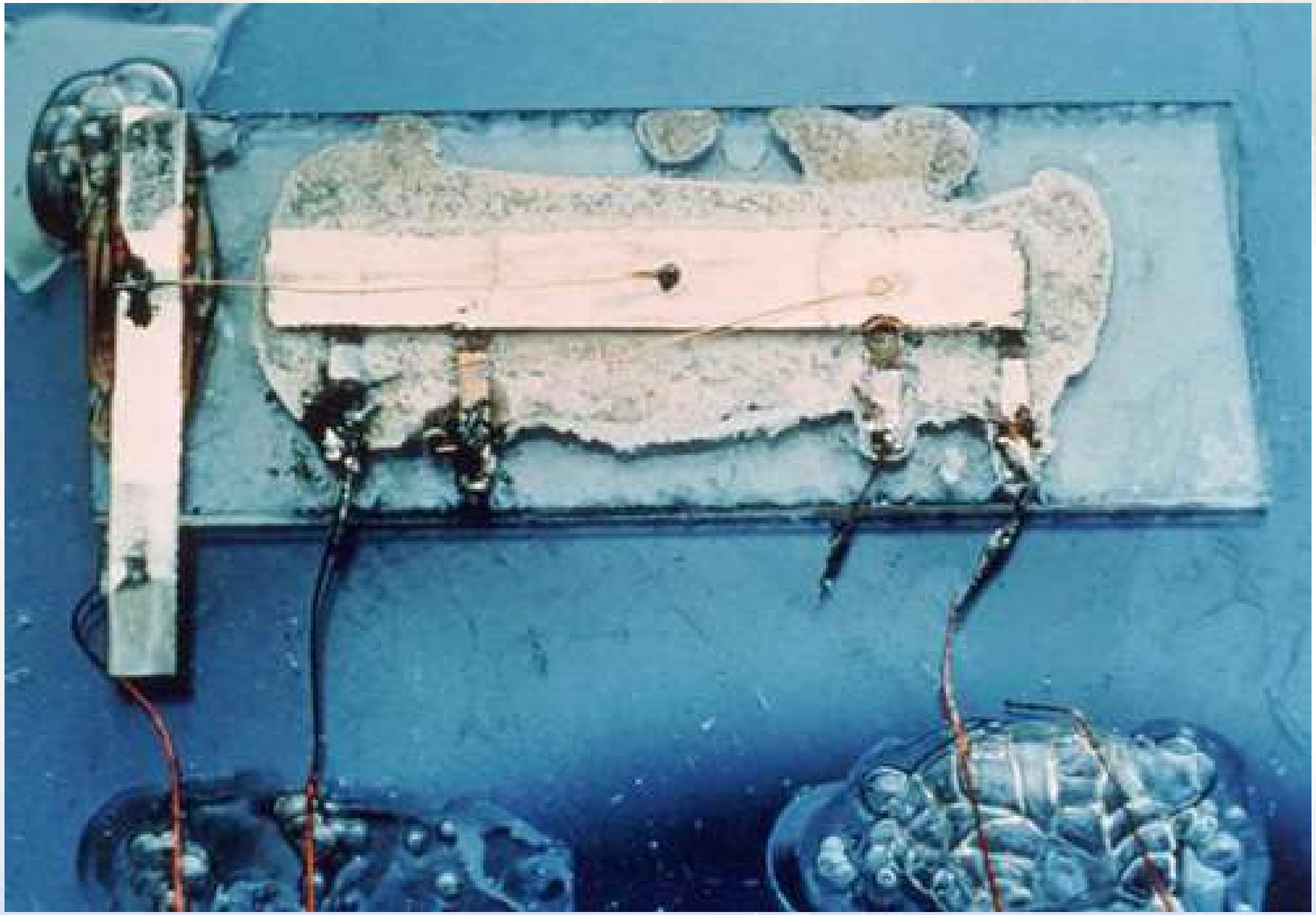
There is no automated synthesis (c.f., the systemC/RTL-to-FPGA flow)

