What will we do next time?

- Amplifiers and differential pairs
  - Why differential?
- Stability
  - Why stability?
  - Phase margin
  - Compensation

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Lecture 1, ANIK

Introduction, CMOS

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Analog integrated circuits

Abbreviated as ANIK (from Swedish)

- What is analog?

- What is integrated circuits?

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Analog integrated circuits

WWW:	http://www.es.isy.liu.se/courses/ANIK
WP:	http://mixedsignal.wordpress.com
FB:	http://www.facebook.com/mixedsignal
Twitter:	@jjwikner

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Analog integrated circuits

Aim:

The purpose is to give basic knowledge in analysis and design of analog and discrete-time integrated circuits integrated in CMOS technology.

- to give knowledge about different types of A/D- and D/A-converters.
- to give knowledge about termination of some combinations of wires and load.
- to give knowledge about noise and distortion.

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

- Describe CMOS-transistor in different modes.
- Describe the relationship between different design parameters and performance metrics.
- Analyze CMOS-amplifiers and current mirrors 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.
- Describe different types of A/D- and D/A-converters and their function.
- Describe different methods for terminating wires.
- Describe different types of noise and distortion, and also determine different type of noise- and distortion metrics.

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Analog integrated circuits

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, current mirrors, inverters, 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, transfere functions, determine of output signal, offset errors. A/D-vonverters: Different types, quantization and quantization errors, comparators, resolution. Termination of wires: different tecniques, high frequency systems, reflection. Noise: Different types, spectral density, noise band-width, models and metrics of noise, noise in devices. Distortion: Quantization, aliasing, bandwidth, and harmonic distortion.

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Analog integrated circuits

Course literature:

The following books are used as reference material:
Johns and Martin, Analog Integrated Circuit Design, Johns and Martin, Wiley & Sons, 1997
Gray, et al., Analysis and design of Analog Integrated Circuits, Wiley & Sons, 2008
Allen and Holberg, CMOS Analog Circuit Design, Oxford University Press, 2008
Razavi, Design of Analog CMOS Integrated Circuits, Mc Graw Hill, 2004
Bengt Molin: Analogelektronik, Studentlitteratur 2001 (in Swedish).
Material handed out during the course.

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.

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Analog integrated circuits

- Course has been around since the 1980's
  - Constantly evolving (you are the guinea pigs)
  - Last year, less of a success, hopefully better this year
- New for this year
  - Updated lessons material
  - Established quizzes in studiehandboken
  - No transmission wire theory (only 10 lectures)

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Analog integrated circuits

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

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

- **Niklas U. Andersson** (Lessons ATIK)

  Ph.D. student
  Ericsson, Infineon, Sicon, Anacatum, Acreo, LiU

- **Prakash Harikumar** (Lessons ANIK, Labs, Miniproject)

  Ph.D. student
  B.Sc., Thiruvananthapuram, Kerala, India, M.Sc., LiU

What is analog (bar voltage/current)?

There are a lot of trade-offs

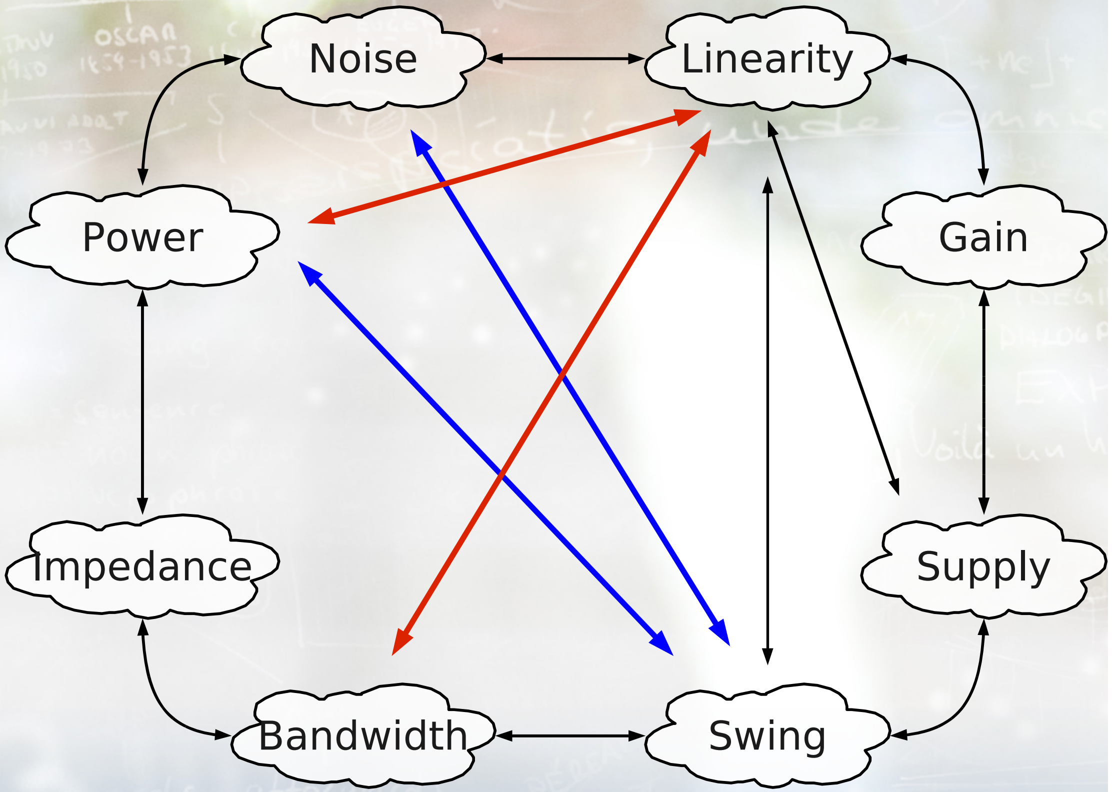
Design targets not as "orthogonal" as in digital design.

