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1. Introduction to the department ELEC

1.1 INTRODUCTION TO THE LONG TERM STRATEGY OF THE DEPARTMENT ELEC

‘ELEC’ stands for “Fundamental Electricity and Instrumentation” (in Dutch: “Algemene Elektriciteit en Instrumentatie”) and the name corresponds to the educational and research tasks and objectives of the department. The main research activity of the department is the development of new measurement techniques using advanced signal processing methods, embedded in an identification framework. When we make a measurement, we have to make a number of decisions: firstly a model for the considered part of reality is proposed (e.g. for a resistance measurement Ohm’s law can be selected, describing the relation between the voltage across the resistor and the current through it); next a number of measurements is made (e.g. a number of current and voltage measurements); finally the quantities of interest are extracted from these measurements by matching the model to the data. Often an intuitive approach is used. However, in the presence of measurement errors this can lead to a very poor and even dangerous behaviour: the user wouldn’t remark that something is going seriously wrong. This is the major motivation for the development of the identification theory. It offers a systematic approach to ‘optimally’ fit mathematical models to experimental data, eliminating stochastic distortions as much as possible. As such it can be considered as the modern formulation of the measurement problem, and for that reason the identification approach is the “fil rouge” in most of the activities of the department.

Each measurement (or identification session) consists of a series of basic steps:

- Collect information about the system;
- Select a (non) parametric model structure to represent the system;
- Select the model parameters to fit the model as well as possible to the measurements (this requires a "goodness of fit" criterion);
- Validate the selected model.

Most of the research activities of the department are related to one of these problems, but this does not narrow our focus. At this moment we deal with a very wide scope of application fields:

- Systems covering the frequency range from a few mHz up to 50 GHz,
- Linear systems and non-linear systems,
- Lumped systems and distributed systems.
We applied the measurement and modelling techniques to the identification of electrical machines (frequency range 0.01 Hz till 1 kHz, linear models, 2 inputs and 2 outputs), mechanical vibrating systems (frequency range below 5 kHz, linear or non-linear, up to 2 inputs/2 outputs), electronic circuits and filters (frequency range up to 5 MHz, linear and non-linear models, single input/single output or multiple input/multiple output), underwater acoustics (frequency range up to a few MHz, 1 input and 2 outputs), distributed systems (telecommunication lines, up to a few hundreds MHz), microwave applications (frequency range up to 50 GHz, non-linear, 6-port measurements). Since a few years we apply those methods also to the analysis of biological samples used as records of global climate change. For some of these applications the efforts are focused on the development of new measurement instruments (measurement of telecommunication lines, non-linear microwave analyser), for others we focused completely on the development of new data processing and modelling techniques, or even worked on the underlying fundamental theoretical aspects.

To cover this wide application range, we make use of an extensive measurement park. Most of it nowadays consists of VXI-based data-acquisition systems, although we have also some classical instruments like network and spectrum analysers. All these instruments are computer controlled in a Matlab™ environment.

### 1.2 RESEARCH TEAMS OF THE DEPARTMENT ELEC: OVERVIEW OF THE 4 TEAMS

#### 1.2.1 Team A: Automatic Measurement Systems, Telecommunications and Laboratory of Underwater Acoustics.

- Identification of distributed systems
- Incorporation of knowledge engineering in complex measurement problems
- Application of information theory in data telecommunication by wire problems (xDSL)
- Modelling and Identification of transmission lines and wireless channels (LOS and NLOS)
- Wireless local loop
- Signal processing techniques related to measurement in Earth Science problems
- Development of PC and PXI based instrumentation
- Underwater acoustic studies
- Environmental G.I.S. development
- 4G communication
- Navigation techniques, including but not limited by, applications for Location Based Services
- Positioning Techniques using the cellular network (focus on GSM)
- Proactive Location-based Services (LBS) using multiple positioning technologies.
1.2.2 Team B: System Identification and Parameter Estimation of Linear and Non-Linear Systems

- Study and development of basic concepts on identification theory
- Identification of linear and nonlinear concentrated and distributed systems
- Experiment design
- Time and frequency domain system identification
- Development and distribution of a system identification toolbox
- Identification of time-varying systems

1.2.3 Team C: Applied Signal Processing for Engineering (ASPE)

- Instrumentation setup contributions.
- Instrumentation calibration contributions.
- Modelling high frequency nonlinear systems

1.2.4 Team D: Medical Measurements and Signal Analysis (M2ESA)

- Development of customized measurement setups
- Pre/post - processing of medical measurement data
- User-friendly guidelines to accurate and practical signal analysis
- Customized linear and nonlinear modeling techniques for medical and high-frequency applications

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1.3 THE ELEC FUTSAL TEAM

The mixed girls/boys ELEC futsal team was founded in September 2010, and sponsored by the ELEC department. Some intensive recruiting and scouting work was necessary to get a very motivated team together. The goal of the first season was to establish a good team spirit with the support of our international supporter clan.

The lack of talent is abundantly compensated by the tremendous enthusiasm of the team. We organized some training sessions in order to clarify the rules and possible tactics of the game. Only one mistake later everyone knew which way the ball had to go. This resulted in some nice goals, but sadly enough only one win up to now – a forfeit of the opponent. We expect that in the near future more wins will follow now we established some team tactics, and our talent starts to develop.
1.4 STAFF OF ELEC (STATUS 01/02/2012)

1.4.1 General Director

**Johan Schoukens** (head of the department) received both the degree of master in electrical engineering in 1980 and the degree of doctor in engineering (PhD) in 1985 from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. From 1981 to 2000, Dr. Schoukens was a researcher of the Belgian National Fund for Scientific Research (FWO-Vlaanderen) at the Electrical Engineering (ELEC) Department of the VUB where he is currently a full-time professor in electrical engineering. His main research interests include system identification, signal processing, and measurement techniques. Dr. Schoukens has been a Fellow of IEEE since 1997. He was the recipient of the 2002 Andrew R. Chi Best Paper Award of the IEEE Transactions on Instrumentation and Measurement, the 2002 Society Distinguished Service Award from the IEEE Instrumentation and Measurement Society, and the 2007 Belgian Francqui Chair at the Université Libre de Bruxelles (Belgium). Since 2010, he is a member of Royal Flemish Academy of Belgium for Sciences and the Arts. In 2011 he received a Doctor Honoris Causa degree from the Budapest University of Technology and Economics (Hungary).

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1.4.2 Team A: Automatic Measurement systems, Telecommunications and Laboratory of Underwater Acoustics

**Leo Van Biesen** (coordinator of team A) was born in Elsene, Belgium, on August 31, 1955. He received the degree of Electro-Mechanical Engineer from the Vrije Universiteit Brussel (VUB), Brussels in 1978, and the Doctoral degree (PhD) from the same university in 1983. Currently he is a full senior professor. He teaches courses on fundamental electricity, electrical measurement techniques, signal theory, computer-controlled measurement systems, telecommunication, underwater acoustics and Geographical Information Systems for sustainable development of environments. His current interests are signal theory, modern spectral estimators, time domain reflectometry, wireless local loops, xDSL technologies, underwater acoustics, and expert systems for intelligent instrumentation. He has been chairman of IMEKO TC-7 from 1994-2000 and President Elect of IMEKO for the period 2000-2003 and the liaison Officer between the IEEE and IMEKO. Prof. Dr. Ir. Leo Van Biesen has been president of IMEKO until September 2006. He is also member of the board of FITCE Belgium and of USRSI Belgium.

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**Hernan Cordova** was born in Guayaquil, December 19, 1977. In October 1999 he obtained graduated as a Bachelor of Science in Electrical Engineering at the Escuela Superior Politécnica del Litoral (ESPOL), Guayaquil. In august 2004, he finished at the same university a master degree program in Tele-communications Management. Since september 2004, he is going towards the PhD at the ELEC department being supervised by Prof. Van Biesen. His main interests are: Digital Signal processing and Fixed and Mobile Wireless Communications.

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Carine Neus was born in Anderlecht, Belgium, on March 16, 1983. She graduated as an Electrical Engineer (Burgerlijk Elektrotechnisch Ingenieur), option Telecommunication in July 2004 at the Vrije Universiteit Brussel. Carine joined the department ELEC as a research assistant in October 2004 and obtained her PhD in March 2011. She is currently working as a post-doctoral researcher at ELEC. Her main research interest is on the modelling of telephone lines and the estimation of the channel capacity of xDSL lines (ADSL, VDSL,…).

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Taka Yoshizawa was born in Nagoya, Japan, on 22nd April, 1961. He has total of 24 years of industry experience, much of it in 2G/3G cellular infrastructure product design and development at Motorola in the US, where he gained experience in most of the engineering work involved with the lifecycle of mobile infrastructure system. After moving to Belgium in 2006, he joined Technicolor (former Thomson) in Edegem as a System Architect for the femtocell project. Since 2011, he is a Senior System and Standard Engineer at Ubiquisys Ltd in the UK. Since 2007, he has been actively contributing to 3GPP, Broadband Forum, and Femto Forum for femtocell related standardization activities. In 2009, he won the inaugural Femto Forum Award for the recognition for his contribution to femtocell standardization. He has filed ~10 patents (most of them still pending) in both US and Belgium for telecom related technologies. He has a BS degree of Information and Computer Science from Georgia Institute of Technology and an MS Telecommunication from Southern Methodist Univ. in 1992 and 2002, respectively. He is currently pursuing Ph.D. under the guidance of Prof. Van Biesen. His research interest is next generation mobile technology, such as Relay Node, Heterogeneous Network, and Femtocell.

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1.4.3 Team B: System Identification and Parameter Estimation of Linear and Nonlinear Systems

Johan Schoukens (head of the department) received both the degree of master in electrical engineering in 1980 and the degree of doctor in engineering (PhD) in 1985 from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. From 1981 to 2000, Dr. Schoukens was a researcher of the Belgian National Fund for Scientific Research (FWO-Vlaanderen) at the Electrical Engineering (ELEC) Department of the VUB where he is currently a full-time professor in electrical engineering. His main research interests include system identification, signal processing, and measurement techniques. Dr. Schoukens has been a Fellow of IEEE since 1997. He was the recipient of the 2002 Andrew R. Chi Best Paper Award of the IEEE Transactions on Instrumentation and Measurement, the 2002 Society Distinguished Service Award from the IEEE Instrumentation and Measurement Society, and the 2007 Belgian Francqui Chair at the Université Libre de Bruxelles (Belgium). Since 2010, he is a member of Royal Flemish Academy of Belgium for Sciences and the Arts. In 2011 he received a Doctor Honoris Causa degree from the Budapest University of Technology and Economics (Hungary).

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Péter Zoltán Csurcsia was born in Budapest, Hungary, on 17.05. 1985. He obtained his Bachelor of Engineering diploma (BEng in EE, summa cum laude) and his Technical Teacher diploma (Ed in EE, summa cum laude) from Budapest Tech in 2007 and 2008. Parallel with Electrical Engineering he studied technical informatics at Budapest Tech between 2004 and 2008. From 2008 he was a student at the Budapest University of Technology and Economics (BUTE) and at Vienna University of Technology. He graduated in MSc in Embedded Systems and in Applied Informatics (MSc, summa cum laude) in 2010. Now, he is a doctoral student at the BUTE (his advisor Prof. Dr. István Kollár) and at the Vrije Universiteit Brussel (with Prof. Dr. ir. Johan Schoukens). He worked as an IT Teacher from 2006-2010 and as a Program/Web designer. His research interests cover the topics of system identification, digital signal processing, software and and internet technologies.

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Egon Geerardyn was born on April 15th, 1988 in Jette (Brussels), Belgium. He graduated as an Electrical Engineer in Electronics and Information Theory (profile Measurements, Modelling and Simulations) in 2011 at the Vrije Universiteit Brussel. In October 2011 he joined the department ELEC as a PhD student. His main interests comprises system identification of linear and nonlinear systems, workflow automation and Linux.

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Michel Gevers was born in Antwerp, Belgium, in 1945. He obtained an Electrical Engineering degree from the Université Catholique de Louvain, Belgium, in 1968, and a Ph.D. degree from Stanford University, California, in 1972. He holds a Honorary Degree from the Vrije Universiteit Brussel and the University of Linköping, Sweden, and a few other titles. He has been President of the European Union Control Association (EUCA) from 1997 to 1999, and Vice President of the IEEE Control Systems Society in 2000 and 2001. Between 1990 and 2010 he has been the coordinator of the Belgian Interuniversity Network DYSCO (Dynamical Systems, Control, and Optimization) funded by the Federal Ministry of Science. His research interests are in system identification and its interconnection with robust control design, optimal experiment design, data-based control design, optimal control and filtering, and realization theory. He has published about 250 papers and conference papers, and two books: "Adaptive Optimal Control - The Thinking Man's GPC", by R.R. Bitmead, M. Gevers and V. Wertz (Prentice Hall, 1990), and "Parametrizations in Control, Estimation and Filtering Problems: Accuracy Aspects", by M. Gevers and G. Li (Springer-Verlag, 1993). Currently he is 20% active at the department ELEC as Professor emeritus.

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Jan Goos was born in Geel (Belgium) in 1986. He graduated from the Katholieke Universiteit Leuven as an engineer in Computer sciences (Artificial Intelligence) in 2009 and in Mathematical Engineering in 2011. In October 2011 he joined the department of ELEC as a PhD student. His main interests are the measurement and modeling of Linear Parameter Varying (LPV) systems, but he also loves non-linear dynamics.

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John Lataire was born in Brussels, Belgium, in 1983. He graduated as an Electrical Engineer in Electronics and Information Processing in July 2006. He received the degree of doctor in Engineering Sciences (Doctor in de Ingenieurswetenschappen) on March 24, 2011. Both degrees were obtained at the Vrije Universiteit Brussel, Belgium. From October 2007 till October 2011 he has been on a Ph.D. fellowship from the Research Foundation - Flanders (FWO). Since August 2006 he is working as a researcher at the department ELEC-VUB, Brussels, Belgium. His main interests are the measurement and identification of slowly time-varying, weakly nonlinear dynamic systems, formulated in the frequency domain.

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Anna Marconato was born in Trento, Italy, on April 8th, 1980. She received the B.Sc. in Mathematics and the M.Sc. in Telecommunication Engineering from the University of Trento, Italy, in 2002 and 2005, respectively. In 2009 she was awarded a joint PhD degree from the University of Trento, Italy, and the Vrije Universiteit Brussel, Belgium. From September 2009 she has been a post-doctoral researcher at Department ELEC, Vrije Universiteit Brussel, Belgium. Her main research interests are in the fields of nonlinear system identification and machine learning.

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David Oliva Uribe was born on May 24th 1975, Mexico City, Mexico. His research interests are in the field of system identification techniques for piezoelectric transducers, in particular the characterization of biological tissues using tactile sensors in medical applications. He graduated with Honours in Electronic and Communication Engineering in 1997 and obtained a Master in Sciences with Specialization in Manufacturing Systems in 2000, both from Tecnológico de Monterrey in Mexico City. From April 2007 to December 2010 he worked as Team Leader of the Research Group of Medical Engineering and Mechatronic Systems at the Institute of Dynamics and Vibrations Research from the Leibniz University of Hannover. Since January 2011, he joined the Department ELEC, Vrije Universiteit Brussel, where he is working toward a joint PhD degree.

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Rik Pintelon was born in Gent, Belgium, on December 4, 1959. He received the degree of Electrotechnical-Mechanical Engineer (burgerlijk ingenieur) in July 1982, the degree of doctor in applied science in January 1988, and the qualification to teach at university level (geaggregeerde voor het hoger onderwijs) in April 1994, all from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. Until September 2000 he was a Research Director of the Fund for Scientific Research - Flanders (FWO) and part time lecturer at the VUB in the Electrical Measurement Department (ELEC). Presently he is a full time professor at the same department (ELEC). His main research interests are in the field of parameter estimation / system identification, and signal processing.

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Koen Tiels was born in Halle (Belgium) in 1987. He graduated as an Electrotechnical-Mechanical Engineer in July 2010 at the Vrije Universiteit Brussel. In September 2010 he joined the ELEC department as a PhD student. His main interests are in the field of nonlinear block structured system identification.

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Laurent Vanbeylen was born in Elsene, Belgium, on January 6, 1983. He graduated as an Electrical Engineer in Electronics and Information Processing in 2005 at the Vrije Universiteit Brussel. Laurent pursued a PhD since August of the same year, at the department ELEC, and obtained the degree in 2011 with his thesis entitled "Nonlinear dynamic systems: blind identification of block-oriented models, and instability under random inputs". Presently, he is active at the ELEC department as a doctor-assistant. His main interests remain in the field of nonlinear dynamic systems, with the emphasis on the identification of nonlinear feedback models.

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Mattijs Van de Walle was born in Bonheiden on the 25th of October, 1979. He received an engineering degree in electronics from the ‘De Nayer instituut’, Sint Katelijne Waver, Belgium, in 2002. After teaching electronics and telecommunication at the Vrij Technisch Instituut (VTI), Leuven, for two years, he took up studying again to receive the degree of electrical engineer from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 2007. Currently, he is working as a PhD research student at the VUB, department ELEC. The aim of his research is the analysis of flutter in a non-linear framework.

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Anne Van Mulders was born in Jette on September 19, 1984. In July 2007, she received the degree of Mechanical Engineering from the Vrije Universiteit Brussel. She joined the department of ELEC in September 2007 as a PhD student. Her main research interests are in the field of nonlinear system identification.

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Dhammika Widanage was born on November 3rd 1983, Kuwait City, Kuwait. His research interests are in the fields of system identification, in particular the effects of nonlinearities on process models, multiple input multiple output systems and of control. He was awarded a Ph.D. in 2008 for research done in the Systems Modelling and Simulation Research Group and graduated with a First-Class Honours in Electronic and Communication Engineering in 2004 (BEng - Bachelor of Engineering) both from the University of Warwick, UK. From June 2008 he has been a Postdoctoral Research Fellow in the System Identification and Parameter Estimation Research Team in the Department of Fundamental Electricity and Instrumentation at the Vrije Universiteit Brussel.

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1.4.4  Team C: Applied Signal Processing for Engineering (ASPE)

Gerd Vandersteen (coordinator of team C) was born in Belgium in 1968 and received the degree in electrical engineering from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 1991. In 1997, he received his PhD in electrical engineering, entitled “Identification of Linear and Nonlinear Systems in an Errors-in-Variables Least Squares and Total Least Squares Framework”, from the Vrije Universiteit Brussel/ ELEC. During his postdoc, he worked at the micro-electronics research centre IMEC as Principal Scientist in the Wireless Group with the focus on modeling, measurement and simulation of electronic circuits in state-of-the-art silicon technologies. This research was in the context of a collaboration with the Vrije Universiteit Brussel. From 2008 on, he is working as Prof. at the Vrije Universiteit Brussels/ELEC within the context of measuring, modeling and analysis of complex linear and nonlinear system. Within this context, the set of systems under consideration is extended from micro-electronic circuits towards to all kinds of electro-mechanical systems.

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Griet Monteyne was born in Vilvoorde, Belgium, on January 19, 1985. She graduated as an Electrotechnical-Mechanical Engineer (Burgerlijk Ingenieur) in July 2007 at the Vrije Universiteit Brussel (VUB), Brussels, Belgium. In October 2007 she joined the ELEC department of the VUB as a PhD student. Until October 2009 her research was in collaboration with the department ANS (Advanced Nuclear Systems) of the SCK-CEN (Belgian Nuclear Research Centre) in Mol, Belgium. Currently her work is related to geothermal heat pumps. The object is to model the thermal dynamic behavior of the surrounding geology by use of noise analysis techniques.

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Yves Rolain (1961, Belgium) received the Electrical Engineering (Burgerlijk Ingenieur) degree in July 1984, the degree of computer sciences in 1986, and the PhD degree in applied sciences in 1993, all from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. He is currently a research professor at the VUB in the department ELEC. His main interests are microwave measurements and modelling, applied digital signal processing and parameter estimation / system identification.

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Maarten Schoukens was born in Jette (Belgium) in 1987. He graduated as an Electrical Engineer in Electronics and Information Processing (profile Measurement and Modelling of Dynamic Systems) in July 2010 at the Vrije Universiteit Brussel. In September 2010 he joined the department ELEC as a PhD student. His main interests are in the field of nonlinear block oriented system identification of multiport microwave systems.

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Diana Ugryumova was born in Kiev, Ukraine, on October 26th, 1984. She received the degree in Applied Mathematics (chair of Mathematical Theory of Systems and Control) at the University of Twente in the Netherlands in March 2010. Diana joined the department of ELEC in May 2010 as a PhD student. Her current research is about identification of distillation columns. The aim of this research is to enhance the performance of a distillation column through a better modeling and control strategy.

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Team D: Medical Measurements and Signal Analysis (M2ESA)

Wendy Van Moer (coordinator Team D), (12/07/1974), received the Engineer and Ph. D. degrees in Engineering from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 1997 and 2001, respectively. She is currently a part time lecturer with the Electrical Measurement Department (ELEC), VUB and a post-doctoral researcher of the Research Foundation-Flanders (FWO). Her main research interests are nonlinear measurement and modeling techniques for medical and high-frequency applications. She was the recipient of the 2006 Outstanding Young Engineer Award from the IEEE Instrumentation and Measurement. Since 2007 she has been an associate editor for the IEEE Transactions on Instrumentation and Measurement and in 2010 she became an associate editor of the IEEE Transactions on Microwave Theory and Techniques.

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Kurt Barbé received the M.Sc. degree in mathematics (option Statistics) and the Ph.D. degree in electrical engineering from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 2005 and 2009, respectively. He is currently a Postdoctoral Research Fellow with the Flemish Research Foundation (FWO). At the VUB, he is with the Department of Fundamental Electricity and Instrumentation (ELEC) and a member of the research team Medical Measurements and Signal Analysis (M2ESA). His research interests are system identification, time series analysis, digital and analogue signal processing, statistical methods, finite and short sample measurement analysis and biomedical applications. Dr. Barbé has been an Associate Editor for the IEEE Transactions on Instrumentation and Measurement since 2010 and he is the recipient of the ‘Outstanding Young Engineer Award 2011’ of the IEEE Instrumentation and Measurement society.

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Per Landin received the M.Sc. in engineering physics from Uppsala University in 2007 and the lic. tech. (teknologe licentiat) in telecommunications from KTH/Royal Institute of Technology in 2009. He is currently working towards a joint Ph.D. with the VUB, ELEC department, and KTH, signal processing department. His main research interests are in the field of modeling and correction of nonlinear high frequency devices, and high frequency measurement systems.