There is no direct porting between new processes and geometries

Plenty of guru knowledge required

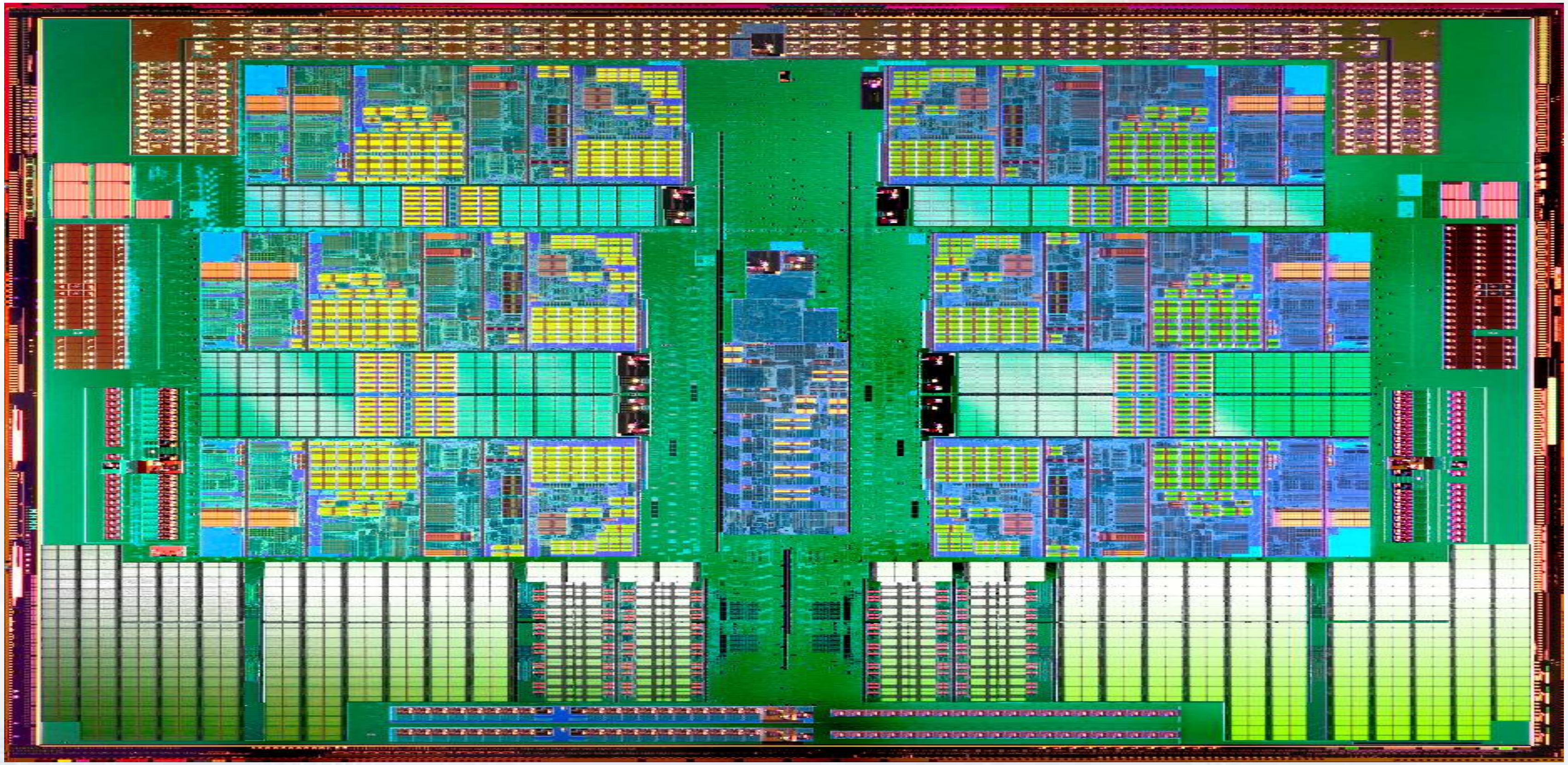
What is an integrated circuit? @1947

What is an integrated circuit? @1959



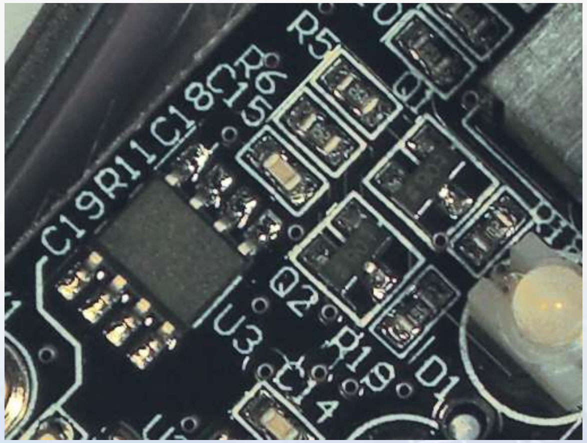
Courtesy of Texas Instruments

What is an integrated circuit? @2010



Courtesy of Advanced Micro Devices, Inc. (AMD) (Stretched picture)

What is a board-level system?



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What is an integrated circuit? @future

"Everything" will integrate into one single chip

- Mixed-signal
- RF
- Digital
- Analog
- Memories
- Communication

http://en.wikipedia.org/wiki/GNU_Free_Documentation_License

A brief history of time 2

Compare with Moore's law

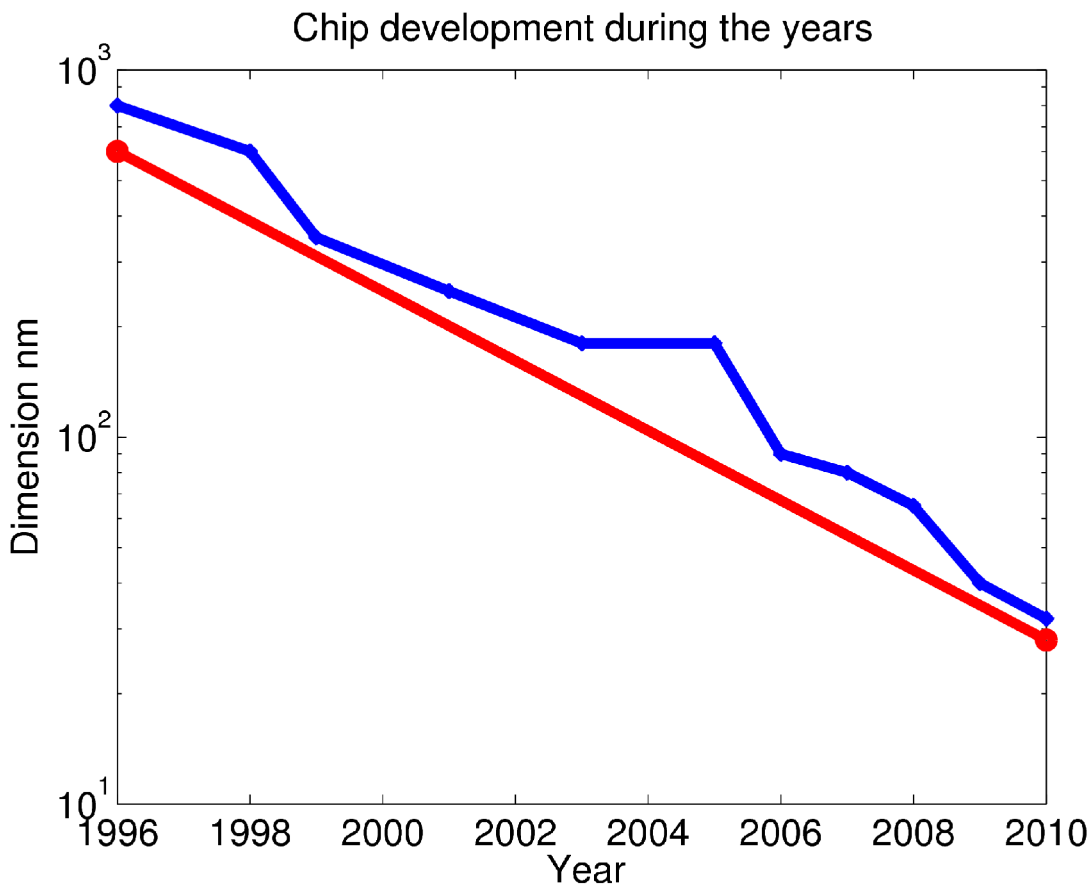
Every blah-blah month, the complexity doubles

Does analog scale?

With lower geometries, does analog become better - or worse?

What's the main limitation?

Cost? Physics? Law-of-nature?



A brief history of time ...