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 automated porting between new processes and geometries

A lot of guru knowledge required



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What is an integrated circuit? @1947

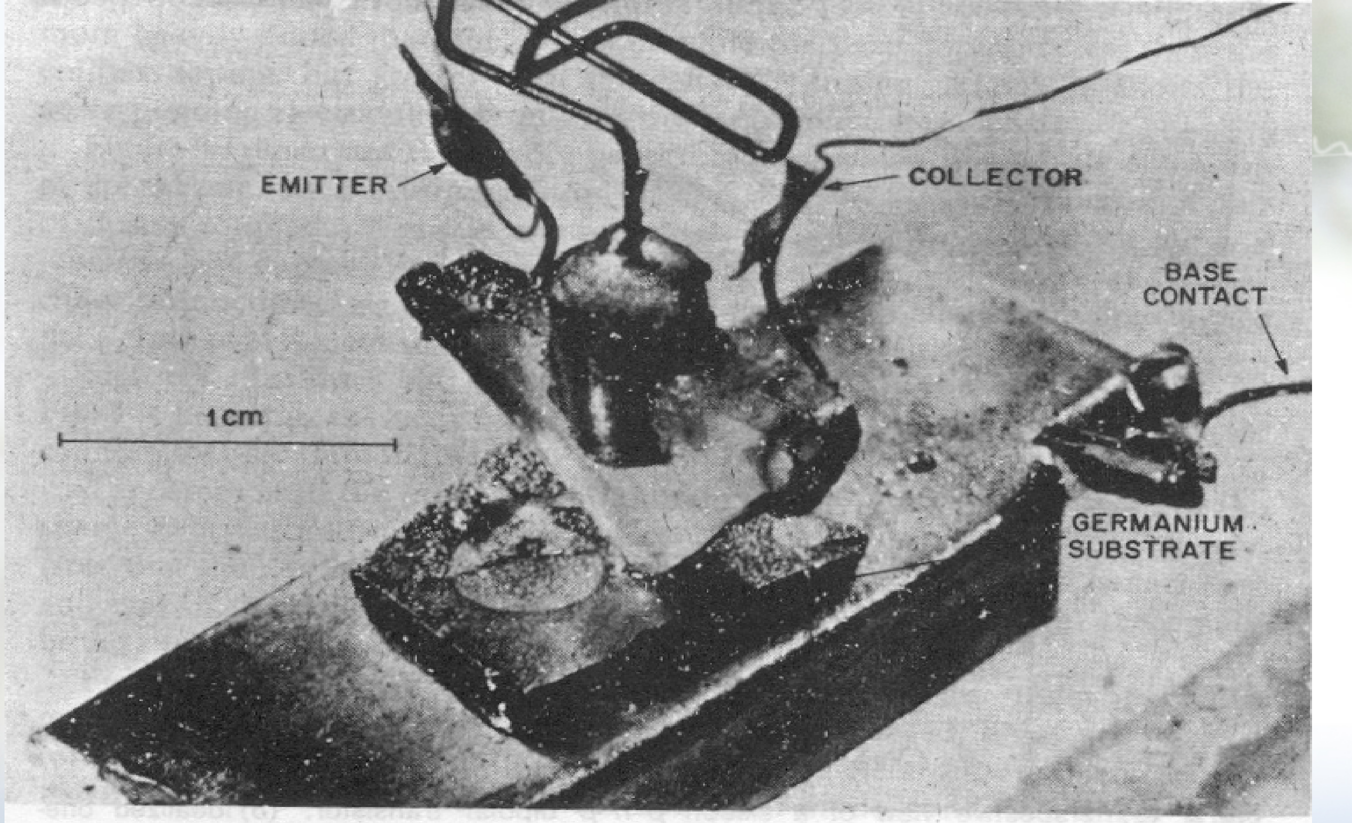

Fig. 1 The first transistor.[1]

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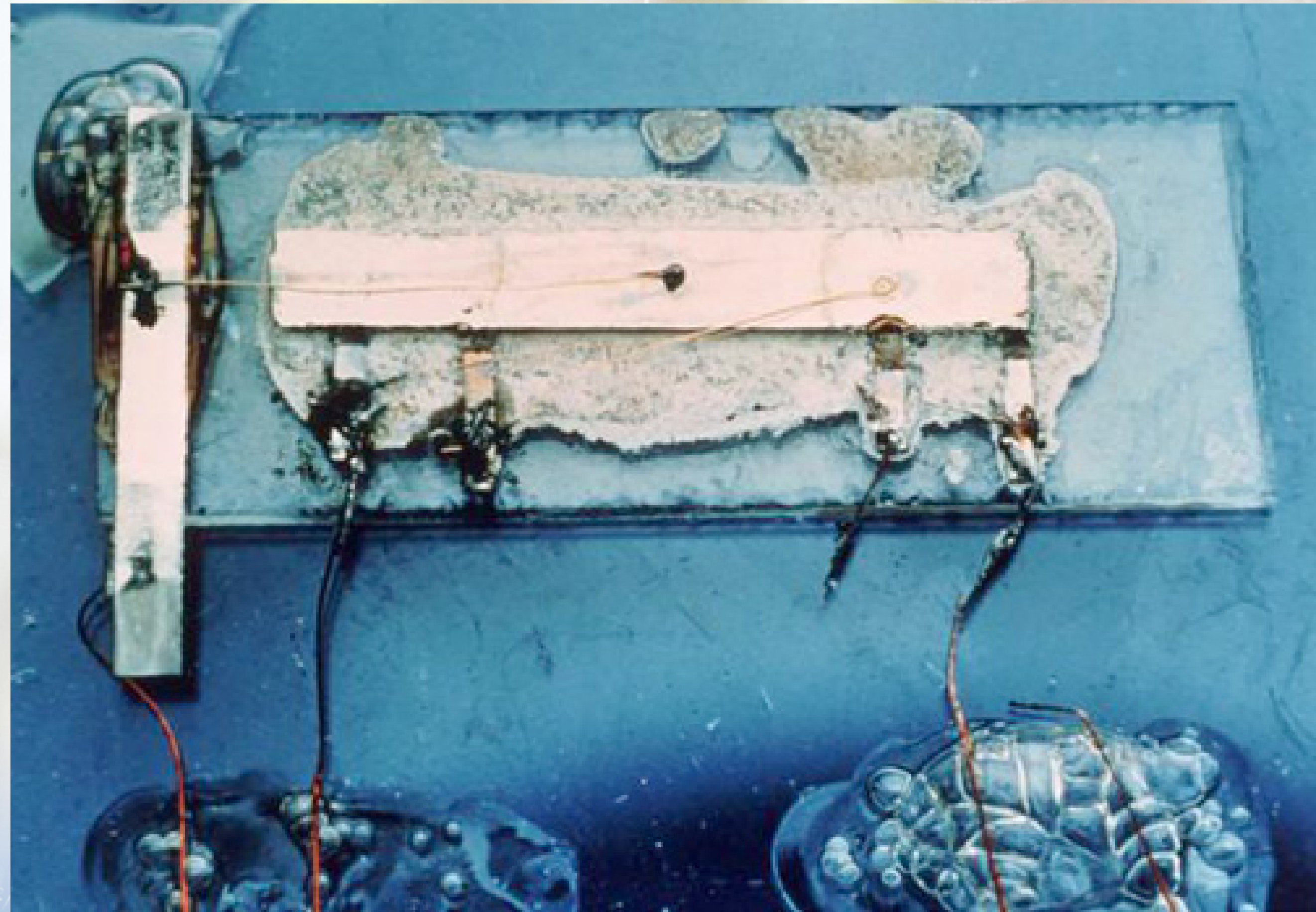
What is an integrated circuit? @1959