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Lieve Lauwers was born in Jette, Belgium, on March 15, 1982. She received the degree of Electrical Engineering (option Photonics) in 2005 from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. In August 2005 she joined the department ELEC of the VUB as a PhD student. Her research interests are in the field of nonlinear system identification.

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Charles Nader was born in Lebanon, on July 11, 1982. He received an M.E. in electrical engineering from the Lebanese University ULFG2, Lebanon, in 2005 and an M.Sc in EE/Telecommunication from the University of Gävle, Sweden in 2006. In 2007, he joined the University of Gävle, center for RF measurement technology, and the Royal Institute of Technology, signal processing lab, Sweden, where he is currently working on his Ph.D. with a research focus on improving radio frequency systems performance by digital signal processing. In 2010, he received the degree of Licentiate of Engineering in Telecommunication/Signal Processing from the Royal Institute of Technology. In 2010, he also joined the Vrije Universiteit Brussel, ELEC Department, Belgium, where he is working toward a double PhD degree.

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Oscar J. Olarte Rodríguez was born in Colombia, March 31, 1980. In June 2004 he received the degree of Electronic Engineer from the Universidad Industrial de Santander (UIS). In September 2007, he obtained in the same University his Master degree in Electronic Engineer. In November he joined department ELEC at the Vrije Universiteit Brussel (VUB) for his PhD. His main research interests are in the field of signal processing and time series.

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1.4.5 Technical and Administrative Staff

Wim Delcourte Wim Delcourte was born in 1962 (Belgium). He graduated as an Industrial Engineer (Industrieel Ingenieur) in 1987. Since May 1989 he is with the department ELEC of the Vrije Universiteit Brussel (VUB full time tenure). Actually he is responsible for the design of electronic measurement instruments for research and education, for the repair and maintenance of complex measurement instruments and computers (20%). He also takes care of the management of the computerrooms of the faculty (80%).

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**Bea Huygen** was born in Uccle (Belgium) on May 30, 1970. She graduated as beauty consultant and runned a beauty center for 12 years. The period 2008-2010 she worked as a receptionist in the medical sector. In april 2011 she joined the department ELEC, as a part-time secretary.

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**Johan Pattyn** was born in 1974 (Belgium). After 2 years of engineering studies he joined the navy to become a radar technician. Since december 2009 he is with the department ELEC of the Vrije Universiteit Brussel (full time tenure). He is responsible for Rapid PCB Prototyping and also is involved in the maintenance and repair of the instruments and circuits for the students lab’s.

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**Ann Pintelon** was born in October 1963 (Belgium). In 1985 she received the Ms degree in Physical Education (VUB). Since 1990 she has been with the department ELEC at the Vrije Universiteit Brussel on a GOA contract (Measurement, Modelling and Identification of Dynamic Systems), and since 2008 she is working on ”Methusalem”: Centre for Data Based Modelling and Model Quality Assessment (4/5 tenure). She is mainly responsible for the scientific reports of the department ELEC (annual report, web-pages ELEC, …); the management of the infocentre (library, publication list, …); the administrative organisation of conferences and workshops; hosting of visiting researchers; and administrative support to the associated editor of Automatica in the dept. ELEC.

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**Sven Reyniers** was born in 1973 (Belgium). He has several years of ICT - experience in multinationals, including several international missions (France, Germany). Since 2006, he is working at the Vrije Universiteit Brussel (full time tenure) at the department ELEC. As system and network administrator he is responsible for the health and availability of the department servers and network.

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1.4.6 Professors Emeriti

**Alain Barel** was born in Roeselare, Belgium, on July 27, 1946. He received the degree in Electrical Engineering from the Université Libre de Bruxelles, Belgium, in 1969, the Postgraduate degree in telecommunications from Rijks Universiteit Gent (State University of Gent), Belgium, in 1974, and the doctor of applied science from the Vrije Universiteit Brussel in 1976. He worked as assistant and Lecturer at the Vrije Universiteit Brussel (VUB). From 2006 until September 2011 he has been 10% active at the department as Professor emeritus and teaches microwaves.

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**Michel Gevers** (see 1.4.3)

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**Ronny Van Loon.** Born in Antwerp, 1940, he obtained a degree in Physics at the ULB, and a PhD in Science at the VUB. He joined the VUB in 1970 as assistant, then Professor at the Faculty of Applied Science. In parallel with the teaching activities, he had research and logistic activities as a medical physicist at the university hospital AZ-VUB: from 1982 on in the Radiotherapy department focusing on EC granted projects in Hyperthermia, from 1989 on in the Radiology department involved in dosimetry and quality assurance. He directed the subgroup QUARAD (“Quality in Radiology”), a team involved in dosimetry, radiation protection and quality improvement in radiology. This group is acting in Belgium as reference centre for the Quality Assurance of the technical aspects of breast cancer screening. Prof. Van Loon is the Past-President of the Belgian Hospital Physicist Association, and member of the Board of the "Federal Agency of Nuclear Control" and the "Belgian Society of Radioprotection". He was delegate of the VUB in the VLIR-cooperation and Development Cell, and coordinates a cooperation project in Hanoi (Vietnam) and in VLIR International Training programme on Medical Physics. Until September 2005, he was still 10% active at the department ELEC as professor emeritus. He also contributes to the IAEA’s (International Atomic Energy Agency) teaching programs on radiation protection in medical applications of ionizing radiation. Presently he is scientific advisor at the "Belgian Museum of Radiology", Brussels, and he is active as a voluntary researcher at the dept. ELEC. In October 2008, he received the title of "Doctor Honoris Causa" from the Hanoi University of Technology.  
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## List of phone numbers and e-mail addresses (Status 01/02/2012)

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</tbody>
</table>
1.4.8  PhD-students from other departments, universities, institutions...

- BSc Herman CORDOVA, ESPOL, Ecuador: Promoter: L. Van Biesen
- ir. Mirko SCHOLZ, IMEC-Leuven, promoter: G. Vandersteen and D. Linten (IMEC)

1.4.9  Industrial Partnership

- Dr. ir. Alain GEENS, BeIV
- ir. Frank LOUAGE, MSc Zobeida Cisneros Barros; Address Systems N.V.
- Dr. ir. Luc PEIRLINCKX, Phonetics Topographics, Belgium
- Lic. Marc PERSOONS, Tresco Navigation Systems
- ir. Serge TEMMERMAN, SEBA service NV (measuring instruments for telecom. cables)
- Dr. Frank UYTDENHOUWEN, Banana-Telecom
- Dr. ir. Marc VANDEN BOSSCHE, Dr. ir. Frans Verbeyst; NMDG Engineering bvba

1.4.10  National or international contacts

1.4.10.1  Visiting professors/researchers

- Niclas BJÖRSELL, University of Gävle, Center for RF Measurement Technology, Sweden: 07/11/2011 – 08/11/2011. Presentation "Development of advanced excitation signals and sampling techniques for improved RF system performance"
- Péter Zoltán CSURCSIA, Budapest University of Technology and Economics, Department of Measurement and Information Systems, Budapest, Hungary: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems
- Marco Antonio DE ROMÁN MELLO, UPAEP Mexico, Biomedical Engineering: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems
- Ignat DOMANOV, KUL, Kortrijk, Belgium: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems
• **Keith GODFREY**, University of Warwick, School of Engineering: 02/04/2011 – 06/04/2011, and 06/05/2011: Member of Jury of PhD Lieve Lauwers, 20/12/2011 – 23/12/2011: cotutelle agreement: meeting with Hin Kwan Wong and Johan Schoukens


• **Liron HUANG**, KTH, Sweden: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems

• **Magnus ISAKSSON**, University of Gävle, Centre for RF Measurement Technology, Sweden: 29/03/2011 – 30/03/2011. Presentation “Modelling and pre-distortion of RF power amplifiers”

• **Ylva JUNG**, Linköping University, Sweden: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems


• **Per LANDIN**, University of Gävle, Center for RF Measurement Technology, Sweden: 01/02/2011 – 30/06/2011. PhD student, Cotutelle agreement.


• **Mikaya LUMORI**, University of San Diego, Electrical Engineering, San Diego, CA, USA, 03/06/2011 – 26/8/2011 Sabbatical on System Identification.


• **Gessami MONTALBAN**, University of Valencia, Spain: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems

• **Michael MÜHLEBACH**, ETH Zürich - Eidgenössische Technische Hochschule Zürich, Switzerland: 19/09/2011 – 22/01/2011. IASTE student – research on system identification


• **Michal NIEZABITOWSKI**, Instytut Automatyki Politechnika Śląska, Poland: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems

• **Jean-Philippe NOËL**, Université de Liège, Belgium: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems

• **Pieter NUY**, Technische Universiteit Eindhoven, 26/04/2011: cotutelle van David Rijlaarsdam
• Sebastien PERSONNE, Université de Compiègne, France: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems


• David RIJLAARSDAM, Eindhoven University of Technology, Control and Systems Technology: 24/03/2011: PhD John Lataire

• Verena RUPP, KIT - Karlsruhe Institute of Technology, Karlsruhe, Germany: 01/09/2010 – 15/01/2011, IAESTE The International Association for the Exchange of Students for Technical Experience

• Benjamin SANCHEZ, Universidad Politecnica de Catalunya (UPC), Barcelona, Spain: 21/02/2011 – 25/02/2011, research PhD


• Maarten STEINBUCH, Technische Universiteit Eindhoven, 26/04/2011: cotutelle van David Rijlaarsdam


• Jörg WALLASCHKE, the University of Hannover, Germany: 18/12/2011 – 20/12/2011. Presentation “Piezoelectric ultrasonic systems - Research at the Institute of Dynamics and Vibration Research”

• David WESTWICK, Department of Electrical and Computer Engineering, University of Calgary, Canada: 05/01/2011 – 30/06/2011. Identification of nonlinear systems using block oriented models

• Adrian WILLS, School of Electrical Engineering and Computer Science, University of Newcastle, Australia: 27/03/2011 – 10/04/2011. Presentation “Obtaining Maximum Likelihood Estimates via the Expectation Maximisation Algorithm” and Member of Jury PhD Laurent Vanbeylen


• Efrain ZENETO, KTH, Sweden: 06/05/2011 – 05/06/2011. Doctoral school VUB - dept. ELEC: Identification of Nonlinear Dynamic Systems

1.4.10.2 Scientific missions

- Kurt BARBÉ
  29/05/2011 30/05/2011 IEEE International Symposium on Medical Measurements and Applications 2011, Bari, Italy: presentation of paper “Exploring the fractional haemodynamics in fMRI data”
  06/06/2011 10/06/2011 Participating at IEEE International Microwave Symposium 2011, Baltimore, USA.

- Hermann CORDOVA

- Diane DE COSTER

- Michel GEVERS
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium. Presentation of a plenary lecture on “Modelling and identification: progress and new challenges”
  09/05/2011 13/05/2011 Evaluation of the quality of research at Uppsala University, Sweden
  28/08/2011 02/09/2011 Participating at the 18th IFAC World Congress, Milano (Italy)

- Jan GOOS

- Maulik Jain
  12/05/2011 12/05/2011 IUAP/PAI DYSCO study day at Colonster, University of Liège. Presentation of poster “Design, Realization and measurement of a CMOS Phase Locked Loop (PLL) to study its nonlinear performance”

- Sandor KOLUMBAN
• Per LANDIN

• John LATAIRE
  12/05/2011  12/05/2011  IUAP/PAI DYSCO study day at Colonster, University of Liège. Presentation of poster "Weighted LS Estimation of Spectral Contents & Periodicity of Signals Comprising Multi-Frequency Components"
  28/08/2011  02/09/2011  18th IFAC World Congress, Milano (Italy): Presentation of paper "Frequency Domain Errors-In-Variables Identification of a Time-Varying, Discrete Time System"

• Ebrahim LOUARROUDI
  28/08/2011  02/09/2011  18th IFAC World Congress, Milano (Italy): Presentation of paper "Frequency domain total least squares identification of linear, periodically time-varying systems from noisy input-output data"

• Anna MARCONATO
  15/03/2011  17/03/2011  30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of paper "Combining system identification and machine learning: a fast procedure for the initialization of nonlinear state-space models"
  12/05/2011  12/05/2011  Participating at the IUAP/PAI DYSCO study day at Colonster, University of Liège
• Griet MONTEYNE
  08/05/2011  11/05/2011  10th International Conference on Environment and Electrical Engineering, Rome, Italy. Presentation of paper “On the Use of Laplace and Warburg Variables for Heat Diffusion Modeling”

• Michael MÜHLEBACH

• Charles NADER
  06/06/2011  10/06/2011  IEEE International Microwave Symposium 2011, Baltimore, USA: presentation of paper “Peak-to-Average Power Ratio Reduction Versus Digital Pre-distortion in OFDM-based Systems”

• Oscar OLARTE
  15/03/2011  17/03/2011  30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of paper “A bottom up approach to non-invasive glucose measurements”
  09/10/2011  14/10/2011  The Electrochemical Society meeting, ECS-meeting United States: presentation of paper “The application of odd random phase electrochemical impedance spectroscopy (ORP EIS) in biological sensing applications”

• Rik PINTELOON
  15/03/2011  17/03/2011  30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Chairman
  28/08/2011  02/09/2011  Participating at the 18th IFAC World Congress, Milano (Italy)

• David RIJLAARSDAM
  15/03/2011  17/03/2011  30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of paper “Frequency domain based nonlinear feed forward design for friction compensation”
28/08/2011 02/09/2011 18th IFAC World Congress, Milano (Italy): Presentation of paper “Spectral analysis of block structured nonlinear systems”

- Johan SCHOUKENS
  10/01/2011 10/01/2011 Visit to Prof. Keith Godfrey, Warwick University, cotutelle Hin Kwan Wong
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Chairman
  27/05/2011 29/05/2011 Budapest University of Technology and Economics: receiving the title of Doctor Honoris Causa
  28/08/2011 02/09/2011 Participating at the 18th IFAC World Congress, Milano (Italy)
  12/12/2011 15/12/2011 50th IEEE Conf. on Decision and Control, Orlando, Florida: pres. paper “User friendly Box-Jenkins identification using nonparametric noise models”

- Maarten SCHOUKENS
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011, Presentation of paper “MIMO parallel Hammerstein identification”
  07/06/2011 22/06/2011 Uppsala University Sweden: Attending PhD Course “Nonlinear System Identification and its Applications”

- Koen TIELS
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of paper “Identifying a Wiener system using a variant of the Wiener G-Functionals”
  06/06/2011 01/07/2011 Delft University, The Netherlands: 4 visits in the frame of research on orthonormal basis functions

- Diana UGRYUMOVA
Introduction to the department ELEC

12/05/2011 12/05/2011 Participating at the IUAP/PAI DYSCO study day at Colonster, University of Liège

* David URIBE

17/07/2011 20/07/2011 Hannover University, Germany: Meeting with Prof. Jörg Wallaschek in the frame of research PhD

* Leo VAN BIESEN


* Mattijs VAN DE WALLE


* Wendy VAN MOER

15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Chairman
06/04/2011 07/04/2011 Visit HiG, university of Gävle and KTH, joint PhD degrees
29/05/2011 30/05/2011 IEEE International Symposium on Medical Measurements and Applications 2011, Bari, Italy: presentation of paper "Influence of the cuff deflation mode on oscillometric blood pressure measurements"
06/06/2011 10/06/2011 Participating at the IEEE International Microwave Symposium 2011, Baltimore, USA
22/08/2011 26/08/2011 University of Gävle, Center for RF Measurement Technology: Measurements in the frame of the submission of a transaction paper
15/12/2011 15/12/2011 KTH Stockholm, Sweden: meeting in the frame of Cognitive radios for medical applications
• Anne VAN MULDERS
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of poster "Unraveling polynomial nonlinear state-space models into Wiener-Hammerstein blocks"
  12/05/2011 12/05/2011 IUAP/PAI DYSCO study day at Colonster, University of Liège. Presentation of paper "Converting a polynomial nonlinear state-space model into a block-structure"

• Laurent VANBEYLEN
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of poster "Bounded operation of unstable nonlinear models under small random burst excitations"
  12/05/2011 12/05/2011 Participating at the IUAP/PAI DYSCO study day at Colonster, University of Liège
  12/12/2011 15/12/2011 50th IEEE Conference on Decision and Control, Orlando, Florida: presentation of paper "A state-space view on locally-stable, globally-unstable nonlinear models driven by Gaussian burst inputs"

• Gerd VANDERSTEEN

• Kevin VOET
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of poster "Mirrored parallel Hammerstein predistortion for multitone generation"
  04/09/2011 08/09/2011 Verspecht-Teyssier-DeGroote s.a.s. (VTD) is a spin-off company, Brive, France. Measurement campaign at VTD with Dr. Jean-Pierre Teyssier

• Dhammika WIDANAGE
  15/03/2011 17/03/2011 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011. Presentation of poster "Nonlinear System Identification of the Filling Phase of a Wet Clutch System"
Introduction to the department ELEC

1.5 ORGANISATION CHART OF DEPARTMENT ELEC

Team A: Automatic Measurement Systems, Telecommunications and Laboratory of Underwater Acoustics
Prof. Dr. ir. Leo VAN BIESEN, full-time professor
BSc. Hernan CORDOVA, PhD student
ir. Wim FOUBERT, PhD scholarship (until November 2011)
ir. Carine NEUS, research assistant
MSc. Taka YOSHIZAWA, PhD student

Team C: Applied Signal Processing for Engineering (ASPE)
Prof. Dr. ir. Alain BAREL, Professor emeritus (until September 2011)
ir. Lynn BOS, IWT scholarship, PhD student (until January 2011)
MSc. M. EL-BAROKU, PhD student (until January 2011)
MSc. Maulik Jain, PhD student (Sept. 2010-Oct. 2011)
MSc. Zhi LI, PhD scholarship (Until May 2011)
ir. Greet MONTEYNE, PhD scholarship
Prof. Dr. ir. Yves ROLAIN, full-time professor
ir. Mirko SCHOLZ, PhD student IMEC
ir. Maarten SCHOUKENS, PhD student
ir. Diana UGROYUMOVA, PhD student

Team B: System Identification & Parameter Estimation of Linear and Nonlinear Systems
Prof. Dr. ir. Johan SCHOUKENS, full-time professor
MSc. Pieter CSURCSIA, PhD scholarship (since September 2011)
ir. Egon GEERARDYN, PhD scholarship (since October 2011)
Dr. ir. Michel GEVERS, Professor emeritus
ir. Ian GOOS, PhD scholarship (since November 2011)
ir. John LATAYE, Post-doc.
ir. Ebrahim Louarroudi, PhD scholarship
Dr. ir. Anna Marconato, Postdoc.
MSc. David Oliva Uribe, PhD scholarship
Prof. Dr. ir. Rik PINTelon, full-time professor
ir. Koen TIELS, PhD scholarship
ir. Laurent VANBREYDEN, Postdoc.
ir. Matthias VAN DE WALL, PhD scholarship
ir. Anne VAN MULDERS, PhD scholarship
Prof. Dr. David WESTWICK, post-doc (Jan. 2011 – June 2011)
Dr. Dhammika WIDANAGE, Postdoc.

Team D: Medical Measurements and Signal Analysis (M2ESA)
Prof. Dr. ir. Wendy Van Moer
Dr. Kurt BARBE, Post doc.
ir. Per LANDIN, PhD student, cotutelle
ir. Lieve LAUWERS, PhD post doc.
ir. Charles NADER, PhD student, cotutelle agreement
ir. Oscar J. OLARTE RODRIGUEZ
BSc. Kevin VOET, PhD student (Aug. 2010 – Nov. 2011)

Team E: Identification of Biochemical Signals Systems
MSc. Maïté BAUVENS, PhD student (until March 2011)
MSc. Veerle BEELAERTS, PhD student (until June 2011)

Head of the Department
ELEC
Prof. Dr. ir. Johan SCHOUKENS

Technical and Administrative Staff:
ing. Wim DELCOURT, industrial engineer (20 % Staff ELEC, 80% Staff Faculty IR)
Mrs. Bea HUYGEN, part-time secretary on Methusalem (since April 2011)
mrs. Jenny LIEVENS, part-time secretary (until May 2011)
Mr. Johan PATTYN, technician
MSc. Ann PINTelon, 90% administrative coordinator
ing. Sven REYNIERS, network manager (Methusalem)
1.6 FUNCTIONAL ORGANISATION OF THE DEPT. ELEC

Head of department ELEC

J. Schoukens

- Electronic Design assistance
  J. Pattyn
  W. Delcourte
- Mechanical Design assistance
  J. Pattyn
- Didactical Design assistance
  J. Pattyn
- Purchase Electronic Components
  J. Pattyn
- Purchase General Components
  J. Pattyn
- Instrument Maintenance Coordi.
  W. Delcourte
- Instrument Inventory & Loan serv.
  W. Delcourte
- Office/ Lab. accommodation
  J. Pattyn

Technical assistance

- Centralization
  J. Pattyn
- Correspondence
  Personnel files
- Thesis printouts
- Administration
  Purchases
  Contracts
- Office material stock
  General secretariat
  Accounting

Infocenter

- Instrument and accessory overview
  J. Pattyn
- Library
- Magazine overview
- Literature overview
- Spare manuals
- Thesis books
- Data books
- Course notes
- Lab. Notes
- Internal notes
- Publication list
- Annual Report

A. Pintelon

Research Organization

- Coordination
  Theses/PhD follow-up
  Industrial contacts
  Job students follow-up
  Staff follow-up
  L. Van Biesen - team A
  J. Schoukens - team B
  G. Vandersteen - team C
  W. Van Moer - team D
  J. Schoukens - team E
- Research work
  Research staff

Support to other bodies, internal or external to the VUB

- AUTOMATIC - IFAC
  J. Schoukens, associate editor
  A. Pintelon, administration, follow-up
- IEEE Instrumentation & Measurement Society, Adcom
  R. Pintelon, K. Barbé, G. Vandersteen, W. Van Moer
  associate editors
- IEEE Microwave Theory and Techniques
  associate editor: W. Van Moer
- IMEKO:
  L. Van Biesen, President, Liaison Officer to IEEE
  IMEKO General Council L. Van Biesen, Chairman
  IMEKO Technical Board: L. Van Biesen, member
  IMEKO Editorial Board: L. Van Biesen, member
  IMEKO Advisory Board: L. Van Biesen, member
- ELSEVIER - IMEKO Journal "Measurement"
  L. Van Biesen, associate editor
- Faculty of Electrical Engineering
  J. Schoukens, vice-chairman of Research and
  investment council
  J. Schoukens: member board faculty
  L. Van Biesen, Chairman Council Bachelor Studies
  R. Pintelon, chairman PhD council
  Y. Rolain, chairman IT council
  W. Delcourte, support of system administrator
  W. Van Moer, chairman doctoral school NSE,
  Secretary ORE
- The Royal Academies of Science and the Arts of Belgium
  Member of National Committee of Radio-Electricity:
  L. Van Biesen
- Vrije Universiteit Brussel
  J. Schoukens, member research board
  J. Schoukens, member research council (OZR)
  J. Schoukens, member of Senate
- VUB-ORBAM faculty educational council for Bachelor in
  Engineering Science studies
  L. Van Biesen; chairman

