ERASMUS exchange proposal
"Measuring, Modelling, and Simulation of Dynamic Systems"

COURSE	ECTS
An introduction to system identification (J. Schoukens)	4
Measuring and modelling of nonlinear systems (J. Schoukens)	4
Industrial measurement techniques (L. Van Biesen)	4
Identification of dynamic systems (R. Pintelon)	4
Advanced control methods (R. Pintelon, taught by J. Swevers, KUL)	4
CAE-tools for the design of analog electronic circuits (G. Vandersteen, IMEC)	4
Design and characterization of high-frequency (nonlinear) systems (W. Vanmoer)	4

1. What?

Design of new systems and products is a complex process with a central role for the engineer. A good physical insight is combined with experimental results to come eventually to the best products (lowest price, good quality, no pollution) to concur the competition.
Each step in this design process requires dedicated tools. We should collect good experimental data, often collected in poor conditions (*course: **Industrial measurement techniques***). From these measurements a wide variety of models is extracted for the designer (*course: **Identification of dynamic systems***) that should meet many requirements.
Sometimes the models are used in simulation tools like 'Spice', or they are used to measure parameters that are difficult to access directly, like the damping of a wing, the time constants of an electrical machine. Models are also at the basis of control design (for example the active suspension of a car). A lot of commercial software packages are available on the market to support the design process, but using these tools without understanding can result in a bad or poor design or even create dangerous situations. In a simulation package, many user parameters or set to default values that are not always suitable for the specific situation, and this can jeopardize the results completely (**course:** ***Simulation tools for nonlinear systems***).

During the design, it is very tempting to rely on linear models because they are very intuitive, easy to use, many rules of thumb are available, and it is not too difficult to extract them from measurements. However, nature is not linear. What is the quality of the design under these conditions? Is the stability analysis of the controller still valid? How to design a controller in the presence of nonlinear distortions? How is the bit-error-rate of a high speed communication link affected by a nonlinear amplifier? The courses ***Measuring and modelling of nonlinear systems*** and ***Advanced control methods*** help to answer these questions.
These ideas are practically applied in microwave designs where transistors are often pushed in their nonlinear operation region for power efficiency reasons (optional course: ***Design and characterization of high-frequency (nonlinear) systems***).

Whom? Everybody with the ambition to make good designs, and this in the electrical, electro-mechanical, mechanical, civil, and chemical engineering field. The pre-requisites to attend these courses, are a basic knowledge of system theory, control theory, and signal processing. A basic course is available for an ***introduction to system identification***.

When? Most courses are taught in the first semester.

Introduction to system identification

-aims and objectives:

A course aiming to teach how to built mathematical models starting from noisy data, measurements.

Required knowledge

- a basic course on statistics
- basic digital signal processing

Content

- Why do we need identification methods? A simple example
- The 'ideal' estimator: asymptotic unbiased and consistent estimators; efficiency; Cramer-Rao lower bound
- A systematic approach of the identification problem: least squares, weighted least squares, Maximum likelihood, Bayes estimators
- Estimation in the presence of errors on the input and output data: errors-in-variables methods; instrumental variables; total least squares
- Model selection and validation: introduction to model selection criteria

Identification of dynamic systems

Competencies

-aims and objectives: construction of an appropriate estimator for an identification problem, methods to study the stochastic behavior of estimators, frequency and time domain identification

Previous knowledge

- introduction to System identification
- basics of linear algebra, complex analysis and probability theory

Content

- construction of an appropriate estimator for an identification problem
- analysis of the stochastic behavior (consistency, bias, normality, uncertainty) of estimators when the amount of data tends to infinity
- models for linear time invariant systems (discrete-time, continuous-time)
- (optimal) excitation signals for system identification
- frequency response function (FRF) measurements
- influence nonlinear distortions on FRF measurements
- frequency domain system identification (linear least squares, total least squares, maximum likelihood, subspace methods, non-parametric noise models)
- time domain identification (prediction error methods, parametric noise models)
- identification in the presence of nonlinear distortions

Study Material

L. Ljung (1999). System Identification: Theory for the User. Prentice-Hall: Upper Saddle River.
R. Pintelon and J. Schoukens (2001). System identification: A Frequency Domain Approach. IEEE Press: New York.

Measuring and modelling of nonlinear systems

Competencies

Goal: to give an intuitive insight in the behavior of nonlinear systems
Linear system theory is a simple but very successful description of nature although most systems are nonlinear. For that reason it is important for an engineer to know how the presence of nonlinear distortions can be detected. On the basis of this information, he should decide if linear system theory is still applicable to solve his problem.
On the other hand, some systems are intrinsic nonlinear. Till recent, it was very hard to measure these characteristics. New measurement equipment allows nowadays to characterize also these nonlinear systems. For that reason it is necessary that our engineers have a sufficient background to access this new possibilities.
Applications exist in the mechanical, electrical, electronical and microwave fields. The course

offers a good basis to recognize, understand and deal with such nonlinear problems.

Previous knowledge

System theory
Fourier Analysis
Basis signal processing
Measuring and Modelling

Content

Part 1: Modeling
- Impact of the choice of excitation and the choice of convergence criterion
- Volterra representation of nonlinear systems
- Nonparametric representation of nonlinear systems
- Best linear approximation of nonlinear systems
- Stochastic nonlinear contributions

Part 2: Measurement
- Detection, qualification and quantification of nonlinear distortions.
- Measurement of transfer functions in the presence of nonlinear distortions.
- Measurement of Volterra kernels in time and frequency domain.
- Nonparametric measurement of nonlinear systems.

Simulation tools for nonlinear systems

Content

The analysis and design of complex systems often starts by simulating the (partial) differential equations that represent the system. Various methods exist to determine the response of the system. However, different techniques are available and optimized depending on the type of system and on the applied excitations.

The type of system heavily determines the set of possible simulation techniques. This implies that different approaches are available when simulating
- autonomous systems such as oscillators,
- mainly linear systems such as amplifiers, filter, …
- frequency translating systems such as mixer and multipliers,
- hybrid systems such as sigma-delta and sample-data systems.

The excitation signals used heavily influence the simulation techniques as well. This results in different approaches when the system is excited with a random signal, a single sinewave or a periodic signal. Take for example the transient simulation which is available in SPICE. This transient simulator is not suited for analyzing some nonlinear high-frequency circuits (due to distributed components) or for the noise analysis in mixers. To solve this problem, simulation techniques such as harmonic balance and the shooting method were developed. They assume that all signal are either periodic of quasi-periodic. However, this makes harmonic balance unsuited for non-quasi-periodic signals, but makes the technique superior for the analysis of nonlinear microwave circuit and the noise analysis of mixer.

The problems and solutions for the simulation of complex systems will be illustrated on analog electronic circuits, while illustrating the link to more general complex systems. This includes methods to perform a transient analysis in the time domain, harmonic balance analysis in the frequency, determining periodic solutions in the time domain using a shooting method, large-signal / small signal analysis,…

The aim of the course is to understand the pros and contras of the different available simulation techniques. This way, he/she should be able to judge which technique is the most appropriate for solving his/her analysis problem. In addition, it will become clear which simulation parameters are crucial for simulating the complex system in an accurate way.

Design and Characterization of RF and Microwave non-linear systems

Competencies

Becoming an expert in understanding, measuring and using nonlinear RF systems.

Previous knowledge

RF electronics, distributed systems, basic knowledge of measurement techniques

Content

Design and characterization of nonlinear RF circuits and systems
+ The classical way: the nonlinear behavior as a perturbation
+ Characterization of amplifiers under different excitation signals
+ Characterization of 'linear' mixers

The nonlinearity as an helpful tool in RF design
+ Power efficient design
+ Ultralinear systems: signal and system level aspects
+ Using the "best linear approximation"
+ Measuring the behavior of such a system
+ Model extraction and a possible feedback to design.

The nonlinearity as a full-grown component
+ Design of distributed mixers
+ Measurement of 3-port devices
+ Modelling and feedback to the designer

Measurements for modelling
+ What are the prerequisites to obtain efficient models that can be validated?
+ Implications on measurement and calibration
+ Identifying the model structure and validation of the model