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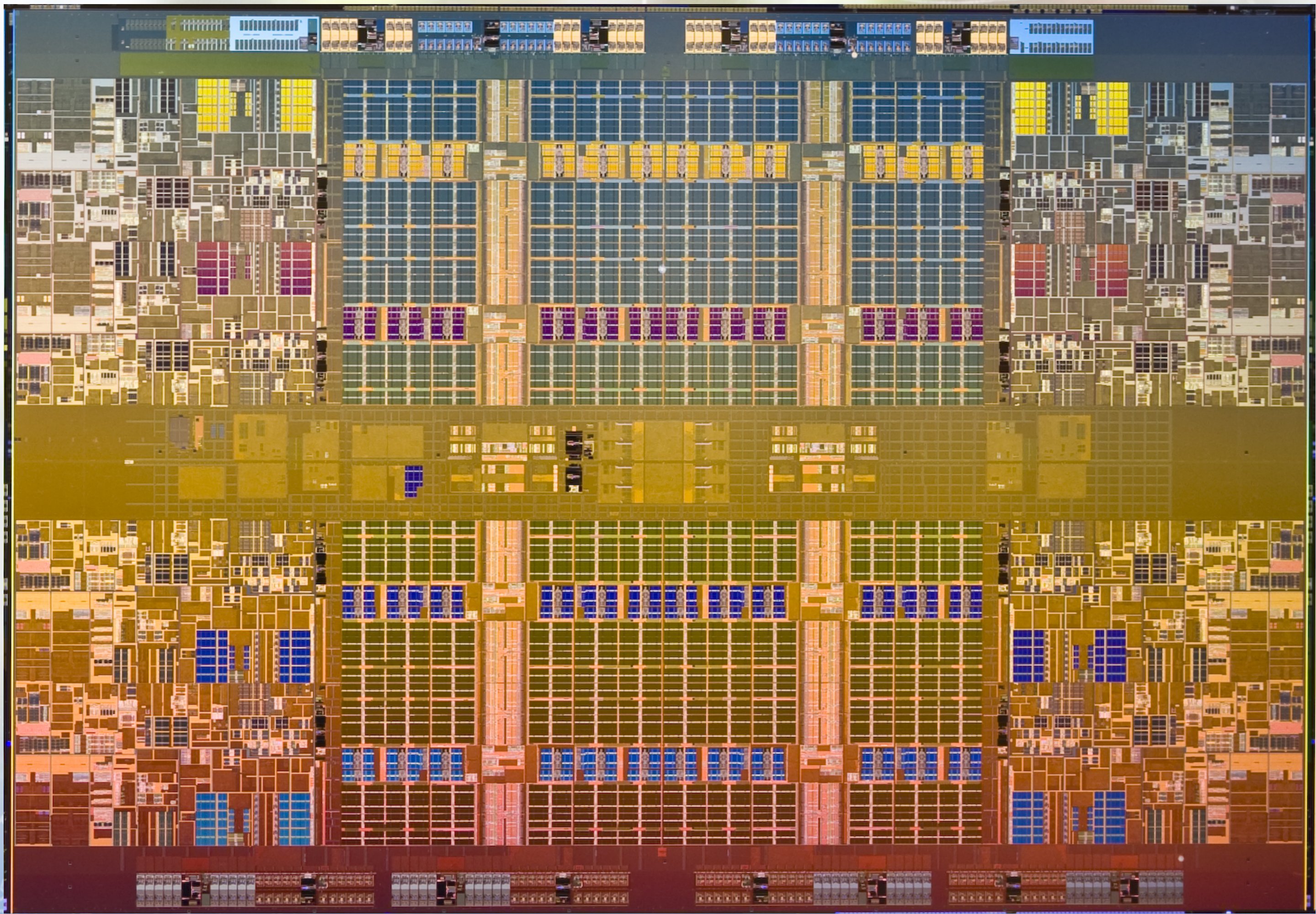
What is an integrated circuit? @2010



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What is an integrated circuit?

- "Everything" will integrate into one single chip
  - Mixed-signal integration
  - RF integration
  - Digital integration
  - Memory integration
  - Communication integration
  - more and more