Personnel

- Job students
- Follow-up
- Scholarships
- Research contracts
- Contract renewal
- Visiting researchers/professors

A. Pintelon

Public Relations

- Annual Report
- Internet - ELEC home page

A. Pintelon

National/international contacts

- Organisation of workshops, conferences, ...
  Research staff
  A. Pintelon
1.7 LIST OF THE MOST IMPORTANT MEASUREMENT EQUIPMENT

1.7.1 Signal Generators

- HP E1445A VXI Arbitrary Waveform Generator, \( f_{\text{max}} < 40 \text{ MHz} \) (3x)
- HP E1340A VXI Arbitrary Waveform Generator, \( f_{\text{max}} < 42 \text{ MHz} \) (3x)
- Synthesizer/Function Generator, Agilent 33120A (2x)
- NI 5411 AWG
- Noise Source, HP 346B, 10 MHz-18 GHz
- Agilent, 4142B, DC power supply
- HP E1434A VXI Arbitrary Waveform Generator, 4 channel source, \( f_{\text{max}}: 65 \text{ KHz} \)
- HP, Signal Generator, HP 83650B, 45 MHz - 40 GHz
- Tektronix, AWG710, 4 GHz
- Tektronix AWG 7052, 5GHz Arbitrary Waveform Generator
- Rhode & Schwarz, Vector Signal Generator, SMIQ06B, 300 kHz - 6.46 GHz
- Agilent 33250A, NI 5411, 2x AWG 33220A
- Agilent 81101A, Pulse generator, 50MHz

1.7.2 Spectrum Analysers, Impedance Analysers, Network Analysers

- 2 channel Dynamic Signal Analyser, HP 3562, 100 kHz (2x)
- Impedance Analyser, HP 4192A, 5 Hz - 13 MHz
- Vector Impedance Meter, HP 4193 A, 0.4 - 110 MHz
- Spectrum Analyser, R&S FSU, 20 Hz- 67 GHz
- µwave Network analyser, E8364B, 10 MHz - 50 GHz
- µwave Network analyser, N5242A, 10 MHz – 26.5 GHz 4 port
- Noise Gain Analyser, Eaton 2075 B, 10 MHz - 1800 MHz
- Network Analyser, HP 8753 C, 300 kHz - 6 GHz
- Spectrum Analyser, HP 8565 E, 9 kHz - 50 GHz
- PNA Network Analyser, Agilent, 5 0MHz - 50 GHz
- Impedance Analyzer, Agilent E4991A, 10MHz - 3GHz
- Anritsu BTS Master MT8222A, High Performance, Handheld Base Station Analyzer

1.7.3 Digitizers

- 4 channel digitizer, Nicolet 490, 200 MHz, 8/12 bit
- 4 channel Digital Sampling oscilloscope, HP 54120T, 20 GHz, 11 bit
- 1 channel, HP E1430A VXI ADC 10 MHz, 16 bit (10x)
- 1 channel, HP E1437A VXI ADC 20 MHz, 16 bit (4x)
- 2 channel, HP E1429B VXI ADC 20 MHZ, 12 bit (2x)
- 8 channel, HP E1433A VXI ADC 196 KHz
- 2 NI 5911 flexres digitizer
- TDS 3032 digital phosphor oscilloscope, Agilent D5060321 300MHz, TDS 2001C 50 MHz
- 6 NI Elvis II

1.7.4 Miscellaneous

- Dual programmable filter, Difa PDF 3700, 100 kHz
- Dual adjustable filter, Wavetek, 100kHz
- Logic state analyser HP 1645A
- µwave power meter, HP436A, 10 MHz- 18 GHz
- 4 VXI racks +4 MXI controllers + Digital cards (2x Agilent E4841A + 1 Agilent E4805A)
- HP E1450, VXI timing module
- HP E1446A, VXI power module generator
- Wafer Probe Station
- Polytec Optical Fibre Vibrometer
  Velocity range (Doppler interferometer): 1, 5, 25, 125, 1000 mm/s/V
  Displacement range (Fringe Counter): 2, 8, 20, 80, 320, 1280, 5120 µm/V
- 2 PXI mainframes + MXI controller + embedded controller
- Custom-built measurement setup for making geo-referenced GSM network measurements
- 4 hTC P3600 smart phones (equipped with 2G, 3G, Bluetooth, WiFi and GPS)
- 2 JRC DGPS 200

1.7.5 Underwater Acoustics

- Raytheon V860 echosounder
- B&K hydrophones, amplifiers etc.
- Panametrics transducers (500 kHz, 1MHz)
- D-GPS Beacon Receiver KODEN (KBR-90)
- 1 watertank + positioning system
- Anritsu BTS Master MT8222A, High Performance, Handheld Base Station Analyzer
# 1.8 FINANCIAL SUPPORT 2011

<table>
<thead>
<tr>
<th>Sponsor (project leader)</th>
<th>Duration project</th>
<th>Activity</th>
<th>Approx. amount (in €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSI302 (K. Barbé)</td>
<td>2011-2013</td>
<td>Central PhD office</td>
<td>3900</td>
</tr>
<tr>
<td>DWTC232 (R. Pintelon)</td>
<td>2007-2011</td>
<td>Dynamical systems, control and optimization (DYSCO)</td>
<td>400000</td>
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<tr>
<td>FWOAL434 (y. Rolain)</td>
<td>2008-2011</td>
<td>Scalable compact macromodels for general microwave and RF structures</td>
<td>138800</td>
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<tr>
<td>FWOAL454 (J. Schoukens)</td>
<td>2008-2011</td>
<td>Iteratief leren van model en regelaar voor sterk niet-lineaire systemen</td>
<td>277600</td>
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<tr>
<td>FWOAL483 (G. Vandersteen)</td>
<td>2008-2011</td>
<td>Analysis, modeling and design of multi-rate discrete-time sigma-delta circuits</td>
<td>23280</td>
</tr>
<tr>
<td>FWOAL561 (G. Vandersteen)</td>
<td>2010-2013</td>
<td>Black box modeling of boreholes for MPC of ground-coupled heat pumps</td>
<td>160000</td>
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<tr>
<td>FWOAL599 (R. Pintelon)</td>
<td>2011-2014</td>
<td>Modeling of complicated time-variant dynamic systems</td>
<td>60000</td>
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<tr>
<td>FWOKN236 (W. Van Moer)</td>
<td>2011</td>
<td>Measurement techniques for characterizing the nonlinear behaviour of microwave systems: a comparison</td>
<td>14507</td>
</tr>
<tr>
<td>FWOTM423 (R. Pintelon)</td>
<td>2007-2011</td>
<td>Measurement and modeling of weakly nonlinear slowly time-varying systems, bench fee PhD John Lataire</td>
<td>14880</td>
</tr>
<tr>
<td>FWOTM445 (W. Van Moer)</td>
<td>2007-2013</td>
<td>Identification of multiport nonlinear microwave systems, bench fee post-doc. Wendy Van Moer</td>
<td>20000</td>
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<tr>
<td>FWOTM562 (K. Barbé)</td>
<td>2010-2013</td>
<td>System Identification of Finite Records, bench fee post-doc Kurt Barbé</td>
<td>8000</td>
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<tr>
<td>FWOTM586 (L. Lauwers)</td>
<td>2011-2014</td>
<td>Bench fee post doc &quot;Identification of dynamic systems in FMRI signals, disturbed by RICE divided noise&quot;</td>
<td>4000</td>
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<td>FWOTM610 (Y. Rolain)</td>
<td>2011-2014</td>
<td>Bench fee PhD student Maarten Schoukens &quot;Identification of block-oriented models with parallel structures for nonlinear systems&quot;</td>
<td>3720</td>
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<td>HERC3 (W. Van Moer)</td>
<td>2008-2013</td>
<td>Multidisciplinary centre for measurements using advanced technologies of the Brussels University Association.</td>
<td>73418</td>
</tr>
<tr>
<td>HOA13 (R. Pintelon)</td>
<td>2007-2011</td>
<td>Een geïntegreerde aanpak voor het opmeten en modelleren van elektrochemische reacties: een nodige voorwaarde voor het vergaren van betrouwbare data.</td>
<td>17500</td>
</tr>
<tr>
<td>IWT419 (J. Schoukens)</td>
<td>2009-2013</td>
<td>LeCoPro Learning Control for Production Machines</td>
<td>82168</td>
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<tr>
<td>Legal Expertise (L. Van Biesen)</td>
<td>Since 1995</td>
<td>Expert to the court</td>
<td>Confidential</td>
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<tr>
<td>License Identification Toolbox (J. Schoukens)</td>
<td>Since 1994</td>
<td>Identification Toolbox</td>
<td>Confidential</td>
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<tr>
<td>NDA29 (L. Van Biesen)</td>
<td>Since 2004</td>
<td>Cellular positioning</td>
<td>Confidential</td>
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<td>NDA65 (A. Barel)</td>
<td>Since 2005</td>
<td>Mutual non-disclosure agreement (NDA): project for a RDS TMC receiver box</td>
<td>Confidential</td>
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<tr>
<td>NDA240 (G. Vandersteen)</td>
<td>2008-2018</td>
<td>NDA – Secrecy Agreement</td>
<td>Confidential</td>
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<tr>
<td>NDA367 (W. Van Moer)</td>
<td>Since 2009</td>
<td>NDA – Secrecy Agreement</td>
<td>Confidential</td>
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<tr>
<td>NDA584</td>
<td>2011-2018</td>
<td>NDA – Non Disclosure Agreement</td>
<td>Confidential</td>
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<td>Sponsor (project leader)</td>
<td>Duration project</td>
<td>Activity</td>
<td>Approx. amount (in €)</td>
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<tr>
<td>(L. Van Biesen)</td>
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<tr>
<td>NDA639</td>
<td>2011-2014</td>
<td>NDA – Confidential Disclosure Agreement</td>
<td>Confidential</td>
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<tr>
<td>OZR1731 (R. Pintelon)</td>
<td>2009-2011</td>
<td>Measuring and modelling of dynamic systems</td>
<td>9828</td>
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<tr>
<td>OZR1732 (Y. Rolain)</td>
<td>2009-2011</td>
<td>Study of microwave systems</td>
<td>37250</td>
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<tr>
<td>OZR1733 (J. Schoukens)</td>
<td>2009-2011</td>
<td>Data driven modelling</td>
<td>19250</td>
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<tr>
<td>OZR1734 (L. Van Biesen)</td>
<td>2009-2011</td>
<td>Physical telecommunication studies</td>
<td>22142</td>
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<tr>
<td>OZR1736 (W. Van Moer)</td>
<td>2009-2011</td>
<td>Measuring and modelling of microwave systems</td>
<td>12000</td>
</tr>
<tr>
<td>OZR2169 (J. Schoukens)</td>
<td>Since 2010</td>
<td>Bench fee Joint PhD VUB-Eindhoven University of Technology, Rijlaardsdam D.J.</td>
<td>2000</td>
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<td>VLR219 (L. Van Biesen)</td>
<td>2009-2014</td>
<td>Cooperation between l’Institut Supérieur des techniques Appliquées (ISTA) and Université Technologique de Kinshasa (UNITEK) in information and communication technology (ICT)</td>
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<td>Coaching PhD Griet Monteyne “Application of noise methods for PWR’s”</td>
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<td>WDG0894 (L. Van Biesen)</td>
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<td>Research Telecommunication</td>
<td>187240</td>
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<td>WDV12 GAMAX kft (J. Schoukens)</td>
<td>Since 2000</td>
<td>Graphical user interface for the frequency domain system identification toolset</td>
<td>Confidential</td>
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Confidential

1/3 ELEC

1/3 patent fund
1.9 AWARDS

1.9.1 Grade of Fellow (IEEE)

The Institute of Electrical and Electronic Engineers, Inc. elected the grade of fellow to:

- Michel Gevers: for contributions to the understanding and identification of linear multivariable systems (1990)
- Johan Schoukens: for contributions to frequency domain system identification and the integration of measurement, signal processing and estimation theory (1997)
- Rik Pintelon: for fundamental research in frequency domain system identification and its applications in instrumentation, control and signal processing (1998)
- Yves Rolain: for contributions to measurement and modeling of nonlinear microwave devices (2005)

1.9.2 Grade of Senior member (IEEE)

- Gerd Vandersteen: In recognition of professional standing (2007)
- Wendy Van Moer: In recognition of professional standing (2007)

1.9.3 Awards from IEEE Instrumentation and Measurement Society (US)

- Johan Schoukens: IEEE society Distinguished Service Award for technical and professional leadership of the IEEE Instrumentation and Measurement Society, 2003
- Yves Rolain received the Recipient of the 2004 IEEE Instrumentation and Measurement Society award “For Contributions to Nonlinear Circuit technology”.
- Johan Schoukens: IEEE Society Distinguished Service Award For technical and professional leadership of the IEEE Instrumentation and Measurement Society as Technical Program Co-Chair of IMTC/96 and author of conference papers on an annual basis, Associate Editor of the IEEE Transactions on Instrumentation and Measurement and member of the Society of Administrative Committee
- Wendy Van Moer received the “2006 Outstanding Young Engineer Award” from the IEEE Instrumentation and Measurement Society for outstanding contributions to nonlinear circuit theory.
- Rik Pintelon received the “2010 TIM Outstanding Associate Editor Recognition” for the meticulous, objective, professional and timely manner by which responsibilities while overseeing the review processes of numerous papers in 2010 are conducted.
- Wendy Van Moer received the "2010 TIM Outstanding Associate Editor Recognition” for important contributions to TIM: for the meticulous, objective, professional and timely manner by which responsibilities while overseeing the review processes of numerous papers in 2010 are conducted.
• Kurt Barbé received the “2011 Outstanding Young Engineer Award” from the IEEE Instrumentation and Measurement Society for the innovative application of statistical techniques and signal analysis in biomedical measurements.

1.9.4 Award from IEEE Control Systems Society

Michel Gevers: Distinguished Member of the IEEE Control Systems Society in recognition of exceptional service to the Society and the profession (1997)

1.9.5 Grade of Fellow (IFAC)

Michel Gevers: For fundamental contributions to system identification and its connection to control (2006)

1.9.6 Belgian Francqui Chair ULB

Prof. Dr. ir. Johan Schoukens (2006-2007): ”Identification of linear systems in the presence of nonlinear distortions: a frequency domain approach”.

Linear models are at the basis of many engineering activities. The aim of this course is to identify these models from experimental data. In real life, nonlinear distortions violate the ideal linear framework. Two solutions are discussed to extend the classic linear modelling approach. First the linear framework will be extended to include these distortions using best linear approximations and nonlinear noise sources. Alternatively, the nonlinear distortions will be explicitly modelled.

Lectures (see pdf-files at http://wwtw.vub.ac.be/elec/ELEcourse.htm):
• Inaugural: System Identification from data to model
• Lesson 1: Frequency Response Function Measurements
• Lesson 2: Impact of Nonlinear Distortions on the Linear Framework
• Lesson 3: System Identification (pdf-file)
• Lesson 4: Identification of Linear Systems
• Lesson 5: Identification of Nonlinear Systems

1.9.7 Awards granted by the VUB, on the proposition of the department ELEC

• Title of Doctor Honoris Causa to Prof. P. Eykhoff (Technische Universiteit Eindhoven) on April 4, 1990 (VUB, Brussels)
• Medal of Excellence to William Hewlett and David Packard on March 3, 1995 (VUB, Brussels)
- Medal of Excellence to Joseph F. Keithley on June 4, 1996 (Gothic Town Hall of Brussels)
- Title of Doctor Honoris Causa to Prof. M. Gevers (Université Catholique de Louvain - CESAME) on November 28, 2001 (VUB, Brussels)

1.9.8 Distinguished Service Award from IMEKO

The International Measurement Confederation extends to Prof. Leo Van Biesen this Distinguished Service Award:

- As recognition and appreciation for his valuable contribution to the international exchange of scientific and technical information relating to developments in measuring techniques, instrument design and manufacture and in the application of instrumentation in scientific research and in industry.
- For his continuous support in IMEKO as member of several TCs, delegate of the Belgian Member Organization to the General Council, President Elect and Chairman of the Technical Board from 2000 to 2003, President of the Confederation from 2003 to 2006 and Past President and Chairman of the Advisory Board from 2006 to 2009.

1.9.9 Doctor Honoris Causa

Prof. Em. Michel Gevers received the title of “Doctor Honoris Causa” from the Vrije Univeristeit Brussel in November 2001 and from the Linköping University (Sweden) in 2010.

Prof. Em. Ronny Van Loon received the title of “Doctor Honoris Causa” from the Hanoi University of Technology, in October 2008, for his personal contributions to the VLIR HUT IUC program in particular and the development of Hanoi University of Technology in general over the past 10 years. Thanks to his tremendous efforts as a key promoter since the establishment in 1998, the VLIR IUC programs with HUT has vigorously developed and reaped fruitful achievements, significantly contributing to the expansion of international network and international academic exchange at Hanoi University of Technology.

Prof. Dr. ir. Johan Schoukens received the title of “Doctor Honoris Causa” from the Budapest University of Technology (Hungary) in May 2011.

1.9.10 Member of the “Royal Flemish Academy Of Belgium For Science And The Arts”

Prof. Dr. ir. Johan Schoukens has been elected in December 2009 as member of the “Royal Flemish Academy Of Belgium For Science And The Arts” for the section “Technical Sciences”.

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1.9.11 Paper/presentation awards (since 2008)

Carine Neus received at the Symposium on Communications and Vehicular Technology in the Benelux (2008) the "Best Paper Award" for the paper "Challenges for Loop Identification and Capacity Estimation of DSL with Single Ended Line Testing".

Carine Neus received from IMEKO the “Best Paper Award” for the paper “Feasibility and problems of DSL loop topology identification via single-ended line tests” presented at the 16th IMEKO TC4 International Symposium and 13th International Workshop on ADC Modelling and Testing, Florence, Italy (September 2008)

Mussa Bshara and Leo Van Biesen received the “Top Six Achievement Award “Winning Paper” for the paper “Potential Effects of Power Line Communication on xDSL Inside the Home Environment” presented at the VIII Semetro. 8th International Seminar on Electrical Metrology João Pessoas, Paraiba, Brazil June 17 - 19, 2009


Mussa Bshara and Leo Van Biesen received the “Best Paper Award” for the paper “Fingerprinting-based Localization in WiMAX networks depending on SCORE measurements”, presented at the Fifth Advanced International Conference on Telecommunications, AICT 2009, Venice/Mestre, Italy, May 24-28, 2009

Yves Rolain received the “Automated RF techniques group best paper award” from IEEE in 2010

John Lataire received the “Best Junior Presentation Award 2010” at 29th Benelux Meeting on Systems and Control in Heeze, The Netherlands. He received the DISC trophy for the presentation of the paper “Frequency Domain Least Squares Estimator of Time-Varying”.

1.9.12 Master thesis awards

Diane De Coster received in October 2011 from FWO the “Barco High Tech Awards for Master thesis”, for her master thesis entitled “Ontwerp en realisatie van een geminiaturiseerde elektronische lock-in detectiemodule voor het meten van biomoleculen in fotonische ‘lab-on-a-chip’ systemen”.

Maarten Schoukens received in March 2011 from IMEC the “IMEC-award for the best Master thesis at the faculty of Engineering, at the Vrije Universiteit Brussel” for his master thesis entitled “Ontwerp en realisatie van een compensatie voor niet-lineaire RF vermogenversterkers”.

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2. Short Description of the Research Projects/ Team

2.1 TEAM A: AUTOMATIC MEASUREMENT SYSTEMS, TELECOMMUNICATIONS AND LABORATORY OF UNDERWATER ACOUSTICS

2.1.1 Introduction to Team A

The activities of team A directly related to fundamental electricity, deal with the set-up of computer controlled measurement systems, the design of new intelligent instruments, the processing of the measured data (DSP and algorithmic treatment) and the implementation of A.I.- techniques in instruments for the automatic interpretation of the acquired measurements. The technical applications areas are quite diverse and cover areas in the field of electrical and electronic systems, but a lot of special care is also given to earth science applications.

This team is also active in telecommunication projects and studies, which deal with voice coded transmissions (telephony) and with robust coded digital transmission (ADSL, VDSL). Communication channels are modelled, with emphasis on the physical layer.

Moreover, in the field of underwater acoustics important research projects are developed since 1985. Fundamental as well as applied research is carried out in the field of the modeling of marine systems, marine acoustics, sub bottom profiling and sediment classification.

Prof. Dr. ir. L. Van Biesen has been the Belgian delegate in the board of IMEKO since 1993 and chairman of the Technical Committee TC-7 on Measurement Science since 1994, up to 2000, has been vice-chairman of the Technical Committee TC-19 on Environmental Measurements since 1999, President-Elect of IMEKO (2000-2003) and was the President of IMEKO (2003-2006), and has been Post-President of IMEKO (2006-2009)
2.1.2 Short Description of the Research Projects of Team A

2.1.2.1 Design and evaluation of Multiple-Input-Multiple-Output channel models for DSL systems  
(Wim Foubert, Leo Van Biesen)

Digital Subscriber Line (DSL) technology provides broadband service over ‘twisted pair’ copper wires of the existing telephone network. Current DSL systems make only use of differential mode (DM) signals, which refers to the electrical voltage difference between the two wires of a twisted pair (see Figure 1). However, in most countries there are two twisted pairs that enter each house. In next generation DSL technologies, all four wires will be exploited. In this way, two differential mode signals and an additional phantom mode signal can be defined. This new signal is the voltage difference between the references of each twisted pair. In the differential mode, the currents in the two conductors of the twisted pair are in opposite direction. In the phantom mode, they are in the same direction and another twisted pair stands in for the return path. In this way, the phantom mode signal is invisible for the differential mode signal on each pair. The phantom mode signal can also be seen as a differential mode signal but now one uses four conductors instead of two. Using also the phantom mode signal in addition to the differential mode signal, the capacity can be three times higher than the conventional differential mode only capacity!

