This presentation describes the organization and the contents of the course “Analog and Telecommunication Electronics” (mandatory course for the Electronic Engineering Master Degree at Politecnico di Torino).

The course is focused on analog circuits, with emphasis on telecommunication systems (mainly wireless).
Lesson A0 - Introduction

- Analog and Telecommunication Electronics course:
  - Goals and contents
  - Key features
  - Organization

- How to use the learning material
  - Textbook and CD-ROM (in Italian !)
  - Website (in English)
  - Other resources

- Identify the reference applications
  - Radio RX and TX structures
  - Modules and circuits for Rx and TX
  - Power circuits

This first lesson includes three parts:
- identification of course context and goals
- guide to course organization and to learning material
- review of prerequisites from previous courses or degree.
A mandatory course for the Master degree in Electronics

Goal of mandatory courses: contents which ALL Electronic Engineers (Master level) must know.

Recommended for some curricula

- Radiofrequency design
- Wireless system design

Can be replaced by “Elettronica analogica e di potenza”

- Same core contents, but different focus
- More work if curricula recommendation not followed (but affordable).
Course goals

- Develop skills, competencies, and abilities in analog and power circuits, regarding:
  - Design at the system level
    » functional characteristics, external behavior of modules
    » interface among modules
  - Design at the circuit level
    » internal structure of modules
    » design flow of modules and error analysis
  - Experimental verification of circuits behavior

- Two reference application areas:
  - Telecommunication systems and circuits
  - Power control systems and circuits

"Analog and Telecommunication Electronics" is basically an Applied Electronics course, aimed to review and complete most of the issues related with analog electronic circuits addressed in the Applied Electronic courses at the first level degree (BSC) in Electronic Engineering.

Digital electronic design is reviewed in the previous course “Digital Electronics”.

The lesson and exercise sequence follows a top-down approach: systems first, than functional units, and finally circuits.

This course uses wireless telecommunication systems as reference application to introduce various functional units based on analog and power electronics. A presentation of basic architectures for radio systems identifies the different parts of a wireless communication system, such as RF front-end (with low-noise and power amplifiers), mixers and oscillators, filters, A/D conversion units, power supply circuits.

For each functional unit, the lessons point out relevant parameters, and provide a detailed description of circuits, with discussion of various implementation choices and analysis of performance and sources of errors.

Some of the circuits presented in the lessons are designed, assembled and tested in the experimental lab exercises.
What you should already know

- **Electronics, Communication, Logic circuits**
  - Operational amplifiers, bipolar and MOS transistor models
  - Digital circuits (gates, FF, counters, registers, …)
  - Signal analysis, signal spectrum, basic modulations.

- **Laboratory experiments**
  - Use of basic instruments and breadboards
  - Handling experimental data
  - Report writing

- **Previous courses (3-Y Electronics degree):**
  - Various on Electronics
  - Signals and Communication

The course assumes students be familiar with basic electronics at a level corresponding to the BSC degree in Electronics:
- Bipolar and MOS transistors,
- Operational Amplifiers and feedback circuits,
- Integrated Circuit technology,

Digital circuits have been already refreshed in the previous Master level courses.

About communication systems, one should known the basic concepts of signal theory, spectral analysis, analog and numeric modulations, as usually provided by previous courses (e.g. Signal Theory and Electric Communications).

The lab exercises require the ability to use basic instruments, such as signal generators, oscilloscope, multimeter, and to build simple circuits.

The web site provides instruction manuals to carry out the experiments and to prepare reports, under the assumption that previous courses provided some training on the use of electronic instrumentation, on handling experimental results, and on report organization and writing.
Lessons are organized in groups, which corresponds to subjects, following as guideline the exploration of a mobile radio system. In the following [] is the reference to the italian textbook “Elettronica per telecomunicazioni”.

A: introduction (this lesson), and review of active devices and amplifiers

B: amplifiers and other modules [Chapters 1 & 2]

   Radio system architectures, amplifiers, oscillators, mixers, …

C: Phase Lock Loops (PLL) [Chapter 3]

   External parameters, circuits, Application examples

D: A/D and D/A conversion systems [Chapter 4]

   Parameters, circuits, Application examples

E: Switched capacitors

   Basic SC circuits, Filters type and design, SC amplifiers and filters

F: Power devices and circuits

   Final power stages, Linear power control, SOA and thermal analysis

G: Power Electronics

   Driving circuits, Switching voltage regulators, Application examples
Top-down approach

- Each subject follows the sequence
  - Description and identification of the function in the context
  - Identification of relevant parameters
  - Analysis of possible circuits
  - Design criteria
  - Sources of errors
  - Examples
  - Design exercise

- Lab experience
  - compare theory with real circuits
  - verify correctness of models

The description of a subsystem or functional units starts with the functional identification ("what" the unit does, which parameters define the external behavior). Next it moves to structure and circuit description ("how" the function is achieved), presenting several choices. Finally, the deviation from ideal behavior (or from the described model) and the sources of errors are discussed, with specific relation with circuit solutions and elements.

This approach reflects the top-down design procedure, at the system and unit levels. A complex electronic system cannot be analyzed or designed as a unique object; it must be broken in subsystems according to a coherent hierarchy of levels. Top level is a behavioral description (what the system does as a whole, in relation with the application); this “behavior” is then divided into lower complexity functions (obtained by functional units, with specification of operation and information exchange for each of them). The same sequence (breaking in lower complexity objects) is repeated till obtaining objects already available or easy to design and test.

By separating “what” and “how” we can better evaluate and compare the various design choices.

Design is verified by simulation and lab experiments, which allow to compare the mathematical models to the behavior of real circuits.
Module organization

- 10 credits: total load 10 x 10 = 100 hours (+ homework)
- 14 week $\rightarrow$ 7,143 h / w (average)
- Assigned 9 hours / week (not fully used):
  - $1,5 + 1,5 + 3 \ (+ 1,5) h$ for lesson/exercises, or
  - $1,5 + 1,5 + 3 h$ for lessons + 3h laboratory (7-8 weeks)

- Workload
  - 40 lessons x 1.5 h 60 120 180
  - 12 exercises x 1.5 h 18 18 36
  - 7 labs x 3 h 21 14 35
  - total hours 99 152 251
- 100 room_hours + 150 selfstudy_hours = 250/25 = 10 credits

The course gives 10 credits; each credit corresponds to 10 hours at Politecnico + about 15 hours homework.

Since the course duration is 14 weeks, that corresponds to $100/14 = 7,143$ h/week + 150 hours homework, distributed in the course weeks and exam preparation.

Assigned room time is 7.5 h/week; some hours will be skipped (total margin: 5 h).

Room hours are grouped as $3 x 1,5 + 1 x 3 h$/week; the double slot (3h) will be used alternatively for room exercises and for lab experiment.

The planned labs include 7 different experiments (the list is tentative, may be changed):
- amplifier 1
- amplifier 2
- PLL 1
- PLL 2
- Standard / Differential DAC and ADC
- Filters
- Power circuits
Lesson A0 - Introduction

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• How to use the learning material
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• Identify the reference applications
  – Radio RX and TX structures
  – Modules and circuits for Rx and TX
  – Power circuits
No single book covers the content of this course at appropriate detail level. General Analog Electronics issues are addressed in Book1. A second textbook (Book2, in Italian) addresses specifically the sections on radio systems, PLLS, and AD/DA converters.

Additional contents, examples, exercises application notes, simulators are in the course website and in a CD-Rom available with Book2.

The web reference for this course is fully open (no password needed), continuously updated, and carries:

- course information (schedule and other notices),
- additional learning material (lab instructions, exercises and examples of exam written tests),
- printouts of the slides used in the lessons,

Similar material in Italian is available from the course “Elettronica delle Telecomunicazioni” (links on the home page of the current website).

The official reference for students is “portale della didattica” (from Politecnico home page, with the password provided at registration). It will host personal information (results of tests), and pointers to the course public website.
The slide provides a list of other useful books; each of them addresses a specific content of this course.

A more complete list, which specifies the contents addressed in each book is in the course website.
Exam procedures

- Detailed document “Exams” in the website
- Final mark \( F \)
  - \( F = 0.8 \, S + 0.2 \, L + \text{[miniproject]}, + \text{[best lesson notes prize]} \)
  - \([xx] \rightarrow \text{optional}\)
- \( S \): Exam results (written exercise & oral discussion)
  - 2h written test + oral discussion (1-2 questions, about 15’)
    (same structure for all sessions)
- \( L \): lab reports
  - Unique mark for the whole team (attending students)
  - +1 for the best report of each experiment (with saturation at 3)
  - Possible to repeat a single missed experiment.

The final mark comes from a combination of written test results, oral discussion, and lab reports evaluation. Additional marks are provided by optional design work and by the “Notes prize”.

The exam types in the end-of-course session and in the other sessions are different; in the former the written test has longer duration, while the oral discussion is shorter. The inverse (short exercise, long oral discussion) applies in other sessions.

The lab report are revised and get a mark for the whole team (for students actually attending the lab).

The best lab report for each experiment gives 1 additional mark on the final lab mark, for students who carried out the experiment. This part of the mark saturates at 3.
The “miniproject” consists in the development of a research, or a simple design, or learning material, with contents related with the course.

The subject of a miniproject must be agreed with the professor at the beginning of the course (not later than week 3).

The miniproject must be concluded with a public presentation, delivered to the class before the end of the course (usually in the last week of the period).

The preparation of best lesson notes gives 3 extra points in the final mark. The notes must be prepared according to the instructions provided on the website, and delivered at the end of the course.

The intention to prepare a note collection must be declared in the first weeks of the course (with possibility to withdraw later).

In each AY, only one “Best note Award” is issued.
This is a “cell free” course.

The use of communication equipment is not required, is strongly discouraged, but (unfortunately) cannot be forbidden unless it causes disturbance to the lesson (ringing, noise, lower attention ...).

Responsible use policy:

In case of disturbance, the responsible person must identify himself/herself, and may be asked to come to the blackboard and carry out some exercise related with lesson contents.

He/She will receive a mark, form -3 to +1, which adds to the final exam mark.

Most safe choice is to switch off the set during the lesson.
Why lab experiences ?

- Engineering: maths & realworld $\rightarrow$ models + experiments
- Goals
  - Verify models towards real cases
  - Verify correctness of design procedures
  - Practice teamworking & communication
- Manuals and guides in the website
- Needs preliminary homework and applied labetiquette
  - Follow instructions
  - Carry out homeworks (Workplan, design, simulations, …)
  - Leave your bench in better conditions than how you found it ….

Lab exercises are a key part of design courses (like this one), aimed at:
- verifying consistency between the “theory” presented in the lessons and the behavior of actual circuits,
- becoming familiar with preparation of design and lab reports,
- training in teamworking.

Measurements allow to check experimental results against the models presented in the lessons, to find the limits of these models, and to verify when the simplified analysis presented in the lessons is no longer valid.

Each experiments includes circuit design, assembly, measurements, and preparation of a report with discussion of results.

Experiments are tuned to make possible fulfillment of requested tasks within the available time only if some preliminary work is carried out as homework, and if the lab work is properly organized, with assignment of tasks across the team.

If the exercise requires to design a circuit, this task must be completed before entering the lab. The team must come to the lab with the complete schematic diagram and the required part list already prepared.
Lab organization

- Two rooms: LED 7 and LED 8
  - 13 + 12 teams, with 3 people/team (2 could be OK, 4 NOT)
  - Define team composition on LED website: [http://led.polito.it/](http://led.polito.it/) section “Prenotazione studenti”

- Complete teams by March 8.
  - Mix language and competences in teams!

- Before coming to the lab, read in the course website (areeweb…): Instructions for lab experiments

- Assistance in the lab:
  - Maurizio Martina
  - Federica Lacirignola
  - (Dante Del Corso)

The lab work is carried out by teams of 3 people (2 could be accepted, after final check on usable desk number).

A mix of competences and language within each team is strongly recommended.

The total number of teams will be defined from “lab reservations” on the LED website.

Time in the lab must be used to build the circuit and to carry out measurement.

All preliminary work must be completed BEFORE the lab (there is not enough time to do it in the lab).

Final report writing can be done in the lab, at the end of the measurements, of after the lab.

Remember: there is a MAXIMUM length for reports.

Reports must be delivered before the deadline specified during the lesson; in this way a feedback can be provided before the next lab session.
Cooperation and teamworking

• The engineer never works alone: organization and cooperation are part of real work environments
  – Lab exercises aim also to exploit cooperation in the workplace: carrying out the experience and writing the report are collective responsibility of the working group.
  – Only with proper preliminary organization and task assignment among the people in the group the experiment can be completed in the available time.
  – Learn to cooperate effectively and organize your work

• Teams with mixed skill & language give better results.
• The cooperation principle does not apply to exams

Design is a complex activity, which requires to combine knowledge in various fields; no engineer can work alone, and there is always a need to cooperate with colleagues and other people. Therefore all engineers must know how to cooperate in the most effective way.

One of the goal of lab exercise is training in teamworking: carrying out the experiment and preparing the report are responsibility of the team, and require the contribution of each member.
Simulators and smart drawings

**Simulators**
- Allow to evaluate the behavior of circuits and subsystems in various operating conditions
- Usually no real-time interaction

**Smart drawing (or active drawing)**
- Interactive graphic simulators; allow to verify in real time the effects of parameter changes
- Similar to real experience in a lab
- Like a lab, need explanation and instructions
  - each simulator in the website or in the textbook has a brief explanatory text
- Ideas on new active drawings? → contact the professor

Simulators allow to evaluate the behavior of a subsystem or a circuit in various operating conditions. Usually real-time interaction is not provided: the user must
- set up simulation parameters, run simulator, look at results.

Smart drawings are simulators with a real time GUI. The user can change the parameters, and directly observe the effects. Their operation is very close to a lab experiment.

Several smart drawings (with captions in English) are available in the course website; the CD with Book2 carries some active drawings in Italian.

Development of simulators and/or smart drawings can be considered “miniproject”, and provide additional marks.
Example of smart drawing

• Response of II order system

<table>
<thead>
<tr>
<th>Title</th>
<th>Result windows</th>
<th>Simulation parameters control</th>
</tr>
</thead>
</table>

Detailed description
Lesson A0 - Introduction

- Analog and Telecommunication Electronics course:
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- How to use the learning material
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  - Other resources

- Identify the reference applications
  - Radio RX and TX structures
  - Modules and circuits for Rx and TX
  - Power circuits
Reference system

- Main reference application: Receive and Transmit radio system, such as
  - Cellular phone (handset & base station)
  - Wireless LAN
  - Other wireless interfaces
  - Positioning receivers
- With an eye also to wireline systems (LAN, …)
  - Similar problems
  - Different channels and parameters
- Additional examples for the Power Electronics section
  - In preparation

The main reference application in this course is a transmitting/receiving radio system.

The block diagram of a mobile phone handset (non last generation) is used in the first part of the course to identify a list of functions, discussed in details in the following lessons.
Radio systems: from simple ...

This a so called “galena crystal” receiver. No power needed, no amplifier, just a tuned antenna and an AM detector build with a “rectifier”: a tungsten needle on a galena crystal. Usable for MW and SW (with good antennas).
This is an example of modern radio architecture (receiver and transmitter). Most of the processing is carried out with digital circuits, and the analog RF front-end has the task to handle RF signals limiting noise and interferers (receiver) or avoiding spurious emission (transmitter).

These radio architecture will be analyzed in detail in the first lesson of part B (B1); the following ones are detailed descriptions of each functional unit and of the inside circuits.
Prerequisites

- MOS and BJT transistors
- Operational amplifiers and feedback circuits
- Logic gates, flip-flops, and sequential circuits (*)
- Analog and digital signals
- Basics of A/D and D/A conversion
- Signal analysis, analog and digital modulations
- Basic power circuits
- Communications
  - basic signal theory, spectral analysis,
  - analog and numeric modulations

(*) as addressed in Digital Electronics

The course assumes students be already familiar with basic electronics:
- Bipolar and MOS transistors,
- Operational Amplifiers and feedback circuits,
- Simple combinatorial and sequential logic circuits (already addressed in the previous course “Digital electronics”).
- Integration technology.

For communication aspects, basic concepts of signal theory, spectral analysis, analog and numeric modulations should have been provided by previous courses.

The following slides provide more details on specific prerequisites, and a few question which are useful to verify actual compliance.
Operational amplifiers

  - Basic feedback circuits

- Actual integrated Op. Amp. & application circuits
  - Models and parameters
  - Applications
  - Voltage comparator

  - MOS and BJT differential stage
  - Complementary output stage
  - Addressed in Analog Circuit Design

Sample tasks to verify knowledge of Op Amps:
- Draw the basic diagrams for inverting and noninverting voltage amplifiers (with feedback Op Amps).
- Draw the models of real Op Amp which take into account
  - differential gain
  - offsets
  - common mode gain
  - frequency response
- Specify the input and out impedance, for voltage amplifier built using ideal and real Op Amp.
- Draw the diagram of a differential amplifier.
- Define common mode and differential gain.
- Which are the benefits of differential stages?
- Why most Op Amps use complementary output stages?
Operational amplifiers - test

- Draw the basic diagrams for inverting and noninverting voltage amplifiers (with feedback Op Amps).
- Models of real Op Amp which take into account
  - Differential gain, Offsets, Input currents, Common mode gain, Frequency response
- Specify the input and output impedance for voltage amplifier built using ideal and real Op Amp.
- Draw the diagram of a differential amplifier.
- Define common mode and differential gain.
- Describe Op Amp output stage

- Amplifiers & Op Amp reviewed in lesson A2

Sample tasks to verify knowledge of Op Amps
Bipolar and MOS transistor

- Basic bias circuits
- Small signal models
- Actual devices
  - Nonlinear models (Ebers-Moll log equation)
  - Saturation and cutoff models
  - Use of datasheets
- Fabrication technologies
  - Spreading of parameters

Sample tasks to verify knowledge of MOS and BJT:
- Draw the linear model and list the main parameters of Bipolar and MOS transistors.
- Describe the saturation and cutoff models for MOS.
- Describe the saturation and cutoff models for BJT.
- Discuss differences between MOS and BJT.
- How can a designer handle the spreading of active device parameters?

MOS and BJT models will be reviewed in lesson A1.
Bipolar and MOS transistor - test

- Draw the linear model and list the main parameters of Bipolar an MOS transistors.
- Describe the saturation and cutoff models for MOS.
- Describe the saturation and cutoff models for BJT.
- Discuss differences between MOS and BJT.
- Describe how a designer can handle the spreading of active device parameters
  - To get stable operating point
  - To get designed gain and frequency response

- MOS / BJT models and circuits reviewed in lesson A1.

Sample tasks to verify knowledge of MOS and BJT:
Signal analysis and modulation

• Basic signals
  – Spectrum of sine, square, pulse, …

• Signal analysis
  – Periodic signals
  – Noise
  – Time-frequency relation

• Filters, resonant circuits

• Modulations
  – Analog AM, FM
  – Digital modulations (ASK/PAM, PSK, FSK, combined …)

Sample tasks to verify knowledge of Signal and Communication:
• Draw the spectrum of sine, squarewave, pulse chain, single pulse.
• Which is the difference among the various types of noise?
• What is a filter?
• Draw the time-domain signals for analog AM (carrier, modulating signal, modulated carrier), and the corresponding spectrum.
• Draw the time domain signals and the corresponding spectrum for some digital modulations.
Signal analysis and modulation - test

- Draw the spectrum of sine, squarewave, pulse chain, single pulse.
- Describe the various types of noise?
- What is a filter?
  - Types, approximation, parameters, circuits, …
- Draw the time-domain signals for analog AM (carrier, modulating signal, modulated carrier), and the corresponding spectrum.
- Draw the time domain signals and the corresponding spectrum for some digital modulations.

Sample tasks to verify knowledge of Signal and Communication:
Lesson A0 – final test

- Describe the goals of this course.
- Which are the course contents, and how are they grouped?
- Which are the reference texts and the main sources of learning material?
- Outline the course organization.
- How can cellular phones be used in this course?
- Why are lab experiences useful in engineering courses?
- Which is the application used as reference for this course?
- Define $Z_{in}$ and $Z_{out}$. Which are the optimal values for a voltage amplifier? What about current amplifiers?
- Which are the main differences between bipolar and MOS transistors?
- Draw small signal models for BJT and MOS transistors.

Every lesson has a “final test” slide.
The goal is to verify understanding of lesson contents. What matter is:
- Understand the question
-- know the answer, or where to find the answer (within the lesson)