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A brief history of time

- Compare with Moore's law

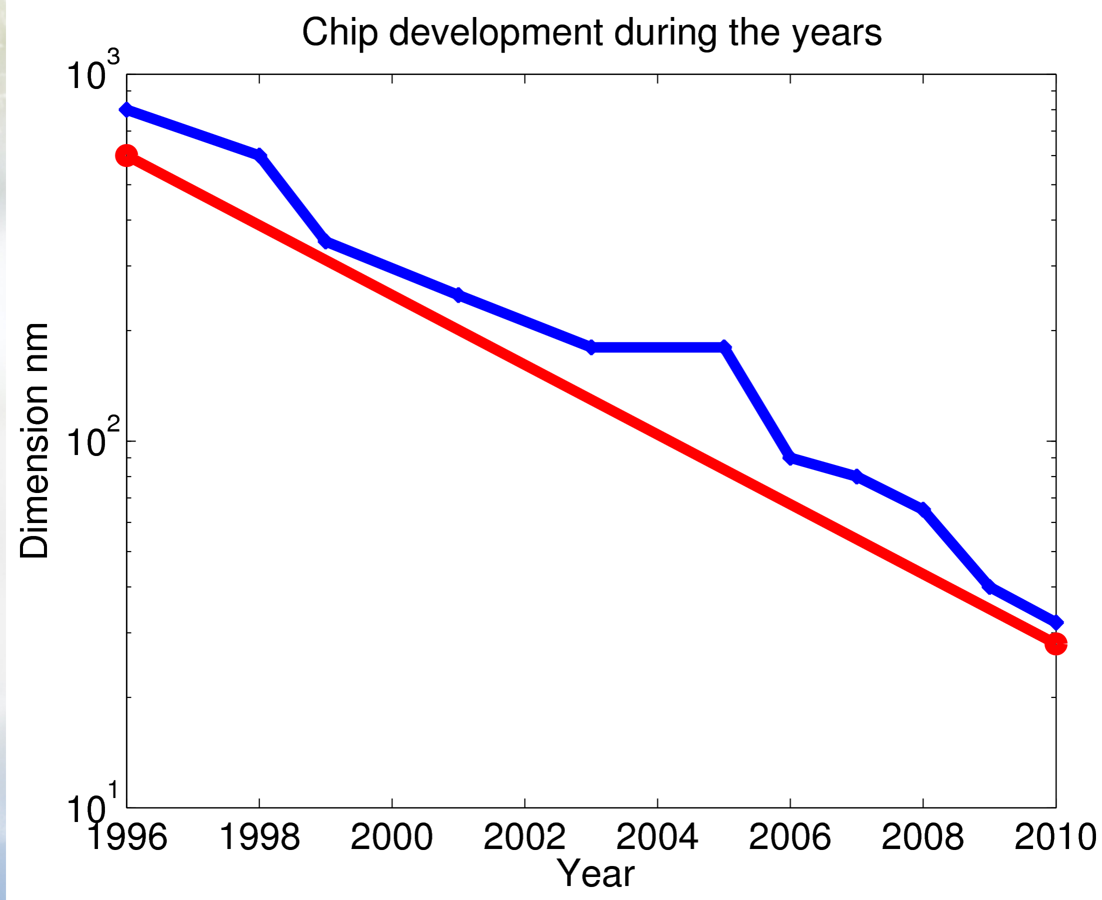
  Every blah-blah month, the complexity doubles

- Does analog scale?

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

- What's the main limitation to development today?

  Cost? Physics? Law-of-nature?



A brief history of time ...

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Course outline

- Lessons follow lectures
  - More or less ...
- Laboratory
  - compulsory for ANIK
  - recommended for ATIK
- Miniproject
  - Wrap-up the labs in a report
- Exam
- Quizzes

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Course outline - Lectures

#	TSTE08 ATIK	TSEI09 ANIK
1	Introduction. Course overview, etc. Analog building blocks 1	Introduction. Course overview, etc. CMOS technology and transistors
2	Analog building blocks 2	Analog building blocks Simple amplifier stages
3	Amplifiers 1 OP, OTA, Stability	Amplifier stages, cont'd
4	Amplifiers 2 Noise	Current mirrors Improved amplifier stages
5	Switched capacitor 1 Basics, Accumulators	Differential gain stages

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#	TSTE08 ATIK	TSEI09 ANIK
6	Switched capacitor 2 S/H, Nonideal effects Continuous-time filters 1	Operational amplifiers 1
7	Continuous-time filters 2 Discrete-time filters	Operational amplifiers 2
8	Data converters 1 ADC and DAC basics	Noise and distortion
9	Data converters 2 Interpolating converters Sigma-delta converters	Data converters DACs
10	Data converters Case study (optional) Wrap-up	Data converters ADCs Wrap-up

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Laboratory and miniproject

- Cadence 6
- Daisy flow
- ANIK lab manual well established

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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

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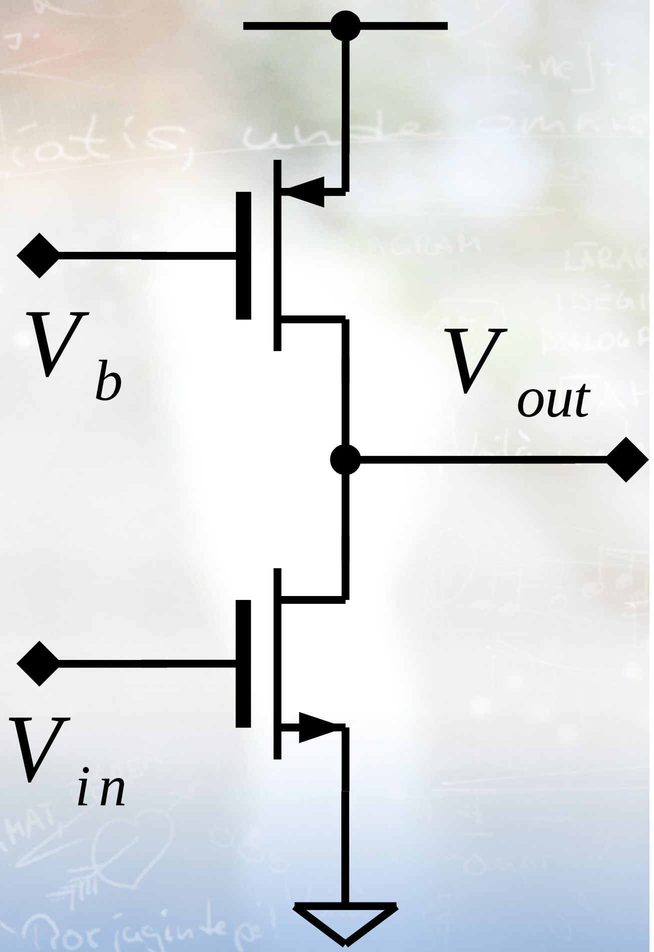
Quiz example

- 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

- **Analog Integrated Circuit Design**, Johns and Martin
- **Analysis and design of Analog Integrated Circuits**, Gray,

  Hurst, Lewis, Meyer
- **CMOS Analog Circuit Design**, Allen and Holberg
- **Design of Analog CMOS Integrated Circuits**, Razavi
- **Analog Design Essentials**, Willy Sansen

"Conclusions": Why analog design?

- Except for the fact that an analog designer gets much more paid?
- **Interface** to the real world is analog.
- Today it is a lot about SOC, **integration** of several different components on one piece of silicon.
- **Always: go to digital as soon as possible**

  Then the data converters are your interfaces - and who designs them?

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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 ...