In order to use also the phantom mode signal, we need reliable transmission line models which take also this signal into account. The derivation of the new models is based on the multiconductor transmission lines (MTL) theory. This theory is only valid for uniform line segments. Figure 40 shows how the behavior of a twisted pair can be approximated. The representation contains a resistor $R$, an inductor $L$, a conductance $G$ and a capacitance $C$. For our model, good approximations for the different physical parameters are indispensable.

This problem is decoupled. First we consider the transversal plane to determine the resistance $R$ and the inductance $L$. Therefore we use a quasi-stationary approximation since the diameter of the quad is much lower than the wavelengths of the transported signals. An analytical expression exists for the transversal plane, which is called the series impedance and was derived by Belevitch [1]. Beside the skin effect, also the proximity effect is taken into account. This series impedance has been validated with measurements as described in [2]. In the longitudinal plane, the considered line lengths are of the same order of the wavelength. A numerical approximation technique will be used to obtain accurate results for the capacitance matrix. Also this matrix has been validated. Therefore a two-dimensional simulator, called Maxwell is used.
Once we have the complete model for a homogeneous quad, twisting will be introduced. The multiconductor transmission lines theory is only valid for uniform line segments. But, if we want to allow wire twists, strands and variations our cable is not uniform at all. To overcome this problem, the system will be split up in very short line segments. Each segment is considered to be uniform and is represented by a transmission matrix. The overall cable description is obtained by multiplication of the different matrices. In this way, it’s easy to increase the number of pairs, change the twist rate, stranding or isolation just by changing one or more parameters in the model.

In the next part, the eigenmodes of the quad are investigated. Since we know the four parameters (R, L, G and C), it is possible to calculate the product YZ where Y represents the admittance matrix and Z is the impedance matrix. Diagonalizing this product gives four eigenvalues and the corresponding eigenvectors. Analyzing this, we notice that the two differential modes and the phantom mode are all eigenmodes of the system. Moreover there is no crosstalk between the different modes. This proves that exploiting also the phantom mode signal will strongly increase the available capacity.

References

2.1.2.2 Modeling of the channel transfer function and the crosstalk for specific historical connectivity practices in DSL copper networks and assessment of the effect on the achievable data rates

(Carine Neus, Leo Van Biesen, Lieven Mertens*, and Kurt Coulier*)

(*) Belgacom

Digital Subscriber Line technologies like ADSL, ADSL2+, VDSL2 and its evolutions offer high-speed data services (e.g. internet connection, digital television,...) to customers over the existing telephone lines. For practical reasons, the telephone lines are not simply a single straight line between the central office and the customer. Lines are bundled for cost effectiveness, repairs have been made, different line types are cascaded,... As a consequence, very peculiar topologies can be found in the field.

In this research, we focus on one specific type of connection, namely ‘retour pairs’, which have a different topology than the ‘direct’ pair (see Figure 3). The retour pair passes the customer’s house and returns after a certain distance “r”, typically at the splice at the end of the cable. Hence their name ‘retour pairs’.

Due to historical reasons many customers receive two twisted pairs at home, and in the majority of these cases it is one direct pair and one retour pair.
Due to the characteristics and spectrum usage of VDSL2, the use of the direct pair for service offering is obvious and recommended. But with the ever increasing request for bandwidth driven by strong competition and customer demand, and with the evolution of VDSL2 towards VDSL2 Vectoring, the operators show a need to better understand the behaviour of the retour pair. After all, the use of the retour pair is economically very interesting since civil works might be avoided in some cases, despite the expected degraded overall performance of the retour pair.

Figure 3: Two twisted pair lines arriving at one customer: one direct pair and one retour pair

This research aims at predicting the achievable data rate on retour pairs. We assume that they will behave differently from a direct pair, as their physical construction is different (i.e. they are folded back on themselves after a certain distance). Basically, two aspects must be studied:

1. The channel transfer function needs to be modelled.
2. The crosstalk needs to be evaluated.

During 2011, a model has been developed for the channel transfer function of a retour pair. The model has been validated in the ELEC laboratory and in the field (in an operational distribution center). In 2012, the crosstalk in the presence of retour pairs will be evaluated.

This project is performed in cooperation with Belgacom.
2.2 TEAM B: SYSTEM IDENTIFICATION AND PARAMETER ESTIMATION

2.2.1 Introduction to Team B

The main interest of the identification team is situated in the development of new identification methods and their application to real life problems. The team is involved with many aspects of the identification theory:

- experiment design
- development of estimators
- modelling problems

The identification of linear and nonlinear systems is studied.

Throughout our work we make the following choices:

- Use of periodic excitations whenever it is possible, use random excitations if it is imposed by the user.
- Use of non-parametric noise models to characterize the stochastic disturbances
- Use of an errors-in-variables framework: all measured signals are assumed to be disturbed by noise.
- Believe your data, not your prejudices.

It will not always be possible to act along these clear principles, but whenever we face a choice, they are an important factor in our decision process.

Another important aspect of our general approach is that we start the process by gathering system knowledge from the measurements. This gives in a very early phase of the identification process an idea of the global complexity of the modelling problem. For the linear systems this phase boils down to the non-parametric measurement of the frequency response function, which is usually of a high quality due to the periodic excitation approach. It contains a lot of information about the system. For nonlinear systems the situation is not that clear, and a number of ideas are under study at this moment.

IDENTIFICATION OF LINEAR SYSTEMS

In the eighties, ELiS, an estimator to identify single input single output (SISO) linear dynamic systems in the presence of uncorrelated input/output noise, was developed at the department ELEC. In a next step this estimator was generalized to multiple input/multiple output systems in the presence of correlated input and output noise.

Since linear dynamic systems are used as a basic modelling tool in a very wide range of applications, it is clear that this work has a lot of applications. We applied this modelling approach to chemical problems (traction batteries, diffusion processes), power engineering (electrical machines, power transformers; fault localisation on a cable), mechanical problems (flutter analysis,
flexible robot arm) measurement area (compensation of the dynamics of an acquisition channel, modelling the dynamics of a sensor), and signal processing (design of digital filters). In all these applications the identified transfer function model was an intermediate step, for example leading to a better physical insight in the structure of the DUT, or to be used to improve the quality of the process control.

Nowadays we are further developing the estimators, making them more robust and user friendly, resulting in a wider applicability of ELiS. Moreover a lot of effort is spent to generalize frequency domain identification methods so that they also can be applied under exact the same conditions as time domain methods, but still offering the advantages of using a non-parametric noise model.

**robustification:**
- what happens if the true model is not contained in the considered model class, for example when non-linear distortions or unmodelled dynamics are present
- what can be done if no noise information is available
- identification of high order systems, identification of an over parametrized model
- generation of improved starting values

**user friendly:**
- is it possible to extract the noise information from the same measurements that are used to identify the system without user interaction
- is it possible to guide the inexperienced user to a good solution of his identification problem
- development of fully automated processing methods: from raw time domain data to validated models (including automatic detection and processing of the periodicity of the signals; extraction of non-parametric noise models; model selection; model validation)

**Generalization:**
- identification of MIMO systems: design of excitation signals, development of new algorithms, constraint estimation (stability, positive definite systems)
- identification of continuous time models using arbitrary excitations
- developing a general theoretic framework linking time and frequency domain identification
- generalization to other fields like electrochemical reactions (÷s) and microwave systems (Richardson)

**IDENTIFICATION OF NON LINEAR SYSTEMS**

In the last 10 years we started to study more intensively identification of non-linear systems. It is not a good idea to define the class of models under study by a negation. Just as it is an impossible task to make a study of the zoology of the ‘non elephants’, it is impossible to grasp all non-linear systems in one framework. We should be more specific and give a positive definition of those systems that we will consider. In this project we focus on those systems where a periodic input
results in a periodic output with the same period as the input (we call it PISPOT systems). This excludes a lot of phenomena like chaos, bifurcation, but it is still a wide class, including hard non-linear systems like clippers, relays, deep saturation etc. Selecting a specific model structure for these systems is still a very complex task. Not only the non-linear behaviour should be properly characterised, also the dynamics should be captured. This requires that many choices from the user, compared to the linear problem, that it is not a good idea to start immediately with a parametric model when identifying a non-linear system. Too many questions would remain unanswered. For that reason, we prefer to start with a non-parametric representation of the system, trying to get a first insight in its behaviour. Only in a second step, we will eventually move to a specific parametric model that might be well adapted to the given problem, using the previously gained insights to select a dedicated model structure.

Our work on identification of nonlinear systems is split in two parts. In the first part we study the impact of nonlinear distortions on the linear identification framework. In the second part we aim at modeling the nonlinearities.

**Linear modelling in the presence of nonlinear distortions**

Linear models are successfully applied to a wide range of modelling problems although they are based on very restrictive assumptions. The real world is not linear, and hence intrinsically the theory is not applicable. However, in practice, the linear approximations are useful and offer important advantages:

- They result in useful models that give the user a lot of intuitive insight in his problem.
- Many design techniques, that cannot be easily generalised to nonlinear models, are available.
- Nonlinear model building is mostly difficult and time consuming, while the additional performance that is obtained might be small. So it is not obvious that the gain in model performance warrants the required efforts to build a nonlinear model.
- No general framework is available for nonlinear systems as it is for linear systems. Often dedicated models are needed, complicating the development/use of general software packages.

For these reasons we work on a generalised linear framework that can be used in a nonlinear environment. Using this framework it is possible to get:

- A better understanding of the impact of nonlinear distortions on the model.
- Optimized measurement techniques that reduce the required measurement time significantly.
- Generalised uncertainty bounds that describe the model variations due to the nonlinear distortions. This allows for a better balanced design that accounts for the model limitations.
- A lower risk of being fooled by the classical linear identification methods that are widely used in commercial packages.
- Simple design rules that help to reduce the undesired impact of nonlinear distortions on practical designs.
The whole approach is based on the observation that for random excitations, a nonlinear system can be represented under very mild conditions by a linear system plus an additive noise source. The linear system $G_R(j\omega_k)$ gives the best linear approximation of the output for the considered class of excitation signals, while the noise source $\gamma_s(j\omega_k)$ represents all nonlinear effects that are not captured by the model.

**Identification of nonlinear systems**

Nonlinear modelling is extremely difficult. The major reason for this problem is the enormous variability that exists. Even when we zoom in to for example Volterra systems, there are still many additional degrees of freedom compared to the modelling of linear system. The only model structure question for SISO-transfer functions is the order of the numerator and denominator. For SISO-Volterra systems, the situation is much more complicated, because the model uses multiple frequency variables that can appear in any possible combination. Hence no simple prior structure selection is possible. For that reason it is our strong belief that the parametric modelling step should be preceded by a non-parametric one. First the user should get an impression of the nonlinear behaviour, and only in the next step he can propose a parametric model structure.

For that reason we studied and still look at a number of non-parametric methods like: Restoring force method, the power transfer method, the non-parametric Volterra models.

For the parametric modelling we follow different approaches: nonlinear block-structured models and nonlinear state-space models

* Non-linear block-structured models consists of linear dynamic blocks combined with static non-linear blocks. In its most general form feedback loops can be present. The major advantage of this structure is that it still provides some physical insight in the system, and it uses a ‘small’ number of parameters. The major disadvantage is that it is extremely hard to find good initial estimates for the individual blocks.

* Non-linear state-space models cover a large class of non-linear systems with a very rich behaviour. They can be considered as a potential candidate for ‘black-box’ modelling of non-linear systems. The major advantage of this structure is that it is much easier to find reasonable initial estimates for the structure for systems with a dominating linear behaviour. The major disadvantage is the large number of parameters that are used. These models provide also less physical insight.

* Finally we study also dedicated non-linear structures to model a number of typical high-frequency components like mixers. For these systems we use either Volterra-based descriptions, or dedicated block-structured models.

**METHUSALEM: Centre for Data Based Modelling and Model Quality Assessment**

This is a project setup by the Flemish government to give long term stability to established research groups. The project runs for 7 years, with a budget of more than 500 000 Euro/ year.

The ultimate goal of the project is to set up and maintain a centre for system identification, summarized in the motto: “From data to model”
The aim of this centre is to develop, acquire and disseminate advanced system identification methods.

**Structure of the project**

This project follows three lines towards this long term goal:

- Development of advanced identification methods for dynamic systems: Development of robust and user friendly methods for the identification of (non)linear dynamic systems. This is the home base of the identification team, and it consists of a ‘natural’ continuation and extension of the activities of the team over the last 20 years.
- High risk new challenges: Start-up of completely new high risk research lines that need a substantial development compared with the existing theory and methodology. It consists of two sub-projects:
  - Development of a ‘non-asymptotic’ identification theory: How to deal with modelling problems where the number of data points is in the same order as the number of parameters?
  - Identification in the presence of noise and model errors: Development of a new paradigm that balances/tunes noise disturbances and model errors.
- Learning, dissemination, networking: The aim is to acquire and disseminate actively knowledge from/to other fields by offering one year research grants for visitors.
  - Learning: On the one hand we want to acquire system identification methods that are developed in other fields like statistics, econometrics, and are unknown within the control- and measurement society (learning), by hosting specialists of these fields for longer periods.
  - Dissemination: On the other hand, many scientific disciplines face the problem of extracting mathematical models from experimental data, while this does not belong to their core business. Here, we want to give an active support to transfer sound identification methods to these groups, by hosting and paying PhD-students of external (VUB-) groups for a longer period.
  - Networking: Extend the existing international network of post-doc and senior researchers by combining short term and/or long term visits.

2.2.2 Short Description of the Research Projects of Team B

**2.2.2.1 Estimation of non-parametrically slowly time-varying systems**

(Péter Zoltán Csurgcia, Johan Schoukens, Istvan Kollár)

*Cotutelle: Vrije Universiteit Brussel (J. Schoukens) and Budapest University of Technology and Economics (I. Kollár)*

The aim of my current work is to develop a new method which estimates non-parametrically slowly time-varying systems represented by a two dimensional impulse response function \( h_{UV}(t,r) \). A generalized B-spline technique is used for double smoothing: once over the different excitation time (which refers to the system memory) and once over the actual excitation (referring to the system behaviour). If the parameter changing of the observed system is sufficiently slow, then we can use a new approach to decrease the number of parameters to be stored i.e. decrease the
degree of freedom and the computing time. The proposed algorithm is based on modified, generalized B-spline basis functions.

Let me give a very simple simulation example to compare the proposed method with other, traditional methods for surface fitting. Let us consider a time-varying system represented by a second order inverse Chebyshev low-pass filter with changing ripple ratio and resonance. The acceptance level in this case 27.76 (a weighted cost function is used).

![Figure 4. On the left side is the system under test is shown: second-order Chebyshev low-pass filter with time-varying parameters: ripple and pass-edge frequency, on the right side the weights](image)

The following figure shows the best estimation with the highest order what we can use in Matlab® with embedded polynomial fitting (poly55, normalized, ‘LAR’ optimized). The weighted error (28.85) is above the acceptance level (27.76).

![Figure 5. Polynomial estimation with orders of 5/5 using Matlab®. On the left side the estimation is shown, and on the right side the rms value of the Euclidean distance between true and estimated systems in decibel scale](image)

The next one is computed by LOWESS method (with span of 2.5%). This result is already acceptable (weighted error 21.41) but the computing time is around thousand times higher than in the above case.

![Figure 6. LOWESS method with best fitting parameters. On the left side the estimation is shown and on the right side the rms value of the Euclidean distance between true and estimated systems in decibel scale.](image)

The next example shows the results of the modified double smoothing technique with 2/3 degrees of spline polynomial, using only each twelfth point on the frequency and on time axis. This estimation was the fastest and the best among all.
2.2.2 DEVELOPMENT OF USER-FRIENDLY SYSTEM IDENTIFICATION METHODS
(E. Geerardyn and J. Schoukens)

When a system model is constructed by engineers or other scientists, a plethora of technical choices is to be made. Each of these choices has an influence on the quality and usability of the obtained model. Bad choices can cause the constructed model to be unfit for its intended purpose. For laymen in system identification it is hard to make well-guided choices.

In this project we will develop methods for system identification that are user-friendly in the sense that little system identification knowledge is assumed from its users. This should bring system identification techniques within reach of a broader public of specialists that are not necessarily formally educated in system identification. We will consider three major divisions in this task: robust experiment design, generation of initial values and proper model validation.

Robust Experiment Design:

A first step in system identification is measuring the system behaviour. With measurements, also disturbances such as noise or nonlinearities are observed. When these phenomena are not treated in a suited way, the accuracy of the model will be influenced. For a non-specialist in system identification this causes insurmountable problems. In this project we focus our attention on robust experiment design that requires little foreknowledge from the user. On the other hand, we will also study proper pre-processing (such as the local polynomial method) of the measurements such that subsequent steps in the process are facilitated and more information can be extracted from the measurements.

In practice, excitation signals with a power spectrum that is distributed in 1/f (e.g. quasi-
logarithmic multisines) are suitable robust excitation signals that require little foreknowledge of the system under test. In Figure 8 such a quasi-logarithmic signal is compared to a linear grid multisine, with the same power, for a broad range of systems. Such a quasi-logarithmic signal clearly provides a lower uncertainty that is almost independent of the resonance frequency of the system. In [3] it is elaborated that such quasi-logarithmic multisines offer a simple approach to obtain a specified variability of the transfer function of LTI systems, while keeping signal power limited, albeit effective over a large frequency range. A more elaborate input design procedure is also being developed to further examine these excitation signals and their effect on the model uncertainty.

**Generation of initial estimates:**

After measurements are performed and properly processed, an optimization step is carried out to find a model that fits the observations. Generally, this step requires starting values which are not self-evident to generate. We will study whether this optimization step can be made more robust and self-starting, especially for poor signal to noise ratios.

**Model selection and validation**

The third part of this project focusses on model selection and model validation. With most of the current techniques the user has to choose a model architecture, model order, etc. This requires, yet again, a fair amount of experience from the user. A thoughtful choice is to be made between the complexity and the accuracy of the model. This is not an obvious choice, as a model that is either too simple or too complex will yield unreliable and unsatisfactory results. Therefore, we will also focus some effort on model selection such that usable models can be obtained automatically. The end goal of this project is to deliver methods that allow users with a limited experience/training in system identification to obtain usable, validated models of their systems more quickly and easily.

**References:**


2.2.2.3 **State Space Identification for Linear Parameter-Varying Systems**  
*(Jan Goos and Rik Pintelon)*

**Introduction**

Although the linear time-invariant (LTI) system identification framework has proven its merits for many years, in quite some applications the linearity and time-invariance hypotheses are only approximately true or not valid at all. The need to operate processes with higher accuracy and efficiency has therefore resulted in the realization that the non-linear (NL) and time-varying (TV) nature of many physical systems must be handled by the control design.

In the linear parameter varying (LPV) framework, the dynamic relation between the input and output signals is still assumed to be linear, but it is continuously adapted based on the actual value of the scheduling parameters. Besides the excitation one should also choose a periodic or non-periodic scheduling. A common assumption is the bounded rate of variation of the coefficients and parameters.

**Gain scheduling**

Because LTI-systems have become a well-known framework, they have given rise to an intuitive form of LTV modelling, called gain-scheduling [3]. Here, the basic concept is to linearize the NL system model at different operating points, result in in a set of local LTI descriptions of the plant. Next, the LTI model or the according controller designs are interpolated to obtain a global solution of the entire operation regime.

The obvious advantage of this approach is that only LTI system should be estimated. However, a full measurement must be carried out for each operating point, and we cannot capture dynamics with respect to the varying parameters. We will therefore opt for a direct, global identification method.

**Model class**

The goal of this research is the development of algorithms for the identification of time-varying dynamical systems. The calculations will be done directly in the frequency domain, in contrast to [2]. In a first step, a non-parametric estimate of the noise and system model is estimated, as described in [1]. In a second step, one of three specific model structures can be extracted:

1. A differential or difference equation with parameter-varying coefficients [5, 6]
2. A parallel structure of LTI systems, each followed by a parameter-varying gain [6]
3. A state space model with parameter-varying A,B,C,D matrices
LTV state-space

Although some promising work has already been done on points 1. and 2. in [5, 6], we know from [4] that a conversion from one model class to another is not as straightforward as in the LTI case anymore. We will concentrate on the latter class, because state space can be used directly in control applications. The research is therefore immediately relevant to the industry, which results in a variety of applications and test setups. The drawback of using the state-space representation

\[
\begin{align*}
x'(t) &= A(p(t))x(t) + B(p(t))u(t) \\
y(t) &= C(p(t))x(t) + D(p(t))u(t)
\end{align*}
\]

is that we do not have a direct relation between the input \( u \) and the output \( y \), while these are the only measured values. It will therefore be necessary to estimate the states \( x \), e.g. by adapting a sub-space algorithm to cope with the time variation.

References


2.2.2.4 A frequency domain approach to the identification of time-varying systems (John Lataire and Rik Pintelon)

This research topic aims at generalising the existing frequency domain identification techniques, available for LTI (Linear Time Invariant) systems, to slowly LTV (Linear Time-Varying) systems. LTV systems are found in applications where the system's dynamics are dependent on external conditions (as for instance the impedance of a metal subjected to corrosion), or on measurable external parameters (the modal parameters of a wing of an airborne plane are depending on the flight speed and altitude) which vary with time.

The considered methods can be decomposed into non-parametric, and parametric ones, as explained in [1], and in the two next subsections.
Non-parametric identification

The evolution of the instantaneous FRF (Frequency Response Function) of the system is computed. This is done in a non-parametric fashion, that is, at a discrete set of excited frequencies. As such, the model order selection problem is (mostly) circumvented.

Such a non-parametric model provides immediate visual insights into the system’s dynamic behaviour, as illustrated in Figure 9. Also, it allows one to validate a parametrically identified model.

Parametric identification

A fairly generic dynamic model of linear time-varying systems is identified parametrically. The model consists of an ordinary differential equation with time-varying coefficients. The latter coefficients are described as combinations of user defined basis functions, such that arbitrary (be it slow) variations are allowed.

The identification procedure is implemented in an errors-in-variables framework. The power spectra of the disturbing noise on the input and output signals can be plugged into the identification procedure non-parametrically. This allows one to decouple the problem of estimating the system from the estimation of the power spectrum of the disturbing noise. It has been shown that a consistent estimate of the system parameters is obtained. An illustration of the evolution of the identified instantaneous poles and zeroes of an electronic circuit with a time-varying resonance frequency is shown in Figure 10.

Best Linear Time Invariant Approximation of a Linear Time-Varying System

What would happen if the data from a Linear Time-Varying (LTV) system was processed by tools for Linear Time Invariant (LTI) systems? This question arises when considering applications, where LTI models are preferred, but where, for some reason, the dynamic behaviour changes with time.