Course elements

Lessons follow lectures

Three Laboratories (software)

A set of computer-aided lessons

2 x 2 hours

Exam

Written exam, open-book

Quizzes

Five (best-of-three)

Course outline - Lectures 1

#	TSEI12 ANDA
1	**Introduction, MOS transistors basics and board-level basics.** What does the inside of a CMOS IC look like? Basic building blocks and how do they behave from an analog point of view? What is a PCB? What is the nomenclature? What is the state of the art on this side? What does a resistor look like? Differences between PCB and silicon?
2	**Analog circuits 1. Amplifiers, phase margin and stability.** We start with the most basic circuits, such as single-stage amplifiers and work our way upwards. Why is in stability a problem and how to mitigate those problems.
3	**Analog circuits 2. More amplifiers of different kinds.** In some applications, high-speed amplifiers, or high-gain amplifiers are required and how do we design them? What to look for in data sheets when assembling.

Course outline - Lectures 2

#	TSEI12 ANDA
4	**Noise and performance measures.** How accurate is "accurate"? For any system and given global specification we have to break it down into the subcomponents of our board/chip. We need to understand what cost measures to apply. We consider terms as SFDR, SNDR, INL/DNL, etc. In many applications, signal levels and required resolution are very demanding. We need to design for low-noise and wide bandwidth. How do we calculate the noise in our signal chain? How can we decouple to further reduce noise?
5	**PCB vs. Silicon characteristics.** Even a small board becomes big when the clock frequencies are high. Any metal strip will have a certain delay and reflections in the interconnections will also hurt the signal. How do we cope with this on a PCB? How can we prepare our circuits for these environments? What kind of tools do we have? Termination methods such as parallel- or serial termination, etc.

Course outline - Lectures 3

#	TSEI12 ANDA
6	**Filters and data converters** To condition our signals we need filters - what types? How should supply decoupling capacitors be selected? How many, etc.? In the digital-to-analog interface we need data converters. How do we adjust voltage levels, etc., to align the digital with the analog interface?
7	**Timing, Clocking 1** In a mixed-signal domain, how do we clock our devices and how do we minimize the noise from the digital domain into the analog domain? Should we share ground? Have one ground plane? How is the switching noise from the clock fed into the analog domain? Return currents. Analog differential signalling. How do we signal between different ICs, what standards are there? TTL, ECL, CML, CMOS, LVDS, etc.

Course outline - Lectures 4

#	TSEI12 ANDA
8	**Other aspects. Summary** Advanced clocking - PLL and DLL, asynchronous protocols. ESD. Q & A. Summary
A	**Invited lecture 1** (if time and schedule permits)
B	**Invted lecture 2** (if time and schedule permits)

Laboratory

Three software labs (compulsory attendance)

- CMOS amplifiers (including introduction to the Cadence environment)
- Decoupling capacitors
- Termination and transmission lines

Computer-aided lessons (towards the end of the course)

- Solving problems together with the computer

Exam

Open-book exam

!!!

All material can be brought to the exam

No calculators

Five exercises á five points

Be strategic

Pick your exercises

Quizzes

Five random questions distributed

- One point on each
- Maximum three points that can be accounted for in the exam
- Valid for three exam occasions (March, June, August)
- You will get instant feedback

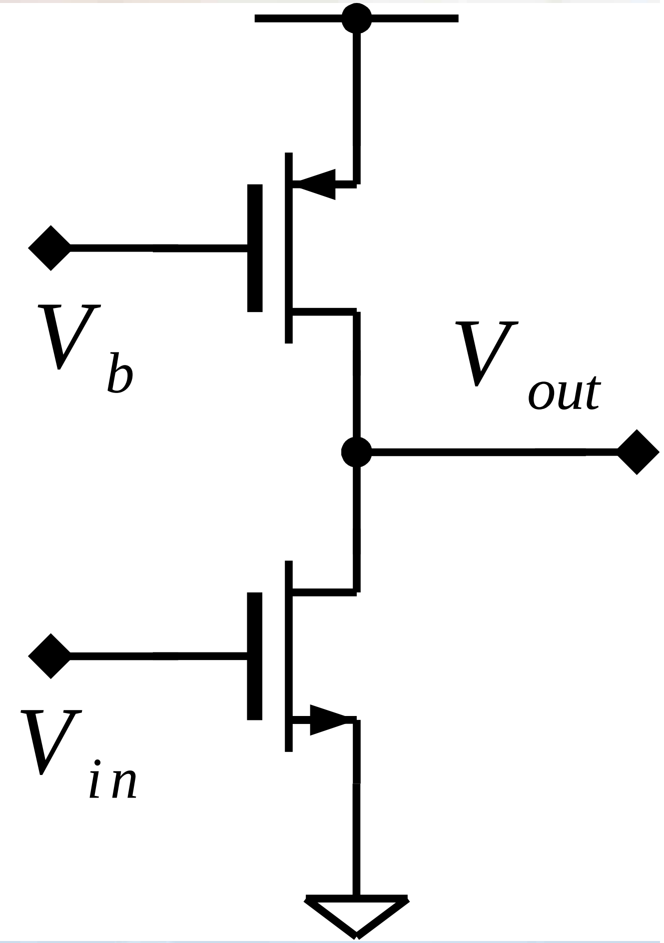
Quiz example

In a common-source amplifier, to minimize the output-referred noise, how should you design the transconductance of the active load?

1) To be as high as possible

2) To be as low as possible

3) The active load does not add noise to the output



Books

High Speed Digital Design: A Handbook of Black Magic, Johnsson and Graham

Analog Integrated Circuit Design, Johns and Martin

Signal and Power Integrity - Simplified, Bogatin

Distributed material

Web resources

... and you need to do some of your own research

Why analog design?

Interface to the real world is analog.

SOC, integration of several different components on one piece of silicon and one board

Always: go to digital as soon as possible

Data converters are your interfaces - and who designs them?

Always: go to integrated solutions as soon as possible

Much larger variety of options, even analog is programmable

Where could this lead?