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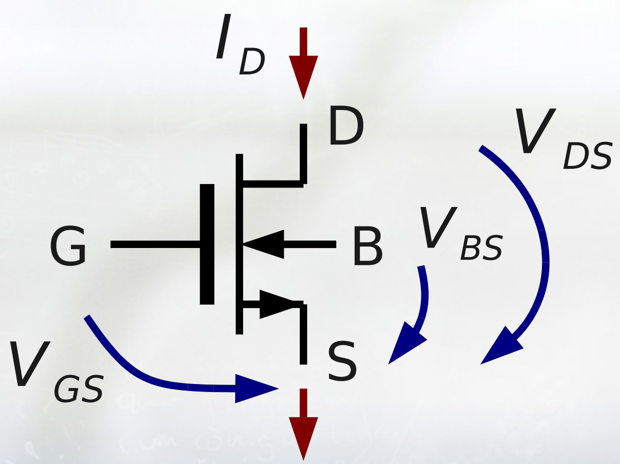
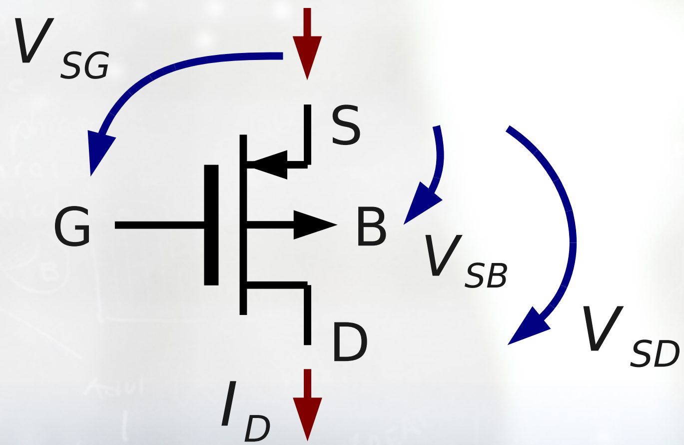
MOS transistor

- **I hate semiconductor physics ...**

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



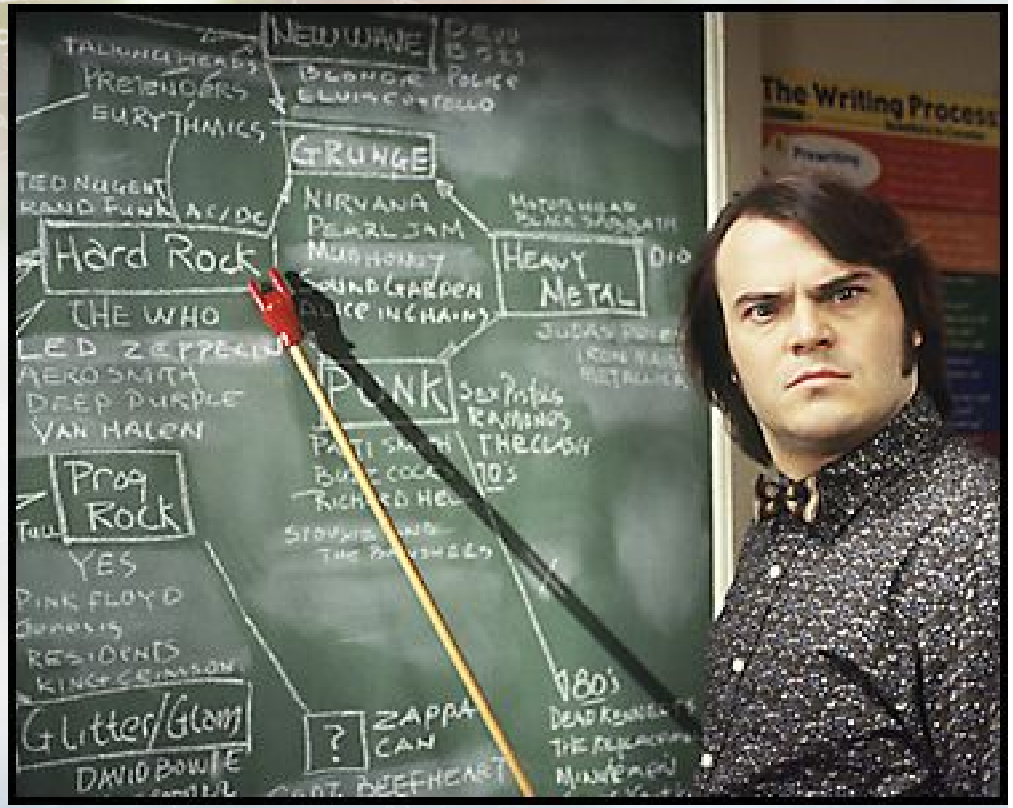
(a) NMOS



(b) PMOS

The physical aspects

- "Planar" technology
- Doping
- Operation
- Saturation
- Linear
- Off
- Capacitive effects
- etc, etc



The regions

Subthreshold (cut-off)

$$I \approx 0$$

$$V_{eff} < 0$$

Linear (low gain)

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

$$V_{eff} > 0, \quad V_{ds} < V_{eff}$$

Saturation (high gain)