Figure 9. Evolution of the identified non-parametric instantaneous FRF of an electronic circuit with a time-varying resonance frequency

Figure 10. Evolution of the instantaneous poles (crosses) and zeroes (circles) of the same electronic circuit as above, identified parametrically
A method was developed that is able to detect the presence of time variations from input/output measurements, if their contributions are lying significantly above the noise floor. This allows one to check whether the uncertainty on the measured FRF is mainly due to the time variation or to the disturbing measurement noise on the signals. In Figure 11, the estimated FRF obtained from the LTI method described in [2], on measurements of the same time-varying electronic circuit as above, is given by the grey line. The uncertainty due to the time variation is quantified by the black dots.

2.2.2.5 Improved Automatic spectral analysis, using an estimated noise power spectrum as weighting. (Mikaya L. D. Lumori, John Lataire, Johan Schoukens)

An existing automatic spectral analysis method [3] has been extended to deal with highly coloured disturbing noise.

The method aims at detecting the period length of a periodic signal, measured at a sample frequency which is a non-integer multiple of the fundamental frequency of the signal. Requiring at least two periods of the signal, the philosophy of the method is to minimise the energy at the spectral lines where no energy is expected (that is, at the unexcited frequencies). As illustrated in Figure 12, the skirt shaped black crosses are compelled to be as steep as possible, ultimately reaching the spectrum given by the circles. This is done by means of interpolating the time domain signal and adjusting the length of the measurement record, yielding a record length that exactly contains an integer number of periods.

The extension consists of obtaining an initial non-parametric estimate of the noise power spectrum. This noise estimate is then used as a weighting into the least squares cost function, thus significantly reducing the uncertainty on the estimated period.

References:


### 2.2.2.6 PARAMETRIC AND NON-PARAMETRIC FREQUENCY DOMAIN MODELING OF PERIODICALLY TIME-VARYING SYSTEMS (E. Louarroudi, R. Pintelon and J. Lataire)

It is well-known that the classical Linear Time-Invariant (LTI) theory provides us desirable results for many problems in daily life [1], [2]. However, in some cases the LTI assumption and the related system identification techniques are not satisfied anymore, like in time-varying processes. In this work we will capture only those systems with system properties that evolve periodically over time. In plain words, the dynamic of the system is allowed to change periodically over time with periodicity $T_{sys}$.

Periodically time-varying (PTV) systems appear in a lot of engineering applications, where the time-variations are either dictated by the random nature of the system, or imposed experimentally via an external (i.e. scheduling) parameter, or appearing due to the linearization of a nonlinear system around a periodic orbit. Examples can be found in control, power distribution networks, sampled data systems, multi-rate filter banks, chemical processes, mechanical systems and so on.

Nevertheless, from an identification point of view, all the previously mentioned (periodically) time-varying systems (randomly and artificially time-varying) belong to the same group. The system can be seen as a black box with measurable input and output channels. A block representation of a PTV system is illustrated schematically in Figure 13 the scheduling parameters are imposed external parameters than can be controlled and measured by the user. When a periodically scheduling sequence is forced experimentally, as depicted in Fig. 1, a PTV-system is created.

**Parametric modelling:**

Periodically time-varying systems are assumed to be well-described by linear, ordinary, continuous-time differential equations with periodically time-varying parameters

$$
\sum_{n=0}^{N_a} a_n(t) \frac{d^n y(t)}{dt^n} = \sum_{n=0}^{N_b} b_n(t) \frac{d^n u(t)}{dt^n}
$$

(1)
where $u_0(t) \& y_0(t) \in \mathbb{R}$ denote respectively the undisturbed input and output signals. The periodically time-varying parameters $a_n(t) \& b_n(t) \in \mathbb{R}$ in (1) are approximated by means of a finite Fourier series (idem for $b_n(t)$):

$$a_n(t) = \sum_{k=-N_b}^{N_b} A_{nk} e^{j k \omega_{sys} t}$$

with $\omega_{sys} = \frac{2\pi}{T_{sys}}$ the fundamental frequency of the system parameters.

The mean idea of this research is to identify a PTV-system using only finite unknown system parameters for the identification. Hence, the identification procedure consists of estimating the time invariant parameters $A_{nk} \& B_{nk}$ (i.e. the Fourier components of the system parameters) from disturbed input and output measurements in the frequency domain – we are working in an errors-in-variables environment. Any model-related can then be computed, like the time-varying parameters, frozen transfer function, frozen poles and zeroes, ... The noise sources in the identification scheme are assumed to be stationary (i.e. time-invariant). This motivated by the fact that for slowly time-varying systems the dominant behaviour is time-invariant. Hence, for generator and process noise the noise sources will be almost time-invariant as well. The system parameters $A_{nk} \& B_{nk}$ are tuned then in such way that the deterministic part of the system matches model (1) as close as possible in least square sense. Using a nonparametric weighting of the noise we get a consistent estimator for slowly varying processes. It is also possible from the identification scheme to calculate uncertainties on the parameters and any model-related quantity from a single realization of the noise, in order to give the estimates a quality label.

**Non-parametric modelling:**

Starting from the kernel representation (or impulse response) it can be shown that a linear continuous-time PTV system can be modelled as an (in)finite parallel structure of weighted LTI systems. In practice, after truncation of this parallel structure, say $2N_b + 1$ branches, we get as steady state response using periodic excitation

$$y_n(k) = \sum_{n=-N_b}^{N_b} G_n(\omega_{k-n}) u_0(k-n)$$

where $u_0(k) \& y_0(k)$ are the discrete Fourier transform (DFT) of respectively $u_0(t) \& y_0(t)$. The goal of this research is estimating the best linear approximation of the LTI blocks $G_n(\omega_k)$ at the excited frequencies $\omega_k$ in the frequency domain, the so-called harmonic transfer functions (HTF), in a nonparametric way embedded in an output-errors framework. In this framework the input is assumed to be known $U(k) = u_0(k)$ and the output is disturbed by noise and nonlinear distortions $Y(k) = y_0(k) + N_f(k) + Y_n(k)$. Also here we make the assumption that both the noise $N_f(k)$ as well as the nonlinear distortions $Y_n(k)$ are stationary. From these HTF estimates the evolution of the dynamics, described by the instantaneous transfer function (ITF), $G(\omega, t) = \sum_{n=-N_b}^{N_b} G_n(\omega_k) e^{j n \omega_{sys} t}$.
can then be achieved in a simple way. To give the ITF a quality label, the variance of the nonlinear distortions, $\text{var}(G(\omega_k,t))_{NL}$, and the noise variance, $\text{var}(G(\omega_k,t))_{\text{noise}}$, are calculated from the $p \geq 2$ periods of the output signal.

The methodology, for estimation non-parametrically PTV systems in practice, makes use of the Local Polynomial Method (LPM). The LPM is based on the fact that for physical systems their dynamics show a smooth behaviour as a function of the frequency, such that they can be locally well approximated by a polynomial of low degree, typically of degree 2. The method allows us to obtain high quality estimates with their corresponding uncertainty, using multi-input single-output (MISO) LTI algorithms that have been recently developed for periodic excitations [3]. The LPM technique is illustrated here on a slowly weakly nonlinear PTV circuit. The circuit is a PTV second order band-pass filter with varying resonance frequency (see Figure 14). In Figure 14 it can be seen that the resonance frequency is changing from 5 kHz to 10 kHz. Also the nonlinear distortion level and the noise floor are depicted, which reveals the weakly nonlinear behaviour of the circuit.

References

![Figure 14. The estimated ITF at the excited frequencies for increasing time instants is given in red ($N_b = 18$). Both the nonlinear distortion (black) and the noise floor are shown (grey).](image)
2.2.2.7 Identification of nonlinear state-space models using machine learning methods (Anna Marconato, Johan Schoukens)

This work is done in collaboration with Johan Suykens (K.U. Leuven, Belgium) and Jonas Sjöberg (Chalmers University, Sweden).

Identification of nonlinear state-space models

The main idea of the proposed approach is to generate good initial values for the model parameters by transforming the identification of a nonlinear dynamic system into an approximate static problem, so that system dynamics and nonlinear terms are identified separately [1]. Classic identification techniques are used to handle dynamics [2], while regression methods from the statistical learning community are introduced to estimate the nonlinearities in the model [3], [4].

This work presents the application of an initialization scheme for nonlinear state-space models of the form:

\[
x(t+1) = f(x(t),u(t))
\]

\[
y(t) = g(x(t))
\]

on a real data benchmark example: the Silverbox problem [5].

Results on the Silverbox example

The initialization scheme consists of three steps:

- First of all, a linear model is determined to describe the dynamic behaviour of the system. Starting from a nonparametric BLA [2], a parametric second order linear model is estimated, and transformed into state-space form.
- Secondly, the unknown nonlinear state \( x(t) \) is approximated in order to cut the recursion in Eq. 1.
- At this point, one-hidden-layer Neural Networks with \( \text{tanh}(\cdot) \) as activation function [3] are employed to solve efficiently the obtained static regression problem.

Finally, after initialization, all model parameters are optimized applying a nonlinear optimization algorithm, e.g. a Levenberg-Marquardt technique.

Figure 15. Error signal given by the best initialized model on the test data (grey line), and test output signal (black line).

Figure 16. Error signal given by the best fitted model (after optimization) on the test data (grey line), and test output signal (black line).
The application of the method on the Silverbox problem gives satisfactory results. Starting from good initialized models (Figure 15), low values of the RMSE are obtained for the final fitted models (Figure 16).

Moreover, the number of parameters is reduced by considering only a few neurons in the hidden layer, obtaining the best result in terms of RMSE on the test data with an optimized model characterized by only 23 parameters.

References


2.2.2.8 2nd edition of the book "System Identification: a Frequency Domain Approach" (R. Pintelon and J. Schoukens)

Preface

During the 10 years since the first edition appeared, Frequency Domain System Identification has evolved considerably. In the second edition we have added new material that reflects our personal view on this development. The whole book has been updated and new sections and chapters have been added. These mainly deal with arbitrary excitations; periodic excitations under non-steady state conditions; discrete-time and continuous-time parametric noise modeling in the frequency domain; the detection, quantification, and qualification of nonlinear distortions; the best linear approximation of nonlinear systems operating in feedback; and multi-input, multi-output systems. Finally, a large number of new experiments have been included throughout the chapters. In the sequel, we explain some of these extensions in more detail.

In the first edition the emphasis was strongly put on the use of periodic excitations because at that time it was the only way to obtain nonparametric noise models in a pre-processing step, which considerably simplifies the system identification task. Although very successful, this approach had a number of shortcomings: (i) it does not account for the noise leakage that increases the variability of the frequency response function (FRF) estimate and introduces a correlation among consecutive signal periods; (ii) it is sensitive to plant transients which introduce a bias in the FRF and the nonparametric noise models; and (iii) it cannot handle arbitrary excitations. Solutions for
these problems are presented in the second edition. These new methods have led to new insights and, hence, also to new guidelines for the user.

The first edition handles the frequency domain identification of parametric discrete-time noise models under the restriction that the DFT frequencies cover the unit circle uniformly. In the second edition this is generalized to continuous-time and discrete-time noise models, identified on (a) part(s) of the imaginary axis or unit circle, respectively. The link with the classical time domain prediction error framework is also discussed in detail.

The first edition was mostly devoted to single-input, single-output systems. In the second edition a full extension to the multivariable case is made for the design of periodic excitations, the nonparametric frequency response matrix (FRM) measurement using periodic and random excitations, the detection and quantification of nonlinear distortions in FRM measurements using periodic excitations, and the parametric transfer function modeling.

In the first edition the experiments were mainly concentrated in one chapter. This chapter has been deleted and replaced in the second edition by new experiments that use the new insights and the newly developed identification methods.

2.2.2.9 FRF measurement of nonlinear systems operating in closed loop (R. Pintelon and J. Schoukens)

To prevent unstable behavior or saturation, frequency response function (FRF) measurements are often performed under closed loop conditions (see Figure 17). For example, open loop gain measurements of an operational amplifier are always performed in closed loop. The difficulty of such FRF measurements is that the nonlinear distortions also perturb the input via the feedback loop. The latter introduces a bias in the estimate of the best linear approximation (BLA), and jeopardizes the interpretation of the output nonlinear distortions. In this project we solve these problems via a generalized definition of the BLA that is valid for nonlinear systems operating in feedback. The classical definition for open loop systems follows as a special case.

For nonlinear PISPO systems operation in open loop (Figure 17 without feedback branch) the best linear approximation (BLA) is defined as

$$G_{BLA}(j\omega) = \frac{S_{yu}(j\omega)}{S_{uu}(j\omega)} = \frac{\mathbb{E}\{y(t)u(t+\tau)\}}{\mathbb{E}\{u(t)u(t+\tau)\}}$$

Eq. (1)
with \( S_{yu}(j\omega) \) the input-output cross-power spectrum, \( S_{uu}(j\omega) \) the input autopower spectrum, \( F\{x(t)\} \) the Fourier transform of \( x(t) \), and where the expected values \( E\{\} \) are taken w.r.t. the random excitation \( u(t) \). The difference \( y_{u}(t) \) between the actual output \( y(t) \) of the nonlinear system and the output \( y_{BLA}(t) \) predicted by the BLA Eq. (2) has the following properties (see Figure 18). It has zero mean and is uncorrelated with - but not independent of - the input \( u(t) \) for any class of random excitations \([1]\). In addition, for the class of Gaussian-like excitations, the discrete Fourier transform (DFT) spectra \( Y_{s}(k) \) and \( U(k) \) of, respectively, \( y_{u}(t) \) and \( u(t) \), have the following properties: (i) \( Y_{s}(k) \) has zero mean; (ii) \( Y_{s}(k) \) is uncorrelated with - but not independent of - \( U(k) \); (iii) \( Y_{s}(k) \) is asymptotically normally distributed; and (iv) \( Y_{s}(k) \) is asymptotically uncorrelated over the frequency \([2]\).

The key difference between the closed loop configuration (see Figure 17) and the open loop setup (see Figure 18) is that, due to the feedback loop, the input \( u(t) \) depends on the nonlinear distortions produced by the system. Therefore, classical definition leads to biased estimates of the BLA for nonlinear systems operating in feedback.

Following the lines of \([3, 4]\) for identifying linear systems in closed loop, we redefine the BLA via the indirect method as

\[
G_{BLA}(j\omega) = \frac{S_{yr}(j\omega)}{S_{ur}(j\omega)} = \frac{F\{E\{y(t)u(t+\tau)\}\}}{F\{E\{u(t)u(t+\tau)\}\}} \tag{2}
\]

with \( r(t) \) the known reference signal (typically the signal stored in the arbitrary waveform generator). Note that Eq. (2) reduces to Eq. (1) in the open loop case (use \( S_{yr}(j\omega) = G_{aw}(j\omega)S_{yu}(j\omega) \), with \( G_{aw}(j\omega) \) the actuator FRF, and where \( \bar{x} \) is the complex conjugate of \( x \)). Using definition Eq. (2) it is shown in this project that the equivalence in Figure 18 can be applied to the nonlinear PISPO system in Figure 18: all properties of \( y_{u}(t) \) (\( Y_{s}(k) \)) of the open loop case remain valid here except that \( y_{u}(t) \) (\( Y_{s}(k) \)) is uncorrelated with the reference signal \( r(t) \) (\( R(k) \)) instead of the input \( u(t) \) (\( U(k) \)).

Finally, the BLA Eq. (2) of the nonlinear PISPO system in Figure 19 can be measured using random phase multisine excitations \( r(t) \) combined with the fast or robust procedure (see \([5]\) for the details).

**Figure 18.** Best linear approximation (BLA) of a nonlinear (NL) period-in, same period-out (PISPO) system.

**Figure 19.** Setup for measuring the best linear approximation of a nonlinear (NL) period-in, same period-out (PISPO) system operating in closed loop. \( m_{u}(t) \) and \( m_{y}(t) \) are, respectively, the input and output measurement errors.
References


2.2.2.10 User friendly Box-Jenkins identification using nonparametric noise models

(Johan Schoukens, Yves Rolain, Gerd Vandersteen, Rik Pintelon)

The identification of SISO linear dynamic systems in the presence of output noise disturbances is considered. A ‘nonparametric’ Box-Jenkins approach is studied: the parametric noise model is replaced by a nonparametric model that is obtained in a pre-processing step, and this without any user interaction. The major advantage for the user is that, i) one method can be used to replace the classical ARX, ARMAX, OE, and Box-Jenkins models; ii) no noise model order should be selected. This makes the identification much easier to use for a wider public; iii) a bias on the plant model does not create a bias on the noise model. The disadvantage of the proposed nonparametric approach is a small loss in efficiency with respect to the optimal parametric choice. These results are illustrated on a series of well selected problems.

In the classical time domain prediction error framework, a parametric plant- and noise model is estimated simultaneously for the system given by

\[ y(t) = G_0(q)u_0(t) + v(t), \tag{1} \]

where \( q^{-1} \) is the backward shift operator, and with \( v(t) \) the disturbing noise modelled as filtered white noise: \( v(t) = H_0(q)e(t) \). The plant and noise models are respectively given by

\[ G_0(q) = B_0(q) / A_0(q), \]

and

\[ H_0(q) = C_0(q) / D_0(q), \]

with \( A_0, B_0, C_0, D_0 \) polynomials in \( q \). During the identification step, the noise model \( H(q, \theta) \) acts as a parameter dependent filter on the residuals in the least squares cost function

\[ V_N(\theta) = \frac{1}{N} \sum_{i=1}^{N} (H^{-1}(q, \theta)[y(t) - G(q, \theta)u_0(t)])^2, \tag{2} \]
which adds a frequency weighting to the cost function. The user has to select the model structure of both the plant model \( G(q, \theta) \) and the noise model \( H(q, \theta) \). The choice of the noise model not only reflects the prior knowledge about the system, it also affects the complexity of the optimization problem to find the minimum of the cost function \( V_{\theta}(\theta \theta) \). For example, choosing \( H(q, \theta) = 1 / A(q, \theta) \) expresses that the plant and the noise models have the same poles, resulting in an optimization problem that is linear-in-the-parameters. This is called the ARX model. In the ARMAX model, there is a larger flexibility in the noise model by adding also zeros to the noise model: \( H(q, \theta) = C(q, \theta) / A(q, \theta) \). Now, a nonlinear optimization problem is faced to minimize the cost function. For the output error model (OE), the disturbing noise is assumed to be white: \( H(q, \theta) = 1 \), and in the Box-Jenkins model there is no relation between the plant and the noise model. It is clear that the Box-Jenkins model can cover the ARX, ARMAX, and OE situation, but it results also in a more difficult optimization problem to be solved. The user has to solve now a double model selection problem: the order of both the plant- and the noise the model should be selected.

The noise model structure selection problem can be avoided if a good nonparametric noise model would be available. It can be used as a parameter independent weighting vector in the weighted least squares method. So only the plant model order has to be retrieved by the user. The numerical search procedure becomes also more robust so that the risk to end in local minima is reduced.

This brings us to the contribution of this project. When dealing with system identification we can consider on the one hand the classical prediction error framework that makes use of parametric noise models. It results in optimal estimates (consistent and efficient), provided that the user makes the correct choices for the plant- and noise model structure and order. However, if the user fails to do so, these highly desirable properties are lost and (large) errors can be created. On the other hand we have the nonparametric noise model approach, where no user interaction at all is requested to select the noise model-structure and -order. Only the plant model structure selection should be addressed. This results in a very user friendly modelling technique at a cost of a loss in efficiency. However, the risk to end up with poor models due to a bad user choice is strongly reduced. So there is a possibility to trade optimal, but high risk methods, for good (not optimal), but low risk methods. In this paper we will study both approaches and discuss the needed trade-off.
2.2.2.11 Reducing the number of parameters in a Wiener-Schetzen model
(Koen Tiels, Peter Heuberger*, Johan Schoukens)

* Delft Center for Systems and Control, Delft University of Technology

We consider the approximation of a single input single output (SISO) Wiener system, which is the
cascade of a linear dynamic system and a nonlinear static system.

A large class of SISO nonlinear systems can be described arbitrarily well in mean-square sense by
a Wiener-Schetzen model [1]. This is the cascade of a single input multiple output (SIMO) linear
dynamic system and a multiple input single output (MISO) nonlinear static system. The linear
dynamics are modelled by a set of orthonormal basis functions (OBFs), while the nonlinearity is
modelled through a multivariate polynomial. The parameters of the model are the coefficients of
this polynomial.

Since the number of parameters increases rapidly with the number of OBFs [2], it is important to
choose the OBFs carefully. In [3], it is shown how a set of poles gives rise to a set of OBFs and
that if these poles are close to the true poles of the underlying linear dynamic system, this system
can be well approximated with only a limited number of OBFs. In the general case with possibly
multiple real and complex valued poles, the Takenaka-Malmquist OBFs are obtained. We first
estimate the system poles using the best linear approximation (BLA) of the system. Although the
quality of the pole estimates is very good, the number of parameters can still be large. This is
because at least one OBF is needed for every pole estimate.

A large number of parameters generally results in a large variability on the estimated parameters.
For that reason, we introduce a new parameter reduction step in [4]. Since the BLA can represent
the system dynamics very well, we propose to replace one of the OBFs by the BLA itself. In that
way, most of the dynamics are represented by only one basis function. The other basis functions
can then be seen as correction terms. Many of the parameters resulting from these basis functions
can be considered small compared to those resulting from the BLA. Simulation results show a
major reduction of the number of parameters, with only a minor increase in the rms error on the
simulated output.

The identification method and the parameter reduction step are extended to MISO Wiener systems
in [5]. Compared to the SISO case, the number of parameters can increase significantly. The
parameter reduction step is then even more desired.

Future work includes a comparison with other parameter reduction methods, such as LASSO (least
absolute shrinkage and selection operator) [6] and other regularization techniques.

References

Short Description of the Research Projects/ Team


2.2.2.12 Differentiation and Characterization of Biological Soft Tissues using Piezoelectric Self-Sensing Actuators for Brain Neurosurgery* (David Oliva Uribe, Johan Schoukens and Joerg Wallaschek) *in cooperation with the Institute of Dynamics and Vibration Research of the Leibniz University of Hannover (Joerg Wallaschek)

In this project we estimate the mechanical parameters of biological tissues (in particular brain tissue) using a piezoelectric tactile sensor (shown in Figure 20). The purpose of the estimation of the mechanical parameters is to provide the tactile sensor a reliable measurement procedure for the differentiation of two biological materials with slightly differences (e.g. tumour and healthy tissue in brain). Potential applications of this research can be addressed in the development of assisting tools for intra-operative tumour delineation and tumour resection in neurosurgery, where is intended to help neurosurgeons with the difficult task of determining tumour boundaries during resection of brain tumours.