Linköping master thesis at the CES 2012 (Las Vegas)

Fingerprints strikes a deal with Tier 1

Signal Processing Devices AB

AnaCatum Design AB

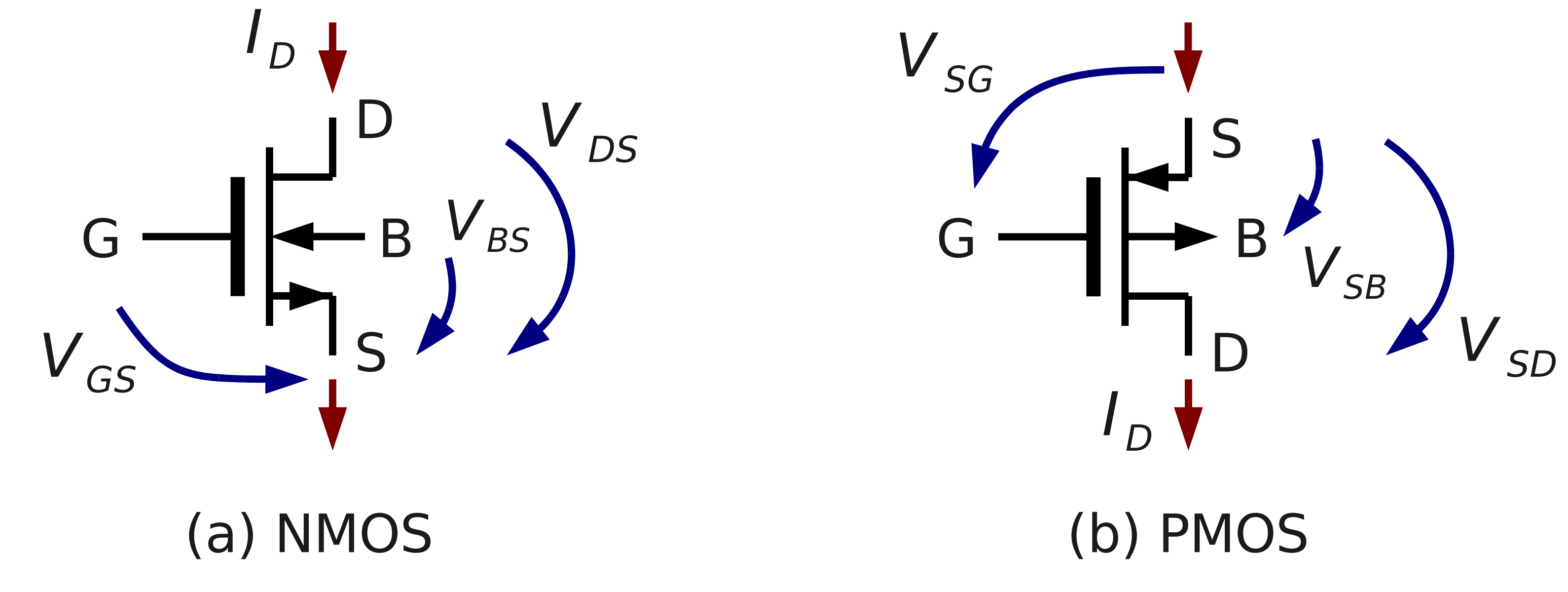
... and more ...

Zzzzzzz, zzzz - get to the point!

MOS transistor

I hate semiconductor physics ...

for me, it is about a couple of symbols and formulas related to them



The physical aspects

"Planar" technology

Operations

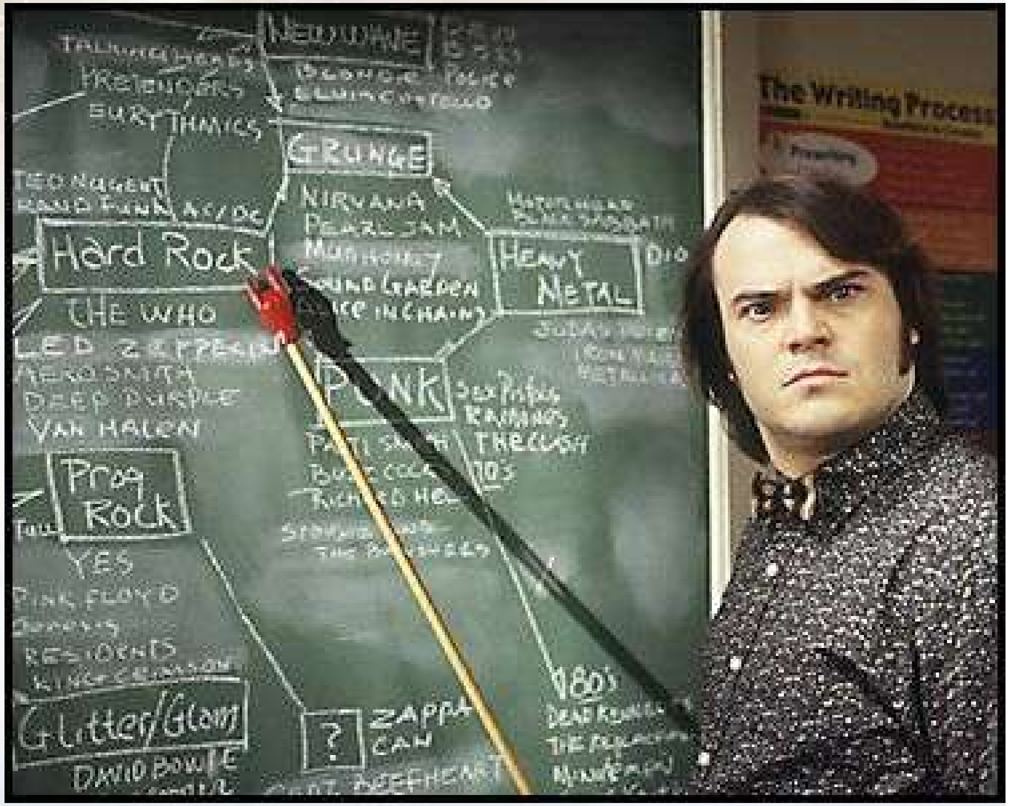
Saturation

Linear

Off

Capacitive effects

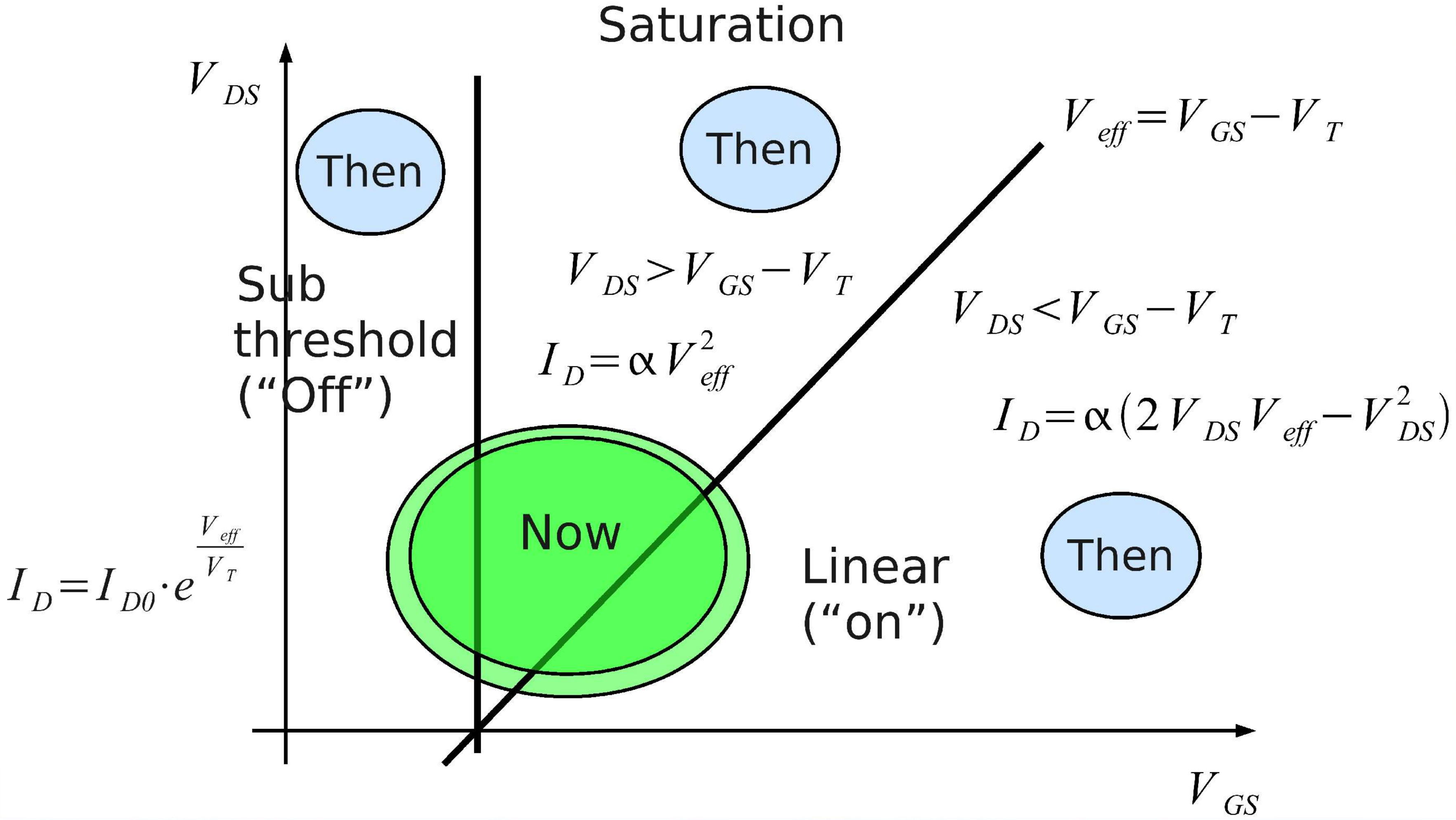
etc, etc



The regions

Subthreshold (cut-off)	Linear (low gain)	Saturation (high gain)
$I \approx 0$	$I \approx \alpha \cdot \left(2 V_{eff} V_{ds} - V_{ds}^2 \right)$	$I \approx \alpha V_{eff}^2$
$V_{eff} < 0$	$V_{eff} > 0$, $V_{ds} < V_{eff}$	$V_{eff} > 0$, $V_{ds} > V_{eff}$

The regions, cont'd



The second-order effects

Subthreshold

$$I \approx I_{D0} \cdot e^{\frac{V_{eff}}{kT/q}}$$

Linear

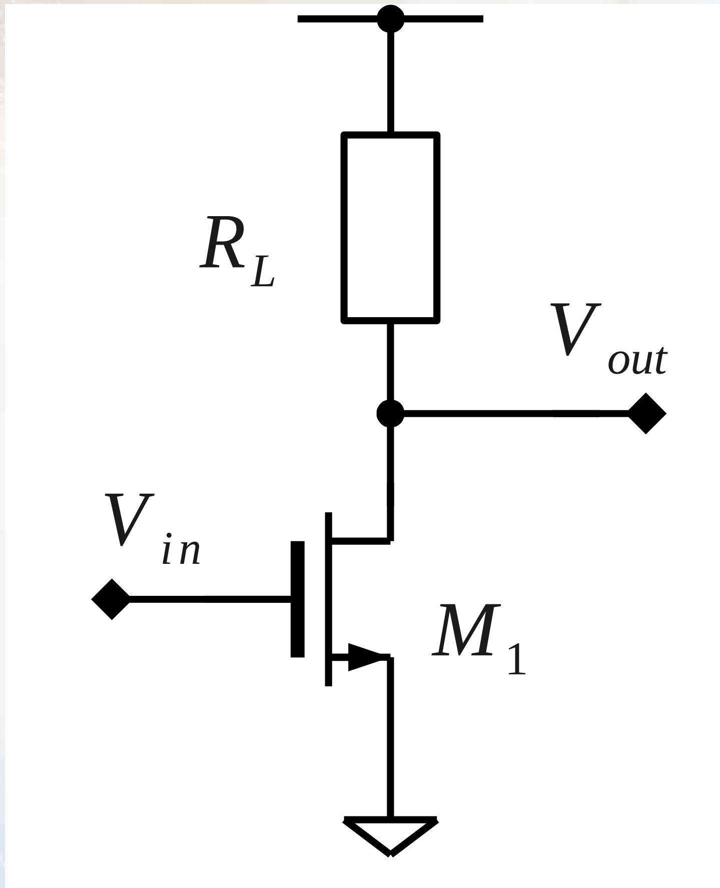
$$I \approx \alpha \cdot \left(2 V_{eff} V_{ds} - V_{ds}^2 \right)$$

Saturation

$$I \approx \alpha V_{eff}^2 \cdot \left(1 + \frac{V_{ds}}{V_\theta} \right)$$

$$V_T = V_{T0} + \gamma \cdot \left(\sqrt{2\Phi_F - V_{BS}} - \sqrt{2\Phi_F} \right), \quad V_\theta = 1/\lambda$$

The first amplifier



A common-source amplifier

$$v_{out} = V_{DD} - R_L \cdot I_D$$

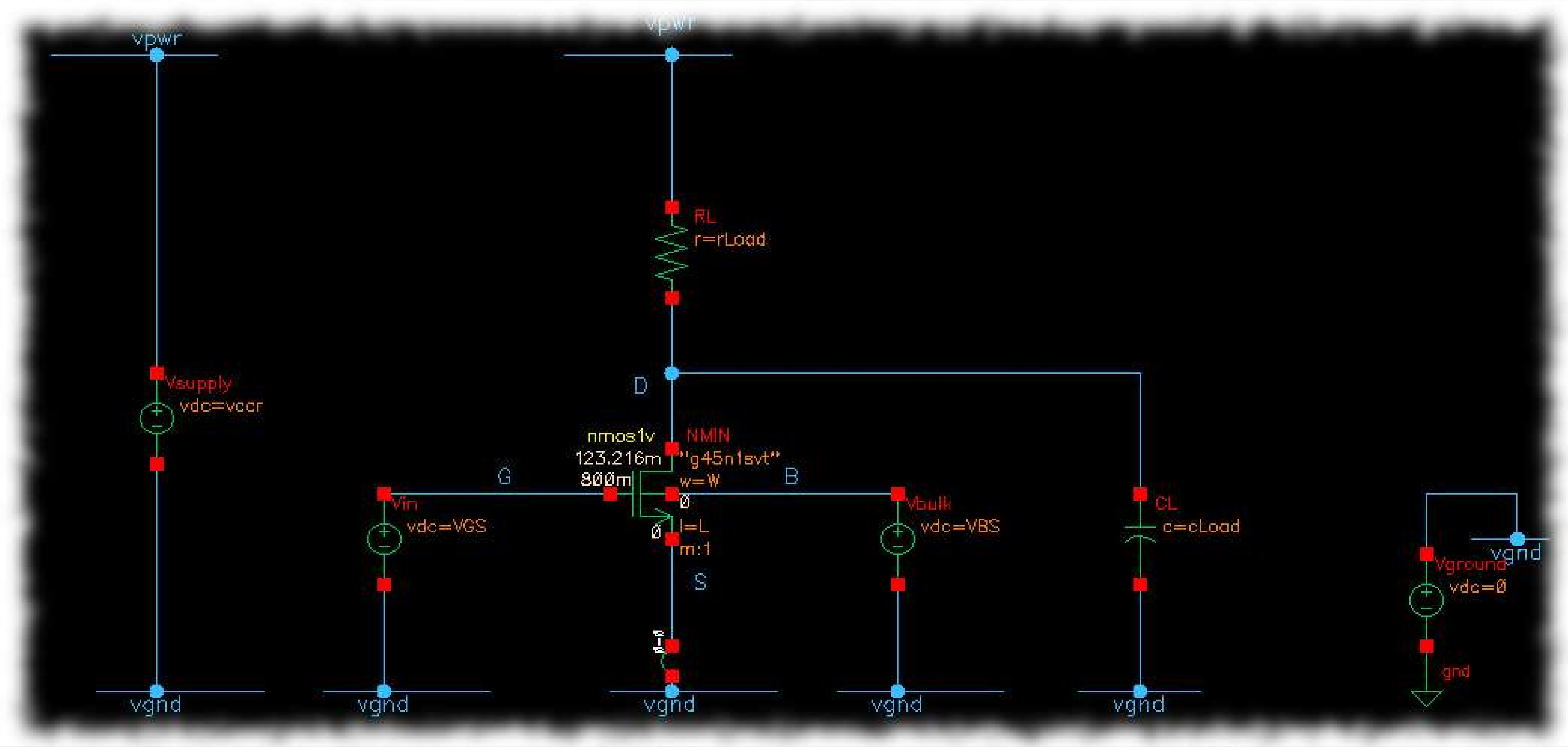
Saturation region

$$v_{out} = V_{DD} - R_L \cdot \alpha \cdot \% v_{eff}^2$$

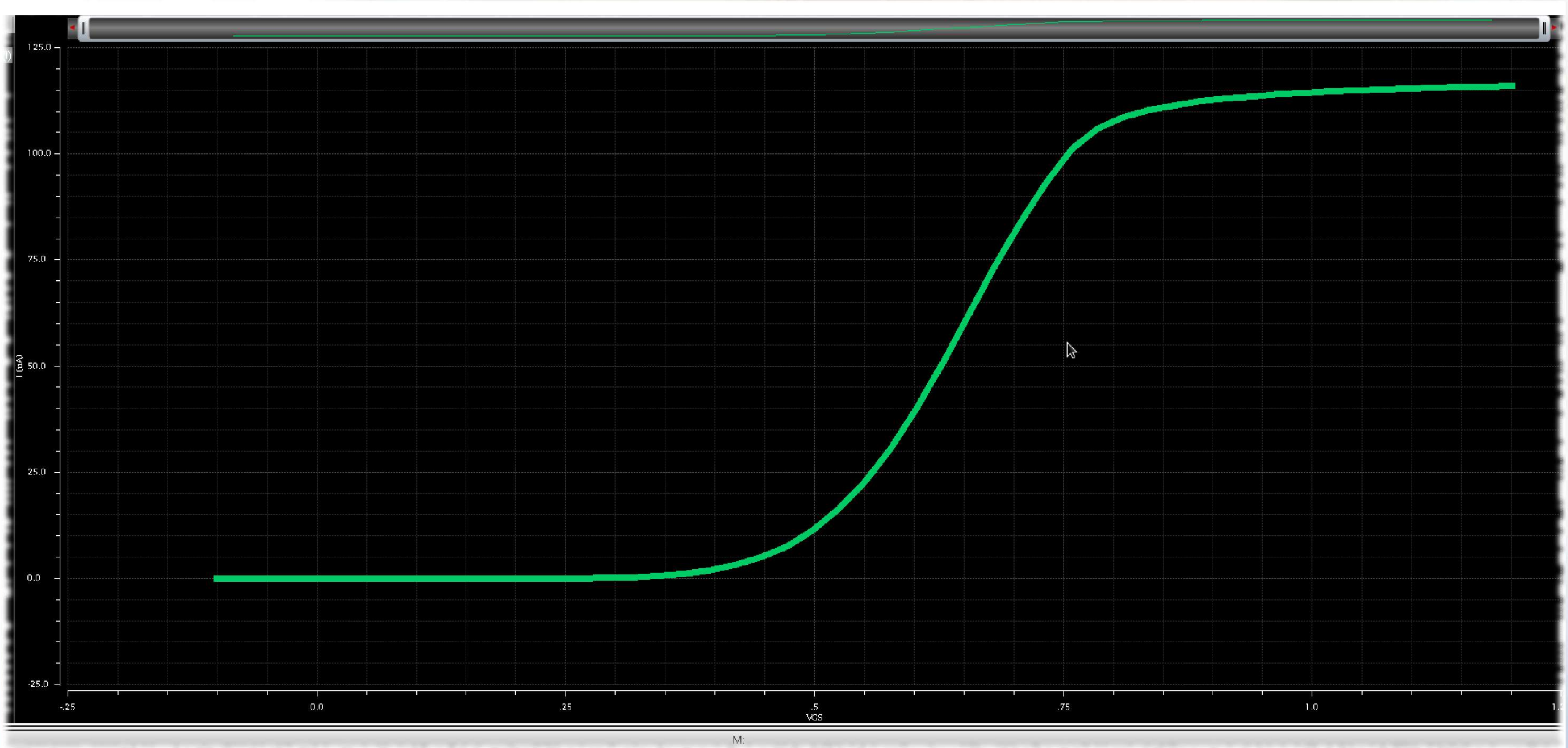
Linear region

$$v_{out} = V_{DD} - R_L \cdot \alpha \cdot \left(2 v_{out} \% v_{eff} - v_{out}^2 \right)$$

A simple testbench



Simulation results, drain current



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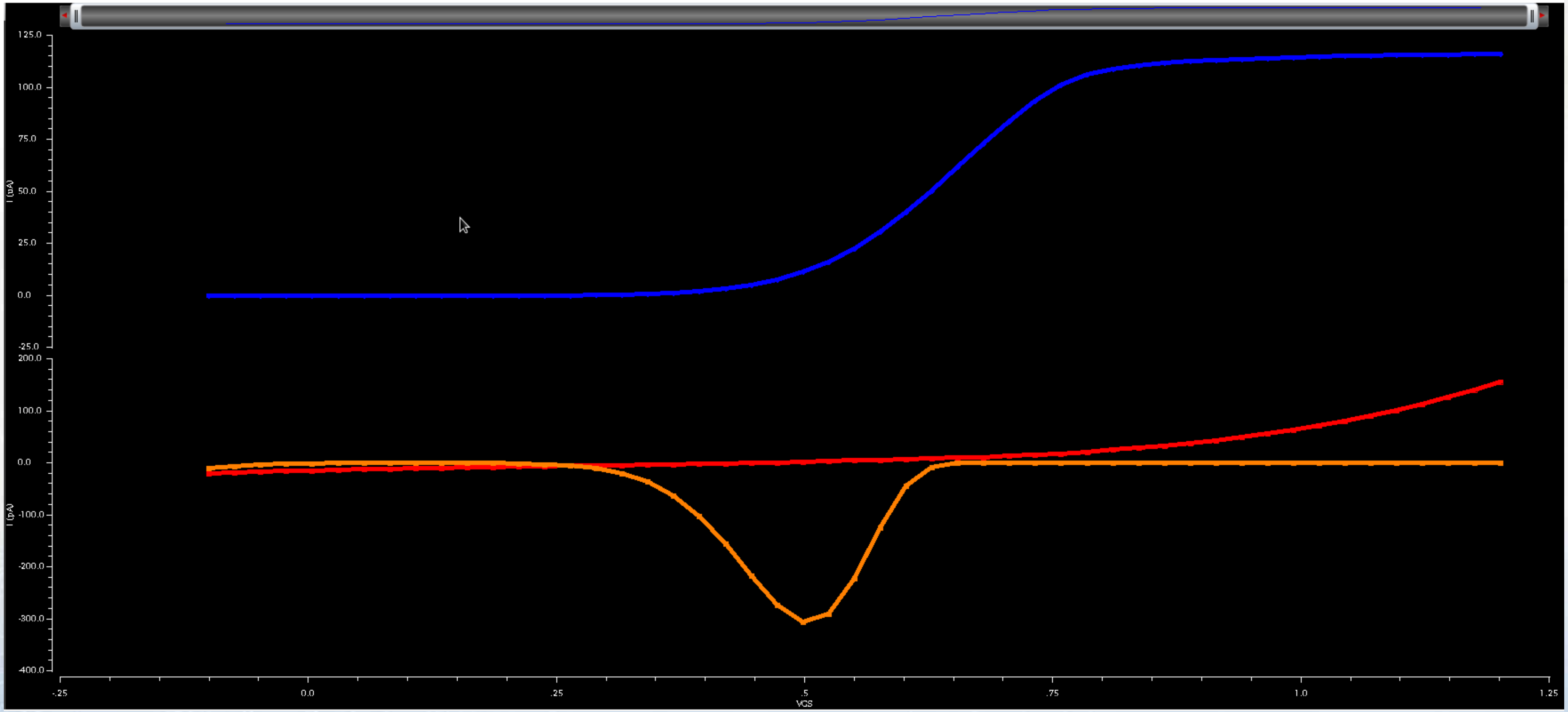
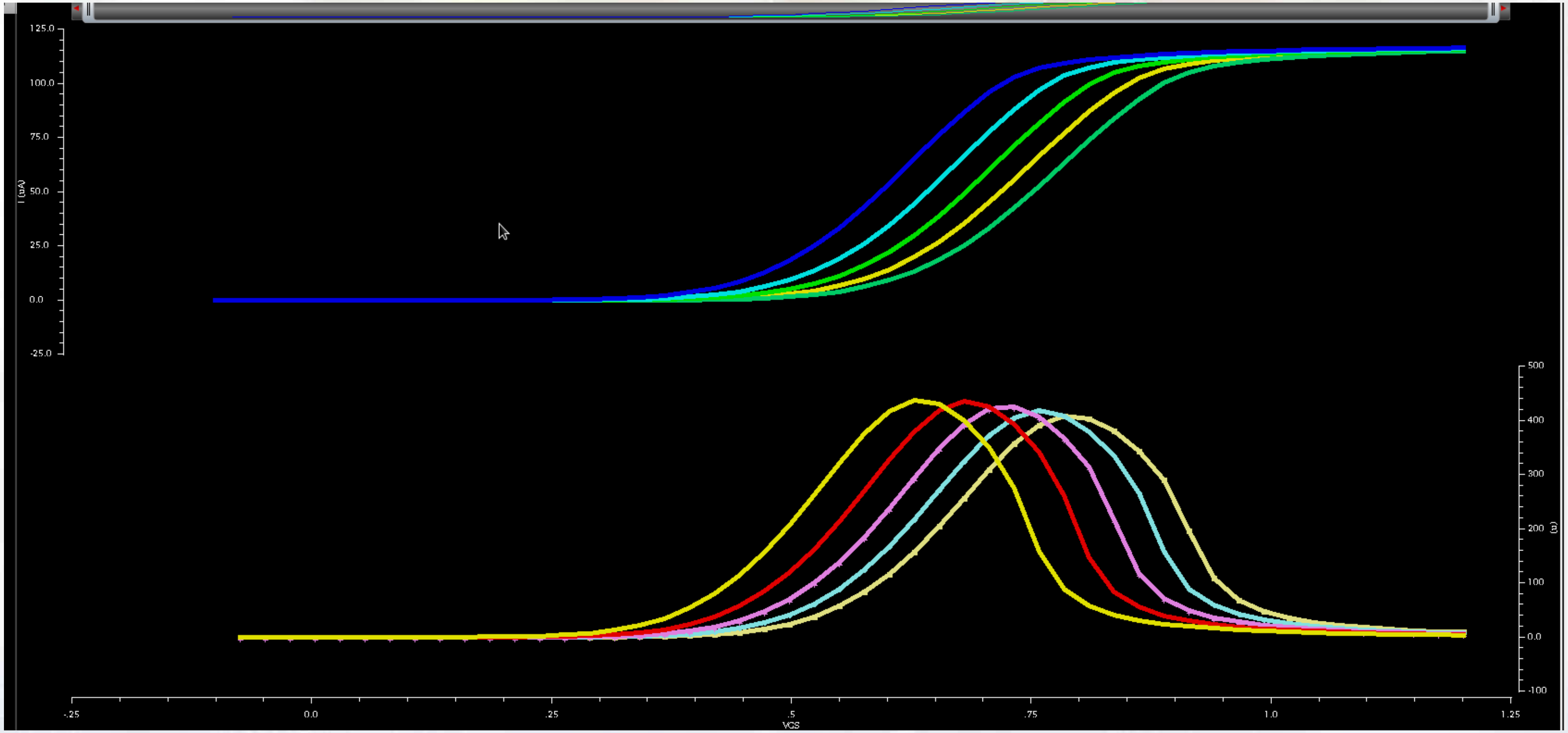
The second order effects



The second-order effects, cont'd



The derivative (lower graph) is the DC gain. The peak is reduced.

Board activities ...

The large-signal scenario

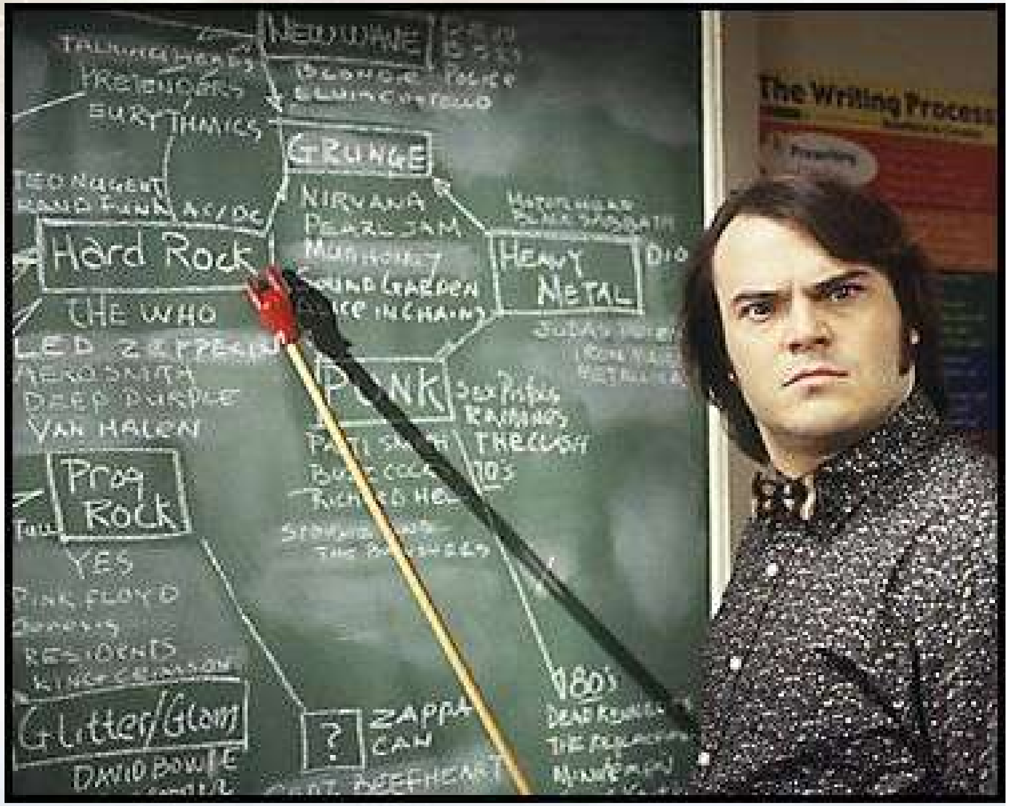
Continued

The small-signal scenario

(Next lecture)

Design centering

Operating point



What did we do today?

Introduction to the course

- Labs, quizzes, exam, etc.

The transistor

- Operating regions
- Functionality

First amplifier and parameters

- A starting point for the lessons

What will we do next time?

Small-signal schematics

Linearization

Further work on the analog building blocks

Common-source, common-drain, common-gate, etc.

Stability and why