$$I \approx \alpha V_{eff}^2$$

$$V_{eff} > 0, \quad V_{ds} > V_{eff}$$

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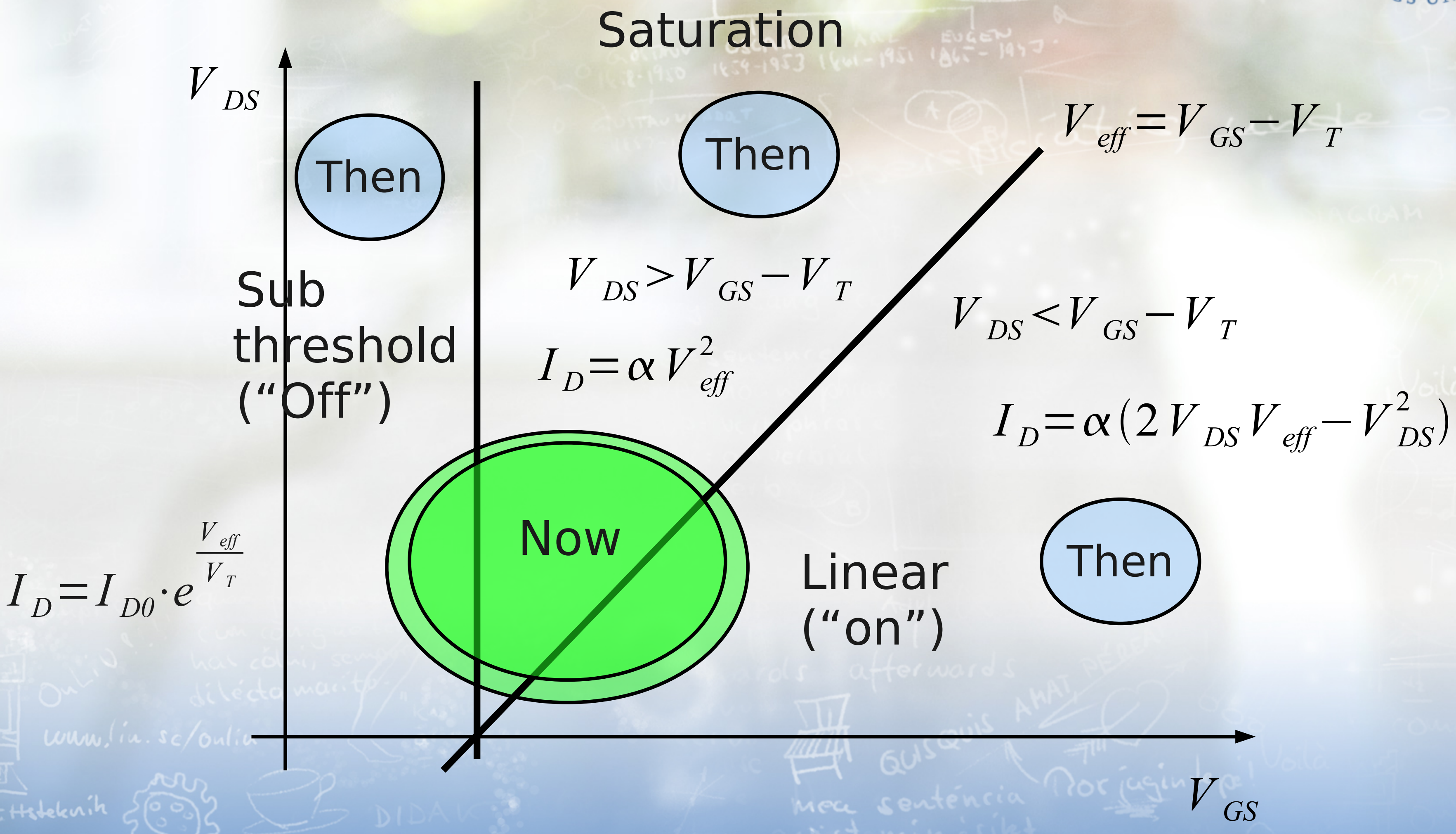
The regions, cont'd



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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