In order to have a reliable instrument that can be used in surgical procedures, it is necessary to enhance the capabilities of the tactile sensor system. This project involves the improvement in measurement time and accuracy of the sensor system using multisine excitation. In addition, we aim to provide the sensor system with the function to characterize the mechanical properties by the estimation of viscoelastic parameters using system identification techniques.

This project is done in cooperation between the VUB dept. ELEC and the Institute of Dynamics and Vibration Research of the Leibniz University of Hannover.
2.2.2.13 Identification of nonlinear systems via a powerful block-oriented nonlinear model
Laurent Vanbeylen

Motivation and goal
Nonlinear operation of nonlinear devices is ubiquitous in practical application examples. When the nonlinearities are small, a linear system may be sufficient. In such a situation, a well-established framework of system identification theory and methods can be used. However, in nonlinear identification, there is still a lot of work to be done.
This topic is concentrating on the identification of the most general block-oriented nonlinear model structure with the restriction that no more than one static nonlinearity (SNL), shown in Figure 22. In literature, it is also referred to as the Linear Fractional Representation (LFR) model. Its flexibility power comes from the multiple-input-multiple-output linear time-invariant (MIMO-LTI) part of the model, which realizes an arbitrary interconnection between the model input, model output, input and output of the SNL. Besides, the model structure is also reasonably parsimonious, since it involves a relatively low number of parameters. The model may be a good starting point as a first nonlinear model candidate, and serve as an initial guess for other nonlinear identification methods, such as the polynomial nonlinear state-space model, relying now on a linear initialization (Best Linear Approximation), which may otherwise be located too far from the global solution of the nonlinear optimization procedure.

In a first step, initial estimates are generated for the considered nonlinear model structure. In contrast to the method presented in the next research item, here the method does not need to build a nonlinear state-space model.

2 The underlying ideas of the method

The method is based on Best Linear Approximations constructed at 2 input amplitude levels. Making the approximation that the input of the SNL (signal $y_2$) is Gaussian, results in a BLA obtained by replacing the SNL by an amplitude-dependent gain. Written in state-space form, it turns out that a certain rank-one modification acts on the state-space matrices, when the input amplitude varies, leading to a variation of the gain related to the SNL.

The method essentially equates the BLA's at both levels (state-space representations obtained via a frequency domain subspace method) to the theoretical expression, taking the unavoidable similarity transformations into account. As a result (after solving the matrix equations), both gains related to the BLA are retrieved, and the MIMO-LTI part.

Next, the SNL can be fitted in a nonparametric way by computing the inner signals (from $u$, $y$, and the MIMO-LTI) and plotting them versus each other in a scatter plot. A weighted least-squares method then yields a parametric estimate. Further details can be found in [1]

The first simulation results (not reproduced here, see [1]) show that the initial estimate of the nonlinear LFR model outperforms both BLA models.

Figure 22. Block-structure of the nonlinear LFR, containing one static nonlinearity and an LTI (linear time-invariant) part. Herein, the G’s represent linear dynamic blocks.
Reference:

2.2.2.14 Identification of a Block-Structured Model with Localized Nonlinearity via nonlinear state-space equations
(Anne Van Mulders, Laurent Vanbeylen, Johan Schoukens)

Introduction
This work considers the identification of a nonlinear time-invariant system; consisting of a Multiple-Input Multiple-Output (MIMO) linear dynamic part and one static nonlinear part (see Figure 22). It is sometimes referred to as Linear Fractional Transformation (LFT) or Linear Fractional Representation (LFR). The structure will be called nonlinear LFR and includes many standard block-structured models. The identification method does assume neither the states, nor the internal signals over the static nonlinearity to be measured. The static nonlinearity (SNL) is assumed to be polynomial.

Thanks to the generality of the structure, one can obtain a Wiener (via $g_W$), Hammerstein (via $g_H$), nonlinear-feedback (via $g_{FB}$) or any other block-structure with one SNL, without needing to choose the specific block-structure a priori. Subscript $d$ in $G_d$ denotes that this block makes a direct linear connection between the in- and output.

Stepwise approach
The proposed method distils the SNL out of a more general polynomial state-space model and next, in a natural way, gives access to the underlying linear dynamic behaviour of the system. The proposed method entails three steps:

1. identification of a nonlinear (polynomial) state-space model [1] with rank-1 property;
2. imposing (nonlinear) dependencies between the nonlinear elements and retrieving certain linear mappings such that the model contains only one static nonlinear block (SNL);
3. final optimisation of the nonlinear LFR structure.

After the final optimisation, the parametric (state-space) models of the four linear dynamic blocks depicted in Figure 22 can be extracted.

In fact, the method can also be considered as a parameter reduction technique, since the first step is the identification of the more general Polynomial Nonlinear State-Space (PNLSS) model. This reduction usually yields some concession on the model error.
**Experimental results**

The method was tested on simulations and on two experimental data examples. One example is the identification of the Silver-box, an electronic circuit that emulates the behaviour of a nonlinear mass-spring-damper system. A second example is the identification of the Agilent-HP420C crystal detector. The results are shown in Table 1.

For every example, the best (in terms of root mean square (RMS) error on the validation data) linear and nonlinear models are given. The Best Linear Approximation (BLA) and PNLSS model can be found in [2].

<table>
<thead>
<tr>
<th>DUT</th>
<th>Approach</th>
<th>Model order</th>
<th>Nonlinear degree</th>
<th>RMSE (mV)</th>
<th>( n_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silverbox</td>
<td>BLA [2]</td>
<td>2</td>
<td>X</td>
<td>13.7</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>PNLSS [2]</td>
<td>2</td>
<td>3</td>
<td>0.26</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>LFR-SNL</td>
<td>2</td>
<td>3</td>
<td>0.35</td>
<td>12</td>
</tr>
<tr>
<td>Crystal detector</td>
<td>BLA [2]</td>
<td>3</td>
<td>X</td>
<td>0.89</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>PNLSS [2]</td>
<td>4</td>
<td>3, state affine</td>
<td>0.259</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>LFR-SNL</td>
<td>2</td>
<td>3</td>
<td>0.286</td>
<td>11</td>
</tr>
</tbody>
</table>

*Table 1: Comparison of the RMS error on the validation data and number of parameters \( (n_p) \). Two examples (DUT’s) are presented. For each example, three models are shown.*

The BLA (parameterised as a linear state-space model) is a model with relatively high RMS error, but with a low number of parameters. When the BLA is extended to a PNLSS model (by adding polynomial terms to the state- and output equations), the number of parameters increases combinatorial. The LFR-SNL model has a much lower number of parameters, and only a slightly increased RMS error, which is a result of the localised nonlinearity hidden in the modelled devices.

**References**


**2.2.2.15 Nonlinear analysis of flutter**

*(Mattijs Van de Walle, Johan Schoukens, Steve Vanlanduit)*

**Introduction**

Flutter is an aerelastic phenomenon that makes structures oscillate when surrounded by a moving fluidum. Flutter can lead to fatigue and/or failure on the wings, flaps and fuselage of an airplane. Laborious testing needs to be done on aircraft to ensure safe operation within a certain flight envelope. While flutter is inherently nonlinear, most models use a linear framework to predict the
critical speed at which oscillations might occur. The aim of this work is the construction of a nonlinear model to more accurately predict the onset of oscillatory behaviour, on the basis of wind tunnel test measurements.

**Experimental setup**

In a first step, we built an experimental setup with which we can create flutter under controlled conditions. This first setup, shown in Figure 23, is a cantilevered airfoil. Because the velocity of the wind tunnel we have at our disposal is limited to 50 m/s and because of safety reasons, we want the wing to get unstable at as low a wind speed as possible. Therefore, a system has been devised that allows the modal properties of the wing to be altered. It consists of a rail on which small weights can be fixed. By tuning the distance from the weights to the aerodynamic centre of the airfoil, the frequency of the first torsional mode can be brought closer to the frequency of the first bending mode. When wind is applied, these modes get even closer to one another and because flutter occurs when these modes start to couple, a lower flutter speed is achieved through the use of this tunable system. To measure and tune the modal parameters of the setup, a shaker and laser vibrometer are used. When actually under test, the shaker cannot be used because once the airfoil gets unstable, the vibration would damage the shaker. New flutter prediction methods have been successfully tested with data taken from this cantilevered setup [2].

As a second step, we are currently building a setup that also allows the use of forced excitations. The setup is shown in Figure 24. Conceptually it is closely tied to a standard two degrees of freedom (DOF) configuration that is often used for flutter research. The advantage of the proposed setup is that instead of using linear springs to characterize the airfoil’s pitch and plunge stiffness, it uses linear motors. Not only does this allow us to choose the stiffness of the pitch and plunge motion, but the linear motors enable us to impose an arbitrarily chosen excitation signal upon the airfoil. In doing so, we hope to better understand the flutter phenomenon and characterize its nonlinear behaviour [1]. Design changes to the setup have made it possible to make it an integral part of the wind tunnel. A modular frame and a system with counter weights have been designed so that the setup can be easily lifted up to make way for other non-related experiments to be put inside the tunnel.
Conclusions

We are able to create flutter in a reproducible manner with the cantilevered setup. We also have control over the speed at which it occurs. New flutter prediction methods have been successfully tested with data taken from the cantilevered setup. At the moment of writing the actively controlled setup has not been finalized.

References


2.2.2.16 Modeling the slip phase of a wet-clutch and charging characteristics of a Li-Ion battery
(Dhammika Widanage and Johan Schoukens)

During the first part of the 2010-2011 academic year the research was focused on the completion of the identification task set out in the LeCoPro Project (Learning Control for Production Machines). This task involved deriving a nonlinear model to describe the slip phase of wet-clutch. A wet-clutch is a mechanical device that transmits torque from an input axis to an output axis via fluid friction. Just before the plates make contact a transitory phase called the slip phase is encountered. This is when the input axis induces a certain amount of rotation on to the output axis plate from the fluid friction. The slip, which is a proportional value of the difference in the input and output angular speed, should gradually be brought to zero, thereby reducing any sudden jerks during contact. A polynomial nonlinear state space model (PNLSS) was estimated that modelled the descent of the slip. Figure 25 shows the slip as predicted by a linear and a PNLSS model and the corresponding measured slip.

In the second half of the academic year, impedance of lithium ion (Li-Ion) batteries was investigated. This work is related to the Project SuperLib (Smart Battery Control System based on a Charge equalization Circuit for an advanced Dual-Cell Battery for Electric Vehicles). With impedance characteristics of the batteries during charging and discharging identified parametric battery models are to be identified. Figure 26 shows the magnitude and phase of the impedance of a battery during its charging phase.
Figure 26. Impedance magnitude and phase during the charging phase of the Li-ion battery.
2.3 TEAM C: APPLIED SIGNAL PROCESSING FOR ENGINEERING (ASPE)

2.3.1 Introduction to Applied Signal Processing for Engineering (ASPE)

The current trend in the microwave world is to build systems with extremely high performance demands to meet the challenges of modern telecommunication applications. As a result, both the linear and the nonlinear operation of these devices has to be modelled with accurately, but with models that are numerically cheap to evaluate. The linear models that are still used for the mainstream developments of circuitry, are very good at describing the small signal behaviour components, subsystems and systems. However, there is an ever increasing demand for nonlinear models that are easy enough to use and to understand, but nevertheless are capable to describe power efficiency or harmonic distortion under realistic operating conditions. The main goal and the common denominator of the work performed in this team is ‘to measure, understand and model devices and systems that operate at RF and microwave frequencies’

To reach this goal a two-layered approach is proposed:

- Gain insight in the device behaviour. This step can be put in parallel with the frequency response extraction or the S-parameter measurement if only the class of linear systems is considered. To be able to extend this towards nonlinear systems, a restriction of the class of allowable non-linear systems is needed. The Periodic In Same Period Out (PISPO) system class is wide enough to contain (saturating) nonlinear amplifiers, mixers, and even voltage controlled oscillators. A system belongs to the PISPO class if a periodic excitation waveform results in a periodic output with the same periodicity. Appropriate data pre-processing and the adequately obtained measurement data allows a trained user to understand the mechanisms that govern the general behaviour of the Device Under Test (DUT). From an identification point of view, this approach is essentially a non-parametric modelling step.

- Extract a parametric model for the device. This can be put in parallel with the extraction of a rational transfer function model for the DUT in the linear case. To be of practical use, this model has to integrate seamlessly in existing simulation frameworks. Special caution is to be used here to avoid that the model’ user lives up to non-realistic expectations. It happens all too often that models are ‘sold’ as soap, leaving it up to the user to detect whether or not the response of a pile of numbers can be trusted. Fortunately, this can be circumvented by a trustworthy validation step. To this end, the model output is compared with the measurements as obtained during the estimation of the first layer model. Differences between model and measurement can then be used to decide whether or not the proposed model structure meets the user demands based on a fair, quantified comparison norm.

The contributions of the team all contribute in some way to the realisation of this long-term goal. The different contributions are first put in perspective below, and next are described in some more detail.

- Instrumentation setup contributions. The complete characterisation of a nonlinear system is much too ambitious goal to realize in a single step. Often, it will even be questionable whether it makes sense to chase this goal at all. Most applications of nonlinear devices use the device for a limited range of possible operating conditions, and if the model is capable to predict the device behaviour under these constraints, the demands of the user are fulfilled. The most common boundary conditions involve the selection of the signal class,
the impedances that are provided at the ports and the biasing levels. To measure nonlinear devices or components, it is of vital importance that the setup is able to mimic real operation conditions during as closely as possible. Thereto, highly flexible instrumentation setups are required. A flexible non-linear network analyser was developed to this end. The device combines the advantages of reconfigurability and ease of use and provides an efficient and easy to use data handling capability.

- Instrumentation calibration contributions. As for today, the instrument fully handles the waveform calibration for two- and three-port measurements in CW regimes. Additional contributions in the phase calibration allow to calibrate and verify waveform measurements for the modulated and pulsed operation.

- Modelling contributions. In the framework of linear time invariant systems, a black box errors-in-variables approach is proposed that does not rely on circuit descriptions. In the end, the proposed black-box approach delivers models that properly describe the linear dynamics of the DUT, detect the presence of modelling errors and have by far better numerical properties than their circuit-based equivalents. On top of that, the model extraction operates almost automatically. In the non-linear non-parametric range of models a ‘energy-transport’ model is proposed that yields simple, yet effective, ways to estimate the dominant non-linear energy transport mechanisms that are present in the behaviour of the nonlinearity. Using this approach allows to increase the users’ level of confidence in the model and mostly avoids the otherwise tedious problem of model structure selection. Parametric models that cover a wide range of frequency and power were then identified based on this previously obtained knowledge of the dominant influences in the model.

2.3.2 Short Description of the Research Projects of Team C

2.3.2.1 Robust or Fast Local Polynomial Method: How to choose? (Griet Monteyne, Diana Ugryumova, Gerd Vandersteen and Rik Pintelon)

Introduction

The Robust (RLPM) and Fast (FLPM) Local Polynomial Methods were developed to find a non-parametric Frequency Response Function (FRF) estimate [1]. In this contribution the methods are compared and applied on experimental data coming from a heat diffusion experiment. Both methods assume that the excitation signal is a periodic signal and that the transient can be approximated locally in the frequency domain by a low-degree polynomial. FLPM also approximates the FRF by a local polynomial with a low degree. This approximation results in a bias error in case a low-degree polynomial cannot approximate the FRF well. RLPM does not approximate the FRF by a local polynomial. Thus, using RLPM avoids this bias error due to under-modelling. Unfortunately RLPM cannot estimate the level of the nonlinear distortions unless data coming from at least two experiments with uncorrelated inputs is available.

Theoretical analysis

The methods consider that the single-input, single-output system is disturbed by filtered white additive noise on the input and the output (Figure 27).
First, the reference $r(t)$, input $u(t)$ and output $y(t)$ signals are collected during $P$ consecutive periods ($N$ samples per period). The DFT spectra of the signals are calculated as

$$X(k) = \frac{1}{\sqrt{NP}} \sum_{i=0}^{NP-1} x(t) e^{-j \frac{2\pi kt}{NP}}$$

where $X=R$, $U$ or $Y$. Transforming the $P$ consecutive periods to the frequency domain implies that only transient and noise are present on the $P-1$ lines in-between every two consecutive excited frequency lines.

Next, the non-excited frequency lines are used to estimate the transient on the input and output signal at the excited frequency lines. This is possible since the transient is locally approximated by a polynomial.

Finally, the estimated transient ($\hat{T}_z = [\hat{T}_r, \hat{T}_u]^T$) is subtracted from the DFT spectra at the excited frequency lines.

$$Z_{new}(k) = Z(k) - \hat{T}_z(k) \text{ with } Z = [Y \ U]^T$$

FLPM then estimates the FRFs between the reference and input/output signal ($\hat{G}_{RY}$ and $\hat{G}_{RU}$) by approximating them locally by a polynomial. RLPM avoids the bias that is potentially introduced by FLPM by calculating the FRF estimates as $\hat{G}_{RY} = Y_{new}(k)/R(k)$ and $\hat{G}_{RU} = U_{new}(k)/R(k)$.

The FRF between input and output signal is for both methods found as $\hat{G}_{UY} = \hat{G}_{RY}/\hat{G}_{RU}$.

**Results and conclusion**

Both methods were used to find FRF estimates for a simple heat diffusion problem. Figure 28 shows that at low frequencies FLPM outperforms RLPM. This is due to the avoided bias and thus confirms the theoretical analysis.

At higher frequencies FLPM seems to outperform RLPM. This is due to the smoothing over the neighbouring frequencies caused by the local polynomial approximation of the FRFs. However, the information content of both FRF estimates is the same.

**Reference**

2.3.2.2 MIMO Parallel Wiener Identification (Maarten Schoukens and Yves Rolain)

Introduction

An identification method for multiple input multiple output (MIMO) parallel Wiener systems (see Figure 29) is proposed. The method is explained in detail in [1].

The MIMO parallel model captures coupled nonlinearities, and power-dependent dynamics (e.g. moving resonance). The restriction is that the structure only allows nonlinear systems with dominant output nonlinearity (e.g. sensor nonlinearities).

The literature contains identification methods for single branch MIMO Wiener systems [2], [3]. But there is not much work performed around MIMO parallel Wiener systems.

Model and method

**The model class:** The model structure is a block-structured MIMO parallel Wiener model as shown in Figure 29. The static nonlinear blocks are modeled using multivariate polynomial functions of the intermediate signals $z(t)$. The LTI blocks can be represented using a nonparametric frequency response function, or a parametric rational function in $s$ or $z^{-1}$.

**Noise framework:** Only output noise is considered.

**The identification framework:** A black box approach starting from input-output measurements of the system is proposed. It can handle a variable number of inputs and outputs. The order of the static nonlinearity can be set by the user, as well as the number of parallel cascades of the different Wiener branches.
First, the overall dynamics are estimated in least squares (LS) sense. These dynamics are decomposed, giving an estimation of the LTI blocks. Next, the static nonlinearities are estimated using a LS estimator. Finally, a nonlinear optimization of the obtained initial estimates is performed to further refine the model.

**Results:** The identification method is tested on a simulation example, giving promising results shown in Figure 30 the errors of the MIMO parallel Wiener model are converging to the noise floor. The simulation proves that the method performs well both for highly nonlinear and moderate nonlinear systems.

**References**


**2.3.2.3 Identification and modeling of distillation columns (Diana Ugryumova, Gerd Vandersteen, Bart Huyck*, Filip Logist*)**

(*KULeuven*)

In this research, we model a binary distillation column using a frequency domain identification approach [1]. The goal is to find an accurate, but simple, black-box model of a distillation column to be used in e.g. model predictive control. A distillation column is in essence a multiple-input-multiple-output (MIMO) non-linear system whose system dynamics varies due to the changes in ambient temperature. Here, we consider a system which is not in steady-state, which introduces leakage errors in the frequency domain.

A recently developed robust local polynomial method (RLPM) together with random-phase multisine inputs are used to eliminate the leakage error and to obtain better estimates of the non-parametric frequency response matrix (FRM) and its variance [2,3]. This non-parametric FRM is then used to fit a low-order rational form parametric model which also includes a time-delay term.

Next, the extracted parametric models are extended to capture its dependency on changes in the ambient temperature. The proposed solution is to let the parameters (time-delays $\tau_i$, zeros $\zeta_i$ and...
poles \( p_i \), of the distillation column model depend on the heat inside the column \( \Delta Q \) (i.e. the difference between the reboiler power, \( u_2 \), and the heat loss over the column, \( Q_{\text{loss}} \)):

\[
\hat{g}(s, \Delta Q) = e^{-\tau(\Delta Q)s} \prod_{i=1}^{n} \frac{s - \tau_i(\Delta Q)}{s - p_i(\Delta Q)}
\]

where \( \hat{g}(s) \) denotes an estimate of the FRM in continuous Laplace domain \( s \). Using this parameterization, the operation of the column with respect to the changes in ambient temperature becomes approximately constant and hence easier to model. Figure 31 shows one of the poles of the 3\(^{rd}\) order rational model from the reboiler power (one of the input variables) to the temperature at the bottom (an output). This transfer function model has zero delay. For a constant reboiler power, the total heat loss varies with the ambient temperature and consequently, the pole varies with the ambient temperature. The pole location becomes almost independent of the ambient temperature then the reboiler power is adjusted such that the heat inside the column, \( \Delta Q \), is independent of the ambient temperature. This makes it becomes possible to extract simpler and more accurate system models.

References

2.4 TEAM D: MEDICAL MEASUREMENTS AND SIGNAL ANALYSIS (M\textsuperscript{2}ESA)

2.4.1 Introduction to project \textsuperscript{M\textsuperscript{2}ESA}

\textit{Problem statement}

Physicians have an enormous amount of practical experience which is most of the time based on old medical principles. The public opinion requires that diagnoses are accurate and infallible. To obtain this for all medical cases, the actual way of working which relies on experience becomes insufficient. Hence, a more robust, rigorous and well-founded approach is desired. Step by step, the medical world realizes the need and advantages of mathematical models in the quest for accurate diagnoses. Although the modelling science is a rather young part of science, the techniques which the modelling grocery has to offer are so abundant that without proper guidance one cannot see the wood for trees. This is the main reason why the medical community is rather reluctant to use the advanced modelling methods.

\textit{Objectives}

In the \textsuperscript{M\textsuperscript{2}ESA} project, the measurement and modelling knowledge available at the department ELEC will be combined. The successful marriage between practice and theory offers the medical world simple, practical, risk-free and powerful tools to satisfy the users’ needs. A trade-off between theoretical/mathematical optimality and user-friendliness will be studied. Indeed, it is important that these emerging modelling techniques can be safely applied and interpreted by the layman user.

Some of the projects that \textsuperscript{M\textsuperscript{2}ESA} focuses on, are the following:

- \textit{Accurate oscillometric blood pressure measurements}: One of the most popular medical instruments used at home is the automatic non-invasive blood pressure meter (NIBP). Most medicine cupboards contain one and a lot of people use it on a daily basis. A cuff is wrapped around the arm of the patient and inflated until the circulation stops. Most classical automatic blood pressure meters are based on the oscillometric principle, which records the oscillations in the cuff pressure during deflation of the cuff. Out of this oscillometric waveform a mean arterial pressure (MAP) as well as a systolic and diastolic pressure is deducted by means of a mathematical algorithm. Each manufacturer of blood pressure meters, however, has developed his proper algorithm which is most of the time patented. On top of that, these algorithms are often not scientifically founded or transparent.

- \textit{Non-invasive glucose measurements}: In the EU and US, 7.8\% of the population have diabetes (www.diabetes.org), of which up to one third undiagnosed. Up to 20\% of the population has a variable degree of glucose intolerance, and might also benefit from early glucose monitoring. Management of diabetes, in particular insulin-dependent forms, requires intensive control of blood glucose. Currently this is done by pricking the fingertip
to draw blood and measure capillary blood glucose on an external sensor strip. This is a
time-consuming, relatively painful procedure and offers only discontinuous monitoring.
Developing a non-invasive glucose measurement procedure would be a considerate relief in
the social, the physical as well as the financial field for these patients. Earlier attempts to
generate a similar application have failed due to the lack of a solid background on the
measurement concept.

- **Functional Magnetic Resonance Imaging (fMRI):** MRI and fMRI is daily used to explore
tumour tissue, infections, brain problems, muscles diseases, etc... Analysing functional MRI
data is often a hard task due to the fact that these periodic signals are strongly disturbed
with noise. In many cases the signals are even buried under the noise and not visible, so
that detection is quite impossible. In the past, different modelling approaches have been
used without proper validation and comparison.

- **Vital signs of foetuses:** The premature mortality rate is still very high although the
precaution and advances in the medical world. The current society puts a large
responsibility on the shoulders of gynaecologists. Therefore it is important to have proper
access to the foetus’ vital signs. This is not only a major measurement challenge but also
requires powerful signal analysis techniques. The main problem is that all non-invasive
measurements are indirect, very noisy and on top of that nonlinear.

- **Breast cancer:** The actual detection of breast cancer, called mammography, is based on X-
rays and is a very painful experience for the patient. New detection techniques based on
low-power microwaves are emerging. The advantages are apparent: no breast compression,
no ionizing radiation, no risk of heating the breast tissue. These new techniques can benefit
from a strong signal analysis and modelling to reconstruct the images of interest.

### 2.4.2 Introduction to project MEMON

**Problem statement**

Wireless communication systems are widely available in our daily life, from mobile communications
to cognitive radios and wireless ad hoc/sensor networks. In order to achieve a standard
performance, more requirements are put on the radio frequency (RF) systems. Signals used in
today’s wireless systems are characterized by high and fast dynamics in their envelope due to the
use of sophisticated modulation techniques. Hence, they have large bandwidths and high peak-to-
average power ratios. As a consequence, high requirements are put on the high power RF
transmitters which are considered to be nonlinear systems and on the RF receivers whose digital
bandwidths are limited due to shortage in high speed analog-to-digital converters, based on
acceptable measurement accuracy.

One of the most important components in wireless communication systems is the radio frequency
power amplifier (PA). Due to the high linearity and efficiency requirements, it is of the highest
importance to accurately characterize the linear as well as the nonlinear behaviour. Characterizing
the linear behaviour of RF components is a well-known technique. However, characterizing the
nonlinear behaviour of these components is a completely different and more involved problem. The
new high efficiency PA and transmitters, based on switched mode amplifiers, are emerging
technologies that certainly require novel measurement methods.
Objectives

In this research project, excitation signals will be designed in order to reduce the requirements on the linear behaviour of RF transmitters. New sampling and reconstruction strategies are developed which allow measuring accurately wide-band waveforms based on relatively slow analog-to-digital converters.

Furthermore, the different measurement and modelling techniques that are nowadays available to analyse the nonlinear behaviour of RF devices will be analysed. A zillion methods have been published and used, but what is clearly missing is guidance for the user. This study will clarify why and how all these methods differ from each other based on either a system theoretical or stochastic point of view. Will all the different techniques be able to co-exist or is there a need for a new evolution?

This research is in collaboration with Prof. Niclas Björsell of the University of Gävle (Sweden) and is funded by a research grant of the Research Foundation-Flanders (FWO).

2.4.3 Short Description of the Research Projects of TEAM D

2.4.3.1 Analyzing the Windkessel model as a potential candidate for correcting oscillometric blood pressure measurements (Kurt Barbé†, Wendy Van Moer† and Danny Schoors‡)

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‡ University Hospital -Vrije Universiteit Brussel, Dept. CHVZ

Introduction

Developing a good model for oscillometric blood pressure measurements is a hard task. This is mainly due to the fact that the systolic and diastolic pressure cannot be directly measured by Non-Invasive automatic oscillometric Blood Pressure meters (NIBP), but needs to be computed based on some kind of algorithm. This is in strong contrast with the classical Korotkoff method, where the diastolic and systolic blood pressure can be directly measured by a sphygmomanometer. Although an NIBP returns similar results to the Korotkoff method for patients with normal blood pressures, a big discrepancy exist between both methods for severe hyper- and hypotension. For these severe cases, a statistical model is needed to compensate or calibrate the oscillometric blood pressure meters.

Different statistical models have already been studied, no immediate calibration method has been proposed. The reason is that the step from a model, describing the measurements, to a calibration, correcting the blood pressure meters, is a rather large leap.
In this project, we study a ‘data-based’ Fourier series approach to model the oscillometric waveform and use the Windkessel model for the blood flow to correct the oscillometric blood pressure meters. The method is validated on a measurement campaign consisting of healthy patients and patients suffering from both hyper–or hypotension.

**Korotkoff versus Oscillometric blood pressure measurement**

The blood pressure of a patient can be measured by wrapping a cuff around the upper arm of the patient and inflating the cuff. This cuts off the blood stream through the brachial artery. During deflation of the cuff, the physician listens with a stethoscope to the sounds in the brachial artery which are created by the blood stream that is restored due to the deflation of the cuff (see Figure 32). Five different sounds can be heard during deflation of the cuff: a tapping sound, a soft swishing sound, a crisp sound, a blowing sound and silence when the artery is completely open again. These sounds are called the Korotkoff-sounds. Since the Korotkoff method is too involved to perform at home and clearly requires trainee skills, automatic blood pressure meters were developed. These non-invasive blood pressure meters are also based on a cuff that is wrapped around the arm of the patient and inflated. Based on a pressure sensor in the NIBP, the pressure in the brachial artery is measured during deflation of the cuff. Out of the measured pressure waveform, also referred to as the oscillometric waveform, a systolic and diastolic pressure is deducted through a mathematical algorithm which is firm dependent. The mathematical algorithm consists roughly of two parts: a pre-processing part to smooth the signal and an optimization part to compute the systolic and diastolic pressures.

**Calibration method for the oscillometry**

The goal of calibrating the oscillometric measurements is to obtain estimates of the systolic and diastolic pressure which are as close as possible to the results measured by the Korotkoff method. In hospitals, the NIBP is calibrated by comparing its results to the physician’s results by means of the Korotkoff method. This is both time consuming and infeasible if no physician is available (e.g. private use at home). Hence, the long term objective is a calibration standard which is based on a statistical model. Assuming that the oscillometric blood pressure meters operate reasonably well for the average healthy person, the calibration should correct the blood pressure meters in particular for patients suffering from severe hyper–or hypotension. This calibration proposed is based on the Windkessel model for the arterial system.
Although there exist other models describing the arterial system, we selected the Windkessel model as this model describes the relationship between the blood flow and the blood pressure. The current-source \( q(t) \) is called the cardial output. Formally it is defined the flux computed as the quantity of blood in liters pumped by the heart per minute and \( p(t) \) denotes the pressure. This Windkessel model follows the differential equation,

\[
RC \frac{d}{dt} p(t) + p(t) = Rq(t)
\]  

(1)

We develop an identification procedure for the differential equation based on the measured oscillometric waveform to detect patients with a high or low blood pressure. A measurement campaign of 75 patients was held in the UZ-Brussel accordingly to the protocols of the British Hypertension Society. The calibration method proposed by means of the Windkessel model resulted in a reduction of the discrepancy between the Korotkoff’s and NIBP’s systolic and diastolic blood pressures with approximately 40% (See tables 2-3). Hence, this paper reveals that models used to describe the dynamics of the blood flow hold sufficient information to calibrate automatic blood pressure meters and detect patients with a large or low blood pressure. Future research is required to optimize the use of such models for calibrating the NIBPs.

<table>
<thead>
<tr>
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<th>Korotkoff/NIBP</th>
<th>Korotkoff/Calibration</th>
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<tr>
<td><strong>RMS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Systolic)</td>
<td>8.42 mmHg</td>
<td>6.08 mmHg</td>
</tr>
<tr>
<td>(Diastolic)</td>
<td>7.59 mmHg</td>
<td>4.42 mmHg</td>
</tr>
</tbody>
</table>

Table 2: The RMS of the error between the Korotkoff and NIBP and the RMS of the error between the Korotkoff and the calibrated values for the healthy patients.

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<th>Korotkoff/NIBP</th>
<th>Korotkoff/Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS</strong></td>
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<td></td>
</tr>
<tr>
<td>(Systolic)</td>
<td>17.97 mmHg</td>
<td>10.59 mmHg</td>
</tr>
<tr>
<td>(Diastolic)</td>
<td>8.48 mmHg</td>
<td>5.27 mmHg</td>
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</tbody>
</table>

Table 3: The RMS of the error between the Korotkoff and NIBP and the RMS of the error between the Korotkoff and the calibrated values for the ill patients.

2.4.3.2 Influence of the cuff deflation mode on oscillometric blood pressure measurements
(Wendy Van Moer and Kurt Barbé)

One of the most popular medical instruments used at home is the automatic non-invasive blood pressure meter (NIBP). Most medicine cupboards contain one and a lot of people use it on a daily basis. A cuff is wrapped around the upper arm of the patient and inflated until the circulation stops. Most classical automatic blood pressure meters are based on the oscillometric principle, which records the oscillations in the cuff pressure during deflation of the cuff. Out of this oscillometric
waveform a mean arterial pressure (MAP) as well as a systolic and diastolic pressure is deducted by means of a mathematical algorithm, which is based on the envelope of the recorded oscillometric waveform. The accuracy of the obtained blood pressure values relies on the accuracy of the envelope. However, in many cases, the oscillometric waveform has no clear envelope and determining the MAP is rather difficult and far from being accurate. As a result, the mathematical algorithm consists roughly of two parts: a pre-processing part to smooth the signal and an optimization part to compute the systolic and diastolic pressures.

Recently, a linearization method for the oscillometric blood pressure waveform has been successfully introduced [1]. This method is based on a frequency-domain signal processing approach and consists of filtering the nonlinear effects present in the oscillometric waveform. This approach results in a much smoother envelope and, hence, more accurate blood pressure values. The observed nonlinear contributions can be generated either by the blood pressure meter, or by the human body, or by a combination of both.

In this work, we investigate the cause of these nonlinearities on an experimental basis. Thereto, the deflation mode of the cuff pressure is varied and the results are analysed in the frequency domain. The deflation of the cuff can be performed in two different ways. One can either decrease the pressure in the cuff either in a quasi-linear way (see Figure 33 (a)) by keeping the valve constantly open, or stepwise (see Figure 33 (b)) by consecutively opening and closing the valve. The commercially available blood pressure meters typically release the pressure in the cuff stepwise. The way the pressure is decreased in the cuff may have an influence on the measured oscillometric blood pressure waveform. The question is whether the deflation mode of the cuff is responsible for all nonlinear contributions present in the oscillometric waveform. If so, the linearization method developed in [1] can be completely justified based on this experimental validation.

In this paper, the deflation of the cuff is performed in two different ways: a quasi-linear deflation and a step-wise deflation. The frequency-domain representation of the oscillometric waveform of both measurements is compared and analysed. In case of the quasi-linear deflation mode, the

![Figure 33: Cuff deflation model](image)
measurements are performed based on the NI Elvis educational design and prototyping platform [2] combined with the Vernier Bio-instrumentation sensor kit [3] (see Figure 34. A commercial automatic blood pressure meter is used to obtain the results for the stepwise deflation mode.

The experiments clearly show that the nonlinear contributions present in the oscillometric waveform of the commercially available blood pressure meter are due to the stepwise deflation mode of the cuff. Hence, linearizing the oscillometric waveform to obtain a more smooth and ideal envelope is recommended in order to obtain more accurate blood pressure results without loss of information.

References:

2.4.3.3 Digital Modeling and Correction of Nonlinear Radio Frequency Components (P.N. Landin, C. Nader, W. Van Moer, K. Barbé)

The available radio frequency spectrum is getting crowded by the increasing number of wireless communication services we are surrounded by: mobile telephony of 2nd, 3rd and 4th generations plus their backhauling networks, wireless local access network (WLAN), BlueTooth, transmitters used for remotely opening the garage door and unlocking the car, television, radio, satellite communication, etc. etc.

To simultaneously accommodate all these communication technologies, more or less, strict requirements are put on the output signal’s power spectrum from each device. This is made to ensure that transmitters in adjacent frequency channels do not interfere with the received signal. In the third generation of mobile telephony, this is measured using the Adjacent Channel Power Ratio (ACPR) and is a measure of the relative distortion transmitted in the adjacent channel to the signal power in the intended channel [1]. These distortions are mainly caused by spectral spreading of the input signal due to the nonlinearities in the power amplifier (PA). The power spectrum of an input signal to a nonlinear PA, the corresponding output power spectrum and the power spectrum of the corrected output signal are shown in Figure 35, along with the main channel and the two adjacent channels.
This project aims in a first step to create models that accurately describe the nonlinear behaviour (thus also the spectral spreading). This is done by studying a nonlinear feedback structure that is to be simplified into a class of models that are easier to handle, namely the memory polynomial models.

The second step is to construct models that can correct, or at least reduce, the non-ideal behaviour by using digital signal processing techniques. To do this, the knowledge of the system obtained from the earlier derived model structures is used to construct simple digital correction methods. These methods have been tested on compressive PAs (standard class-A, AB, B, C and Doherty) and have been found to perform to expectations in terms of linearization performance. Techniques for modelling and correcting out phasing amplifiers have also been tested on high-power state-of-the-art CMOS-based class-D out phasing amplifiers.

Methods based on shaping the input signal to the PA intended at improving the efficiency of the PA have also been tested in conjunction with the digital correction methods, and have been found to increase PA power efficiency from 5-10% up to above 50% while fulfilling linearity requirements in modern wireless communication systems. Simultaneously, the output power could also be increased by 3-5 dB.

The found results from the modelling and, especially, correction of the nonlinear behaviour in amplifiers can have a significant value “in a world where every dB is worth a billion” [2].

References:

2.4.3.4 A robust signal detection method for fMRI data under correct Rice conditions
(Lieve Lauwers, Kurt Barbé and Wendy Van Moer)

Introduction

The goal of functional Magnetic Resonance Imaging (fMRI) is to detect regions in the human brain that show significant neural activity upon stimulus. To do so, a statistical analysis of the data needs to be performed in which the hypothesis that no signal is present (i.e., the null hypothesis) is tested. The main problem of the classical statistical tests is that they are based on the wrong assumption that fMRI data are normally distributed. It is however known from literature that fMRI data are Rice distributed [1], [2]. For high signal-to-noise ratios (SNRs), the Rice distribution converges to a Gaussian distribution [3]. Hence, for high SNRs the performance of the classical statistical tests will hardly suffer from the normality assumption. Unfortunately, in fMRI applications low SNRs are omnipresent such that the characteristics of the Rice distributed data should be taken into account in order to accurately analyse fMRI data. To conclude, it is important to develop statistical methods that yield reliable results in all circumstances.

Classical versus Rice-corrected t-test

In [4], a test statistic (under the null hypothesis) is presented for an fMRI data set \( x \), in case of a known (square wave) fMRI paradigm \( u \) and an unknown standard deviation (std) \( \sigma \):

\[
T_t = \frac{u^T x}{\hat{\sigma} \sqrt{u^T u}} \tag{1}
\]

with \( \hat{\sigma} \) an estimate of the std. Since the t-test given in [4] simply ignores the true Rician distribution of the data, it is in general not suited for fMRI data. Using (1), the user will not be able to detect small intensity variations due to neural activity and, hence, perform a wrong data analysis. We propose a correction for this t-test by taking into account the correct Rice conditions, resulting in the Rice-corrected t-test \( \tilde{T}_t \):

\[
\tilde{T}_t = T_t \frac{\sqrt{2}}{\sqrt{4 - \pi}} \tag{2}
\]
By comparing (1) and (2) we observe the presence of the factor $\sqrt{2}/\sqrt{4 - \pi}$. This correction factor which is independent of $\lambda$ or $\mu$ allows the user to perform a robust statistical analysis of fMRI data, using a single statistical method.

**Simulation experiment**

The performance of the test statistics (1) and (2) were compared via a simulation experiment in which we determined the obtained significance level $\alpha$ of both $t$-tests. In a Monte Carlo simulation of $M = 10000$ runs, we calculated the test statistic in (1) and (2) under the null hypothesis. We specified the significance level $\alpha_{spec}$ to be equal to 5%. Translated in fMRI terms, this means that we accept in 5% of the cases a false alarm: a brain element is considered as active, while it is not in reality (type I error).

In Figure 36, we show the resulting histogram from the Monte Carlo simulation of (1) and (2), given by the black and grey curve respectively. The black vertical line corresponds to the specified significance level of 5%. Qualitatively, we see that the Rice-corrected $t$-test (2) results in a higher rejection ratio.

The cumulative distribution function (cdf) is a more appropriate tool to quantify the simulation results. Figure 37 shows the empirical cdf, together with the theoretical significance level of 5% (black vertical line) and a horizontal dash-dotted line indicating a cumulative probability of 95%. We see that the significance level and the 95-percentile of (2) perfectly match.

This simulation experiment shows that the user-specified significance level $\alpha_{spec}$ is not obtained by the classical $t$-test in (1), while this is achieved by the Rice-corrected $t$-test in (2). The main consequence of this result is that the rejection region of the null hypothesis will not correspond to the user’s demands, resulting in a test with a decreased detection performance.

**References**


2.4.3.5 Dielectric Spectroscopy for Non-Invasive Glucose Measurements

(Oscar J. Olarte1, Wendy Van Moer1, Kurt Barbé1 and Yves Van Ingelgem2)

1 Dept. ELEC, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium
2 Dept. SURF, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium

Introduction

A common non-invasive measurement technique is based on dielectric spectroscopy (DS). This technique allows measuring the properties of the system as a function of the frequency as well as distinguishing between the different processes that could be involved [1]. When developing a non-invasive glucose measurement system, one must deal with different noise sources that need to be identified and quantified in order to provide confidence bounds for the estimated glucose level. Hence advanced signal processing techniques are needed to quantify, detect and discriminate the presence of noise sources as well as the non-linear distortions inherent to the system.

Experimentation

In a first step towards the in-vivo identification of blood glucose levels, in-vitro experiments are performed using different solutions. It let us identify the influence of various constituents of human blood on the system response as well as the variance in the experimentation. Three principal blood components are tested given its prevalence in blood or its influence over the conductivity process. During the experiments the concentration of the investigated substances is maintained at human reference values and its impedance is evaluated over a number of physiological (normal or pathological) glucose levels. The results suggest that the glucose concentration could be identified based on the impedance, by considering the amplitude, phase information and the complex plane.

Results

Experiments using incremental experimentation, room and body temperature and different repetitions show the influence of these factors over the glucose impedance measurement.
According with the results, a low variance in the experimentation is obtained at body temperature as well as in high glucose concentrations.

The BLA combined with ORPM generates information related to the linear behaviour of the system under test, as well as the noise level and the non-linearities present in the system [2]. Based on the results, the BLA describes appropriately the impedance behaviour of each one of the analysed systems.

Although the results are preliminary, they clearly elucidate the capabilities of random phase multisine analysis for glucose measurements. In the future more complex sampled matrices should be analysed (plasma, complete blood, over the skin, fat, etc.). Besides, this is also necessary to test the effect of environmental factors. However, the proposed approach shows a great capacity to detect the impedance levels in the most prevalent blood components.

References


3. Education

3.1 THE INTRODUCTION OF THE BACHELOR-MASTER STRUCTURE

Since the academic year 2004-2005 the “bachelor - master” structure (replacing the candidate - licentiate structure) has been introduced. The initiative for this thorough interference in the programmes of higher education was the Bologna Declaration. The Ministers of Education of 31 European Countries gave in 1999 the start to uniform the higher education in Europe. Although the Bologna process creates convergence, the fundamental principles of autonomy and diversity are still respected. The aim of the Bologna Declaration is to improve in Europe the exchangeability of degrees, the free mobility of students, quality assurance and a flexible study package by introducing credit systems.

3.2 BRUFACE

Brussels Faculty of Engineering (in short "Bruface") is an initiative of the two universities in the centre of Brussels. The Université Libre de Bruxelles (ULB) and the Vrije Universiteit Brussel (VUB) jointly offer a broad spectrum of fully English taught master programmes in engineering.

Starting from the academic year 2011-2012 Université Libre de Bruxelles and Vrije Universiteit Brussel jointly organise the following English taught Master of Science (MSc) programmes

- MSc in Architectural Engineering
- MSc in Chemical and Materials Engineering
- Options Materials | Process Technology
- MSc in Civil Engineering
- MSc in Electromechanical Engineering
- Options Aeronautics | Energy | Mechatronics-Construction | Vehicle Technology and Transport
- MSc in Electronics and Information Technology Engineering

The Université Libre de Bruxelles (ULB) and the Vrije Universiteit Brussel (VUB) are both active in several international higher education networks including T.I.M.E.¹ and UNICA².

¹ Top Industrial Managers Europe: is a network of 51 leading Engineering Schools and Faculties and Technical Universities which offers, through a system of voluntary bilateral agreements between its members, promotion and recognition of academic excellence and relevance to the international labour market in the form of Double Degrees in engineering and in related fields.

² Is a network of 42 Universities from the Capital cities of Europe, with a combined strength of over 120,000 staff and 1,500,000 students. Its role is to promote academic excellence, integration and co-operation between member universities throughout Europe.
### 3.3 COURSES LECTURED IN THE FACULTY OF ENGINEERING

#### 3.3.1 Lectures and practical courses

<table>
<thead>
<tr>
<th>Lectures and practical courses</th>
<th>Credits</th>
</tr>
</thead>
</table>
| **Elektromagnetisme - Prof. A. Barel**  
*Electromagnetism*  
3rd Bachelor of Applied Sciences and Engineering (compulsory) | 6 |
| **Gevorderde controletechnieken - Prof. R. Pintelon – Prof. Jan Swevers (KUL)**  
*Advanced Checking Techniques*  
2nd Master of Applied Sciences and Engineering : Electronics and IT-Engineering (optional)  
2nd Master of Applied Sciences and Engineering: Photonics Engineering (optional)  
3rd Electronic and IT Engineer (optional) | 4 |
| **Identificeren van dynamische systemen - Prof. R. Pintelon**  
*Dynamic Systems Identification*  
2nd Master of Applied Sciences and Engineering : Electronics and IT-Engineering (optional)  
2nd Master of Applied Sciences and Engineering: Photonics Engineering (optional)  
3rd Electronic and IT Engineer (optional) | 4 |
| **Netwerken en filters - Prof. R. Pintelon**  
*Network Analysis and Synthesis*  
3rd Bachelor of Applied Sciences and Engineering (compulsory) | 7 |
| **Systeem- en controletheorie - Prof. J. Schoukens – Prof. R. Pintelon**  
*System and Control Theory*  
3rd Bachelor of Applied Sciences and Engineering (compulsory)  
3rd Bachelor of Applied Sciences and Engineering (optional)  
3rd Bachelor of Mathematics (optional)  
2nd Master of Applied Sciences and Engineering: Chemistry and Materials (optional)  
3rd Chemical and Materials Engineer (optional) | 3 |
| **Hoogfrequent elektronica en antennes - Prof. Y. Rolain**  
*High-frequency Electronics and Antennae*  
1st Master of Applied Sciences and Engineering : Electronics and IT-Engineering (compulsory)  
2nd Master of Applied Sciences and Engineering: Photonics Engineering (optional) | 6 |
| **Meten en identificeren - Prof. Y. Rolain - Prof. J. Schoukens**  
*Measurement and Identification*  
1st Master of Applied Sciences and Engineering : Electronics and IT-Engineering (compulsory)  
2nd Master of Applied Sciences and Engineering: Biomedical Engineering (optional)  
3rd Electronic and IT Engineer (compulsory)  
2nd Bachelor of Mathematics (optional)  
2nd Master of Applied Sciences and Engineering: Chemistry and Materials (optional)  
2nd Master of Applied Sciences and Engineering : Electro-Mechanical Engineering (optional) 3rd year Chemical and Materials Engineer (optional)  
3rd Electro-Mechanical Engineer (optional) | 7 |
| **Bio-informatica en datamining - Prof. Yves Moreau (KUL) - Prof. J. Schoukens**  
*Bioinformatics and Datamining*  
2nd Master of Applied Sciences and Engineering : Applied Computer Sciences (optional)  
2nd Master of Applied Sciences and Engineering : Electronics and IT-Engineering (optional)  
2nd Master of Applied Sciences and Engineering: Photonics Engineering (optional)  
3rd Electronic and IT Engineer (optional) | 4 |
| **Meten en modelleren van niet-lineaire systemen - Prof. J. Schoukens**  
*Measuring and Modelling of Nonlinear Systems* | 3 |

3 The language of tuition of all these courses is Dutch
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<tr>
<td>Statistiek voor ingenieurs - Prof. J. Schoukens&lt;br&gt;Probability and Statistics</td>
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<td>Industriële meetomgevingen - Prof. L. Van Biesen&lt;br&gt;Industrial Measurement Environments</td>
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<td>Navigatie en intelligente voertuigen - Prof. L. Van Biesen&lt;br&gt;Navigation and Intelligent Vehicles</td>
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<td>Signal Theory - Prof. L. Van Biesen&lt;br&gt;Signal Theory</td>
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<td>Stage: elektrotechniek - Prof. L. Van Biesen&lt;br&gt;Traineeship: Electrical Engineering</td>
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<td>Transmissiemedia en -systemen - Prof. L. Van Biesen&lt;br&gt;Physical Communication</td>
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3.4 MINOR “MEASURING, MODELLING, AND SIMULATION OF DYNAMIC SYSTEMS” OFFERED WITHIN THE 2ND MASTER ELECTRONICS AND INFORMATION TECHNOLOGY

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<td>Measuring and modelling of nonlinear systems - Prof. J. Schoukens</td>
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<td>Industrial measurement environments - Prof. L. Van Biesen</td>
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<td>Identification of dynamic systems - Prof. R. Pintelon</td>
<td>4</td>
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<tr>
<td>Advanced control methods - Prof. R. Pintelon - Prof. J. Swevers, KULeuven</td>
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<tr>
<td>CAE-tools for the design of analog electronic circuits - Prof. G. Vandersteen</td>
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<tr>
<td>Design and characterization of high-frequency (nonlinear) systems - Prof. W. Van Moer</td>
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<tr>
<td>Bio-informatics and datamining - Prof. J. Schoukens - Prof. Y. Moreau (KULeuven)</td>
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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 under 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 are set to default values that are not always suitable for the specific situation, and this can jeopardize the results completely (course: CAE-tools for the design of analog electronic circuits). 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
operating region for power efficiency reasons (course: *Design and characterization of high-
frequency (nonlinear) systems*). As an engineer, we are overwhelmed with information that is often
out of the scope or our interest. The course on *Bioinformatics and datamining* opens a new
scientific field that is directed to the problem how to extract the desired information out of
enormous amounts of data. How can we turn data into information?

3.5 DESIGNING SYSTEMS FROM CONCEPTS: THE PING-PONG TOWER
PROJECT

The design of complex systems demands that engineers possess significant set of abstract system-
level thinking skills. Engineering students therefore need to be exposed to the art of solving
problems systematically and have to learn the limitations and the backsides of ad-hoc methods, to
ensure that they should only turn to these methods as last resort alternatives.

To start the process of system-based thinking early, we use an experience based learning project
during the students’ fourth semester to awaken them to a systematic engineering approach. This
project is taken by all engineering students at our university. As a consequence, all the students
are taught the crucial concepts that can lead to the inclusion of sustainable development in
engineering practice irrespective of their final specialization in electronics, mechanics, chemistry....

A feasible toy engineering problem is proposed that includes a lot of practical engineering problems:

The process to be controlled is the stabilization of the height of a Ping-Pong ball floating in a user-
controlled airflow inside a transparent Plexiglas tube. Although students get a strong guidance
towards good engineering practice, they have to choose the method and decide on the practical
implementation themselves.

Pedagogically speaking, the major advantage of this project is that the students gain a lot of
engineering attitudes. Firstly, they gain hands-on experience in a wide range of engineering
applications: digital electronics, analog electronics, power electronics, control engineering, signal
processing, optical system design, and computer engineering all have their role to play in the
project. Secondly, they gain the insight that system-level thinking leads to complexity reduction
and problem partitioning, and therefore allows to solve large-scale problems that would remain
untracktable otherwise. They learn that walking the lines of a systematic design framework leads
to well-understood, high-quality, reproducible and reusable results.
In the next section, we situate the project in the engineering study. Afterwards, we explain the different steps the student should take. Then we describe which engineering attitudes the students gain throughout this project.

3.5.1 Situating the project

At the Vrije Universiteit Brussel, all engineering students follow the same courses during their first four semesters of their bachelor education. In order to help the engineering students to choose between different specializations, they are confronted with four different engineering problems in their fourth semester, one in civil engineering, one in chemical engineering, one in mechanical engineering and one in electronic engineering.

The ping pong tower project has a number of inherent advantages due to its broad range of possible solutions. The solutions that can be built

- are a combination of analog and digital electronics;
- use both hardware and software solutions;
- have the dynamics of the system are in a practical range, making it possible to demonstrate instabilities;
- involve no safety risks due to the use of low voltages;
- make it possible to introduce the students to control theory.

3.5.2 The project

The students need to control the height of a Ping-Pong ball in a tube by means of a fan which blows air in the tube. They need to set and measure the height using a PC. Every group needs to present its work in a scientific way by the end of the project to train their scientific presentation skills.

The goal is that the teams build up a complete solution starting from available basic building blocks:
1. A variable speed fan blows air into a Plexiglas tube whose diameter is 4 mm larger than the Ping-Pong ball.

2. An example interface between the PC and a PIC-based microcontroller board which has a USB connection to the PC. The firmware of the microcontroller board contains the implementation of an analog-to-digital convertor and a PID controller with user adjustable gains besides the present USB interface to the PC. The simple PC program allows the user to set the wanted height and read the actual height of the Ping-Pong ball from the microcontroller board.

3. Various pre-existing modules are available since – due to the limited timeframe – it is impossible that the students build everything from scratch. The pre-existing modules are an ultrasonic position sensor module, a fan power steering module, a microcontroller board and a simple PC program.

3.5.3 From concept to working system

The key idea is to illustrate the usefulness of a top-down design for the control of complex systems. The students are thought to first reason at the system level using simple system models. Next, good engineering practice rules are to be used to specify the modules separately. Then, the selected modules are designed separately from a set of discrete components. The final challenge is to combine everything in a performing system.

During the first one and a half day, the students try to understand the problem by slicing it into smaller sub-problems. During the next day, they decide on their strategy and implementation. The next two days, they spend on implementing their different blocks. The final one and a half day before the presentation, they need to combine the different sub-blocks and tune their controller.

3.5.3.1 Step 1: Understanding the problem

What is a system? This question is the key problem tackled in this phase. Therefore, the students get a short introduction to the system-level concept.

They discover the usefulness of a block diagram of their complete system to support high-level reasoning. They partition the problem into different logical blocks with a smaller complexity. They also have to think about the analog and/or digital interfaces between the different blocks. This brings them to a block diagram like Figure 39 the figure below.

For the first time in their education, the students have to deal with

- the sensors and sensor data,
- the controller,
- the power steering stage for the fan,
- interfacing the digital data between a PC and a microcontroller, and
- the design of a user-friendly interface on the PC.
In order to be able to interconnect all the blocks, they need to decide on the interfaces between the different blocks. Therefore, they write down specifications for the different blocks. The interface specifications of the pre-existing modules are given in a datasheet format. These specifications let the students reflect on the interconnection and make them acquainted with datasheets. The power steering module – for example – has two different inputs: an analog voltage and a digital PWM input that are both controlling the output voltage. They have to decide which type of signal they are going to use and consider the influence of their choice to the rest of the system.

The students experience that most design problems do not have a unique solution, unlike what they found from their courses in mathematics. Although the control loop will always look the same at system level, the block diagrams of the different groups can differ. Some groups implement for example the controller in the PC program, which moves the interface between the PC and the system directly to the controller input. Such choices have a large impact. The students learn to weight off the different advantages and disadvantages, and learn to slice a complex problem into tractable and independent, co-operating blocks.

**3.5.3.2 Step 2: Strategic thinking**

Due to the limited timeframe and their lack of practical experience, it is not possible for every group to build up a complete solution from scratch. Therefore, depending on the number of students in the group, two to three blocks are selected for a design from scratch, depending on the student’s own interest. This allows training their negotiation skills and expressing their leadership. They use the pre-existing modules for the other blocks.

The groups define work packages that fit the workload of two students for the next three days. Since they work in teams of two students, they all feel engaged in the project. They can make their own contribution to the project without being overshadowed by one brilliant student in the group who would otherwise be designing the complete project.

Every team then focuses on the design strategy of their specific block. They have the freedom to choose their approach freely. The sensor – for example – can be realized under different forms: an
ultrasonic height sensor, an optical scan line, an image-based webcam sensor, ... They are also encouraged to propose their own solutions, although the feasibility needs to be checked beforehand.

### 3.5.3.3 Step 3: Creating the different blocks

When they develop a specific block, they learn that the system-based approach used before can be reused. The specific problem is further split into different sub-blocks until they reach the level where building and understanding each part becomes straightforward. Then, each element is realized and tested to meet the prescribed specifications. Afterwards, those elementary parts are combined into subsystems.

For the ultrasonic sensor, this system-based approach results in the design of a transmitter, a receiver and a signal processing unit. The transmitter generates a pulsed 40 kHz signal together with its envelope. The receiver cleans up the measured reflected burst and generates a discrete envelope of the received signal. The signal processing unit measures the time T between the transmitted and reflected burst, which is proportional to the distance L between the sensor and the Ping-Pong ball.

![Diagram](image)

*Figure 40: In the case of the ultrasonic height sensor, the block can be further split into three sub-blocks: the transmitter, the receiver and the signal processing.*

The system-based approach can be recycled ones more. For example, the pulse transmitter in the ultrasonic sensor can be split into different blocks: the 40 kHz oscillator, the envelope generator, the masking of the oscillator by the envelope and the driver for the loudspeaker. These different blocks are basic electronic building blocks that the students already studied or can be found easily in references on electronic circuits or on the internet.

When the different basic building blocks are combined, the students experience the concepts of loading and interference. The loading of a circuit requires the design of an output driver such that
it matches the input characteristics of the next block. The interference is minimized by a careful routing of the power line, proper decoupling and filtering of the appropriate signals. During this step, they learn to iteratively use the system-level approach to end up with a hierarchical design and how elementary building blocks in electronics or informatics can be combined into a sub-system that meets the specifications. They also experience that the basic building blocks seen in introductory courses are used in real systems.

3.5.3.4 Step 4: Going back to the system level

Now that the separate blocks are operational, the challenge lies in their combination, i.e. by suppressing the interference and overcoming the loading of the different blocks.

Finally, system-level testing is performed. Once the system is reaching specs, it becomes time to close the control loop. Here, students encounter feedback loops for the first time. This shows them the power of feedback control and nicely illustrates the properties of the different control actions: The proportional gain which lacks accuracy, the derivative action for speed improvement and the integral action for error removal and the consequent instability.

First – by playing manually with the gains of the different actions – the students discover the advantages and disadvantages of the different actions. Second – by the end of the day – the students are explained how the relay test works. This allows them to obtain a working controller without any heuristic search.

Hence, the way is now opened for them to understand the usefulness and the power of the otherwise so abstract control theory. They learn to evaluate the control behaviour by looking at the tracking behaviour and the disturbance rejection.

During this step, they learn how to combine different blocks to a larger system and also to evaluate and tune the system’s performance by measurements.

To finalize their effort and tune their controller, they need one and a half day.

3.5.3.5 Step 5: Presentation

During the last half day, the groups have to demonstrate their system to the groups and give a scientific presentation of their solution. This presentation trains their communication skill. It also enables them to learn about other implementations from other groups.

3.5.3.6 Conclusion

The project is mainly intended to help the students to make an informative choice about their engineering specialization, and also teaches them a fundamental engineering concept: design a complex control system.
The system-level systematic framework enables the engineer to develop well-understood, high-quality, reproducible and reusable results.

### 3.6 COURSES LECTURED IN THE FACULTY OF SCIENCE AND BIO-ENGINEERING

<table>
<thead>
<tr>
<th>Lectures and practical courses</th>
<th>Credits</th>
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<tbody>
<tr>
<td>Berekenbaarheid en informatietheorie⁴ - Prof. L. Van Biesen</td>
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<tr>
<td>Computability and Information Theory</td>
<td></td>
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<tr>
<td>1st Year Master of Applied Sciences and Engineering: Computer Science (compulsory)</td>
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<tr>
<td>Geographical Information Systems - Prof. L. Van Biesen</td>
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<tr>
<td>2nd year Master of Ecological Marine Management (compulsory)</td>
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<tr>
<td>2nd Year Master of Applied Sciences and Engineering: Applied Computer Science (optional)</td>
<td></td>
</tr>
<tr>
<td>2nd Year Master of Science Ecological Marine Management (compulsory)</td>
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<tr>
<td>Theory of Computation and Information Theory - Prof. L. Van Biesen</td>
<td></td>
</tr>
<tr>
<td>1st Year Master of Applied Sciences and Engineering: Computer Science (compulsory)</td>
<td>6</td>
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<tr>
<td>Analyse, WPO³: Mattijs Vandewalle, Griet Monteyne, Dr. Kurt Barbé</td>
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<tr>
<td>Analysis, Exercises</td>
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<tr>
<td>1st Year Bachelor of Science in Math</td>
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<tr>
<td>Complexe Analyse, WPO⁶: Lieve Lauwers, Dr. Kurt Barbé, Diana Ugryumova, Jan Goos</td>
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<td>Complex Analysis, Exercises,</td>
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<td>2nd Year Bachelor of Science in Math</td>
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<tr>
<td>Wiskundige statistiek, WPO⁷, Dr. Kurt Barbé</td>
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<td>Mathematical statistics</td>
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<tr>
<td>3rd Year Bachelor of Science in Math</td>
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### 3.7 NATIONAL AND INTERNATIONAL COURSES

#### 3.7.1 National courses (since 2003):

**3.7.1.1 Identificatie van systemen (Identification of Systems)**

**Organised by:** University of Gent, "Instituut voor permanente vorming"

**Location:** IVPV - UGent, Technologiepark, 9052 Gent-Zwijnaarde

**Lectured by:** Johan Schoukens and Yves Rolain

**Dates:** 7, 14 and 21 December 2004

Meten en modelleren is een basisactiviteit van vele ingenieurs: modellen worden gebruikt tijdens het ontwerp, in simulatoren en in eindproducten. Het modelleringsproces is een complexe activiteit die in 4 grote delen kan worden opgesplitst: verzamelen van de experimentele data; opstellen van een model; in overeenstemming brengen van een model en data; validatie van de resultaten.

⁴ The language of tuition of this course is Dutch
⁵ The language of tuition of this course is Dutch
⁶ The language of tuition of this course is Dutch
⁷ The language of tuition of this course is Dutch
Systeemidentificatie biedt een systematische, optimale oplossing en wordt in deze module bestudeerd, met als toepassing the identificeren van dynamische systemen. Hierbij wordt de klemtoon gelegd op het aanbrengen van de ideeën, ondersteund door uitgewerkte Matlab illustraties.

De behandelde topics zijn

- Systeemidentificatie: wat? waarom?
  Een verhelderend voorbeeld
  Goede schatters/slechte schatters, wat mag je ervan verwachten?

- Niet-parametrische identificatie van frequentieresponse functies
  Basisidee: van tijdsignaal tot frequentierespons (FRF)
  Experiment design: keuze van de excitatiesignalen, ruisgevoeligheid, uitmiddelen
  Nietlineaire distorties: detectie, kwalificatie en quantificatie

- Parametrische identificatie van de transferfunctie
  Basisidee: van data tot model
  Tijdsdomein- en frequentiedomein-identificatie

- Identificatie van tijdsvariërende systemen
  Basisidee
  Balans volgssnelheid/ruisgevoeligheid

### 3.7.1.2 Courses lectured at the Katholieke Universiteit Leuven (KUL)

- Rik Pintelon: "Identificeren van lineaire dynamische systemen" 18 HOC, 36 WPO (4 credits):
  keuze o.o. in de Master in de wiskundige ingenieurstechnieken

- Johan Schoukens: "Systeemidentificatie en modellering" (6 credits):

- Master in de ingenieurswetenschappen: wiskundige ingenieurstechnieken

- Master in de ingenieurswetenschappen: bouwkunde

- Master in de wiskunde

- Master in de ingenieurswetenschappen: wiskundige ingenieurstechnieken, programma voor industrieel ingenieurs of master industriële wetenschappen (aanverwante richting) (na toelating)

- Yves Rolain: “Meten en modelleren” keuze o.o. in de Master in de wiskundige ingenieurstechnieken

### 3.7.1.3 Open course program-IMEC academy: DSP concept explained with well-chosen exercises.

**Organised by:** imec-leuven

**Location:** imec, Leuven, Belgium

**Lectured by:** Johan Schoukens and Yves Rolain

**Dates:** November 14th, 28th, December 5th, 19th, 22nd (2011)

The course is a basic theoretical introduction to the concepts of digital signal processing.

- Introduction to system theory and signal processing impulse response and transfer functions of linear systems; stability-causality; poles and zeros; sampling DFF=FFT – all with Matlab exercises.
• Introduction to measurement and modelling of linear systems (measurement of the frequency response function; choice of excitation; the effect of noise and leakage; estimation of the parametric model) – including Matlab exercises.

• Handling non-linear distortion: detection; classification and qualification of linear distortion – including Matlab exercises.

• Design of digital filters and systems (basic choices and non idealities: filter examples; compression and expansion ...) – including Matlab exercises.

• Wrap-up: further Matlab exercises applying the techniques on integrated problems. Analysis of implemented filters; evaluating non-linear distortions (impact of quantizing noise).

3.7.2 International courses (since 2003):

3.7.2.1 Characterisation of Multiport Systems through 3-port LSNA Measurements
Location: Seminar at NIST, Boulder, CO, December 2003
Lectured by: Wendy Van Moer
# attendees: 20

3.7.2.2 The use of multisines
Location: Seminar at NIST, Boulder, CO, December 2003
Lectured by: Daan Rabijns
# attendees: 20

3.7.2.3 GIS training in SEAFDEC, Thailand
Location: Samut Prakan SEAFDEC/Training Department, Thailand, Bangkok, 2005
Lectured by: Tesfazghi Ghebre Egziabeher

The theme of the course was interrelated to the use of Geographic Information System for Fishery Management. Participants of the course were members of the Southeast Asian Fisheries Development and Training Centre (SEAFDC/TD), who were professionally engaged in the fishing industry.

3.7.2.4 Measuring, Modeling, and Designing in a Nonlinear Environment
Location: tutorial workshop organized at I2MTC08, Vancouver, Canada, May 2008
Lectured by: Yves Rolain, Ludwig De Locht, Rik Pintelon, Johan Schoukens, Wendy Van Moer

Topics:
• Best linear approximation and design: A perfect marriage (L. De Locht)
• Measurement of the Best Linear Approximation of Nonlinear Systems (W. Van Moer)
• Impact of nonlinear distortions on the linear framework (J. Schoukens)
• Frequency Response Function Measurement in the Presence of Nonlinear Distortions (R. Pintelon)

3.7.2.5  **VUB - doctoral school on Identification of Nonlinear Dynamic Systems**

**Location:**  Dept. ELEC, Vrije Universiteit Brussel, