ELEC Spring School 2012

Within the department ELEC of the VUB (http://wwwtw.vub.ac.be/elec/), we organize the 5th edition of a 4 weeks spring school (from Monday 21st of May 2012 till Friday the 15th of June 2012) to give an intensive training on advanced modelling and simulation techniques of (non)linear dynamic systems, starting from experimental data. Besides classical courses and exercises, we also provide hands-on experience by working on experimental data that you will measure yourself. The participants should have a good basic knowledge in system theory and signal processing. The course covers the following topics:

- A basic introduction to system identification,
- Measuring dynamic systems
- Identification of dynamic systems,
- Measuring and modeling of nonlinear systems,
- Simulation tools for nonlinear systems,
- Nonlinear distortion analysis in microwave and integrated circuits and systems.

A general introduction is added at the end of this mail.

The maximum number of participants will be restricted to 15 researchers.

Participation to this workshop offers a number of advantages. Besides the training, it can also be the start of a collaboration. To some of the participants we can offer a one year grant to start a research collaboration, or even a full four years grant for a (joint) PhD.

Interested candidates are invited to send their curriculum vitae, together with a short motivation why they would like to follow this course, and this before the 16th of January 2012. They can also express their interest in the possibility for a longer cooperation. Please do not hesitate to contact us if you would like to have more information: email: dolivaur@vub.ac.be or johan.schoukens@vub.ac.be

General information

Within the department ELEC (http://wwwtw.vub.ac.be/elec/) we created a 'Centre for Data Based Modelling and Model Quality Assessment'. The goal of this project is to develop, acquire, and disseminate methods to build models from experimental data.

This project follows different lines towards this long term goal:

- Development of advanced identification methods for dynamic systems, including high risk new challenges.
- Learning, dissemination, networking: The aim is to acquire and disseminate actively knowledge from/to other fields by offering training grants and one year research grants for visitors who want to learn how system identification methods can be used in their research project.

The 4 weeks doctoral school fits in the second activity.

Contents of the courses

First we will learn the participants how to identify good models for linear dynamic systems. Next we extend the scope to include nonlinear distortions into the framework. This is also reflected in the organization of the lessons. These are organized around theoretical classes on the one hand, and extensive matlab exercises to get hand on experience on the other hand. Besides detailed course notes, we provide the attendees with the book: J. Schoukens, R. Pintelon, and Y. Rolain (2012). Mastering System Identification in 100 Exercises. Wiley and IEEE Press.

1. LINEAR DYNAMIC SYSTEM IDENTIFICATION

In Part 1 of this course we learn how to built mathematical models starting from noisy data or measurements. In Part 2, we discuss how to measure (linear) dynamic systems using periodic and random excitations. In Part 3, we apply this methodology on the identification of linear dynamic systems.

1.1. Introduction to system identification

Johan Schoukens (Johan.Schoukens@vub.ac.be)

Aims and objectives: give a general introduction to the system identification problem, the basic concepts are introduced. The following topics are covered:

- 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

1.2. Measuring Dynamic Systems

Yves Rolain (Yves.Rolain@vub.ac.be)

In this course we learn how we can measure the frequency response function (FRF) of a linear dynamic system using periodic and random excitations. After a short theoretic introduction, we mainly make use of a series of well selected exercises that provide the attendees how to deal with the following topics:

- using the discrete Fourier transform (matlab fft-function) on periodic signals
- design of broadband periodic excitations
- FRF-measurements using periodic excitations: how to select the power spectrum? how to deal with transients? How to measure the noise characteristics? How to make a noise analysis?
- FRF-measurements using random excitations: advantages/disadvantages with respect to periodic excitations? How to deal with leakage? How to make a noise analysis?

1.3. Dynamic Systems Identification

Rik Pintelon (email: Rik.Pintelon@vub.ac.be)

Aims and objectives: construction of an appropriate estimator for an identification problem, methods to study the stochastic behaviour of estimators, frequency and time domain identification. The following topics are covered:

- construction of an appropriate estimator for an identification problem
- analysis of the stochastic behaviour (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.

2. DEALING WITH 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, electronic and microwave fields. The course offers a good basis to recognize, understand and deal with such nonlinear problems.

2.1. Measuring and modelling of nonlinear systems

Johan Schoukens (Johan.Schoukens@vub.ac.be)

Goal: to give an intuitive insight in the behaviour of nonlinear systems. For that purpose we first provide the attendees with a theoretical framework that will be used next to develop a number of tools that can be easily used in practice to characterize nonlinear systems.

A. A theoretic framework

- 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

B. Practical applications

- 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.

2.2. Simulation tools for nonlinear systems

Gerd Vandersteen (email: Gerd.Vandersteen@vub.ac.be)

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 analysing 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.

2.3. Nonlinear distortion analysis in microwave and integrated circuits and systems

Gerd Vandersteen, Yves Rolain

This is an optional course for participants who are interested in integrated circuits and/or microwave systems

The course aims to demystify the nonlinear distortion analysis of circuits and systems, and more specifically on microwave and IC applications. Combining capability of analysing large circuits through simulation-based methods and the analytical insight provided by symbolic methods enables the analysis of the nonlinear behaviour of complex systems. The simulation-based methods make it possible to pinpoint the dominant nonlinearities, while the symbolic method can be used afterwards to get an analytical insight in the nonlinear behaviour. This will be demonstrated on a large set of practical microwave and integrated circuits examples.

The course revises the necessary notions on Volterra theory, starting from classical linear system theory. This results in a better understanding of the behaviour of the nonlinear system. The complexity of the resulting expressions, however, limits the applicability of this technique to simple systems.

The course also revises the Best-Linear-Approximation (BLA) paradigm, which represents the nonlinear system as a linear transfer function and additive nonlinear distortion components. It enables the separation of the various linear and nonlinear contributions and is able to pinpoint the dominant nonlinear distortions in a complex system and this in a hierarchical way.

In addition to simulations, the course will also focus on practical aspects to retrieve the BLA from measurements. Both low-frequency and high-frequency (GHz-range) measurements techniques will be covered. This must enable the attendees to use the BLA nonlinear distortion analysis technique using both simulated and measured characteristics of their devices.

The power of the Volterra theory and the BLA are finally combined to study a large set of microwave and IC examples. Starting from a single-transistor circuit, the circuits' complexity gradually increases over OPAMP to active filters and sigma-delta modulators. Both the symbolic method and the simulation-based methods are used side-by-side to gain insight in the nonlinear distortion properties of the system.

The attendees of the course are stimulated to apply the proposed nonlinear distortion techniques on their microwave / IC circuit of interest.