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

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

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The first amplifier

- A common-source amplifier

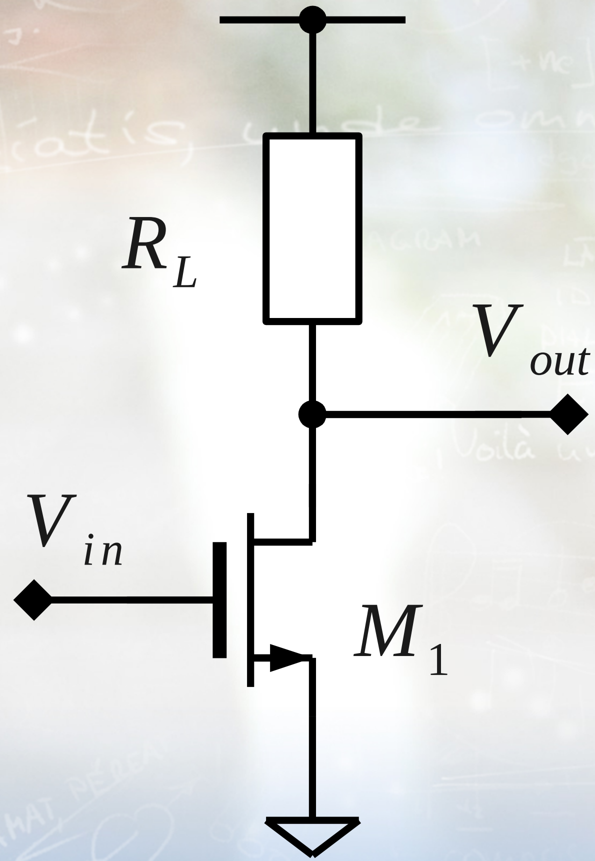
$$v_{out} = V_{DD} - R_L \cdot I_D$$

- Saturation region

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

- Linear region

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



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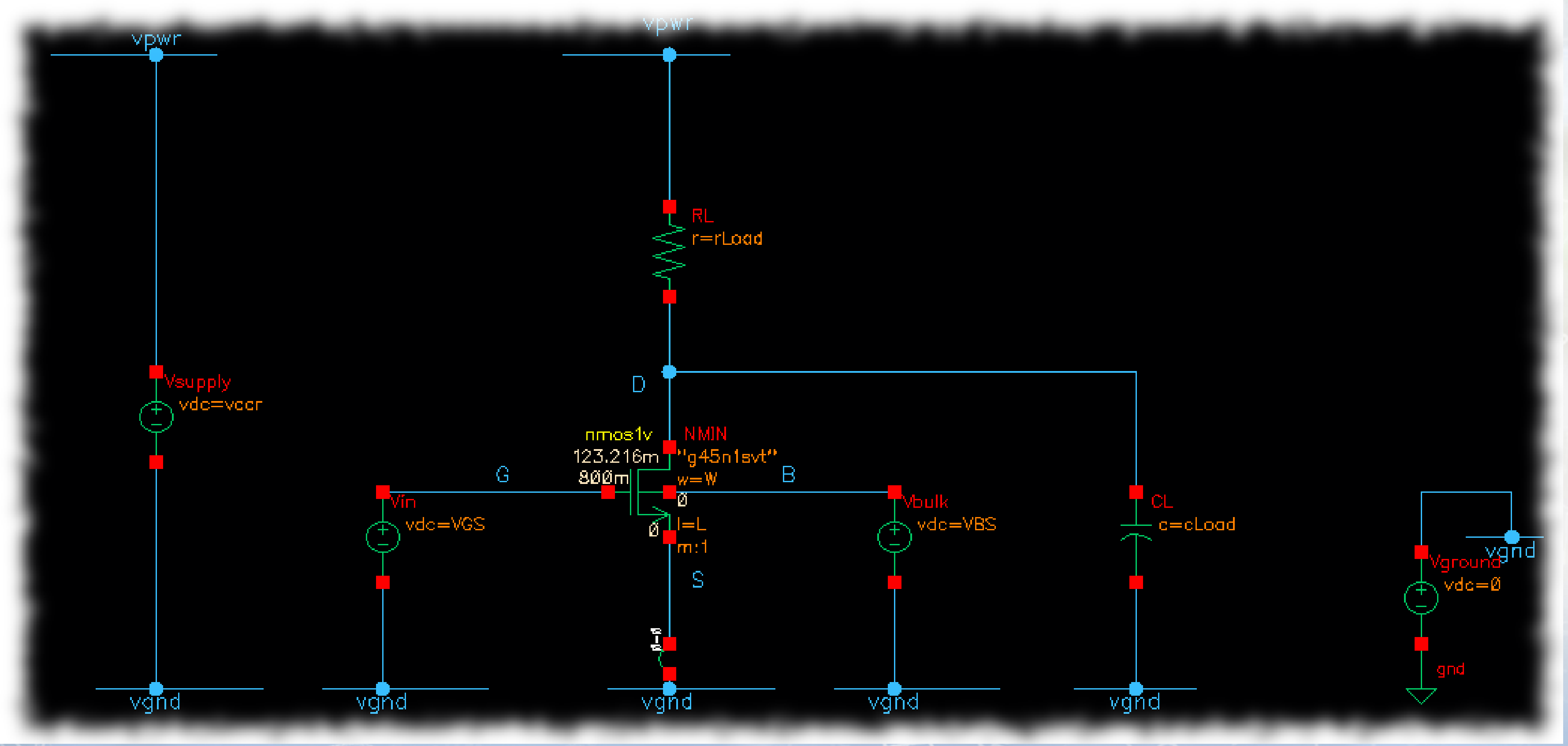
A simple testbench



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Simulation results, drain current

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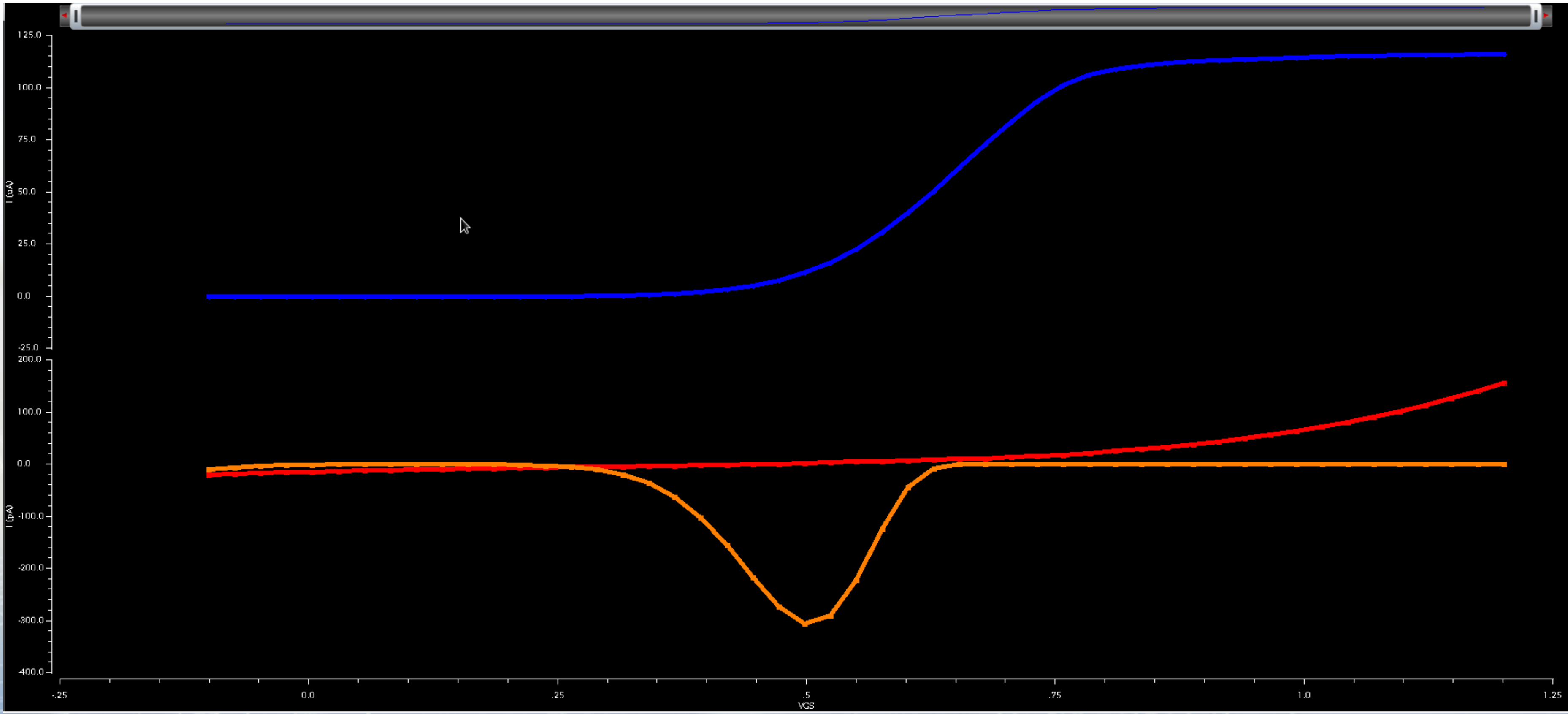
The second order effects



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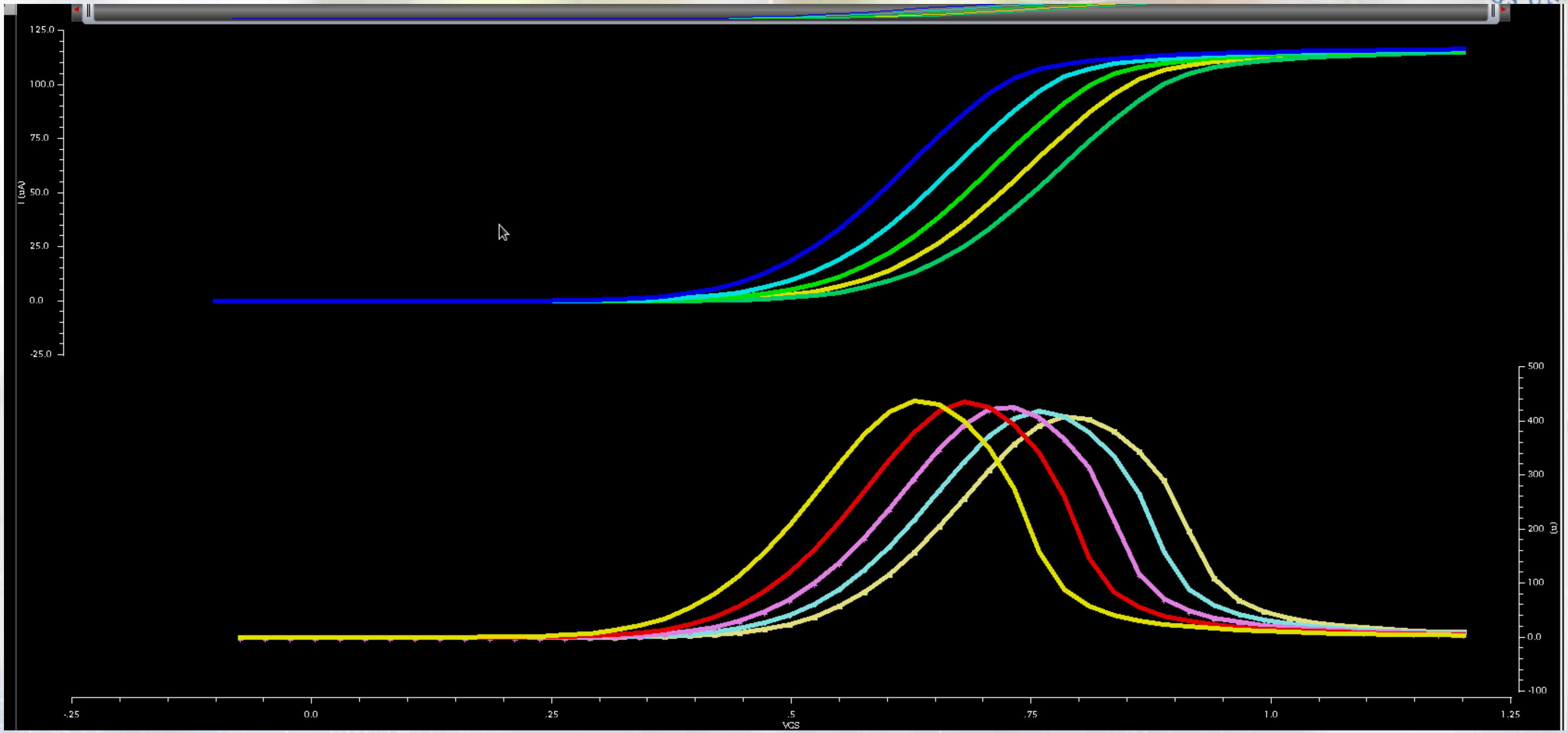
The second-order effects, cont'd



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

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Board activities ...

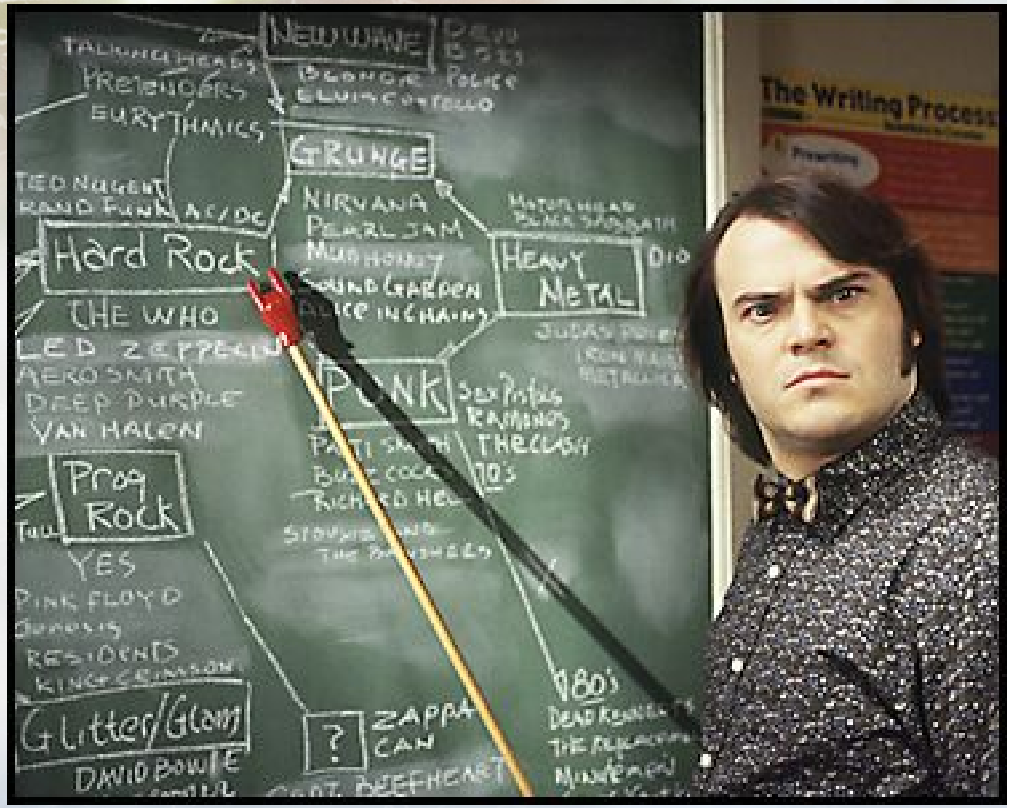
- The large-signal scenario

  Continued

- The small-signal scenario

  (Next lecture)

- Design centering



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What did we do today?

- Introduction to the course
    - Projects, labs, quizzes, exam, etc.
- The transistor
    - Operating regions
    - Functionality
- First amplifier and parameters

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What will we do next time?

- Small-signal schematics

  Linearization

- Further work on the analog building blocks

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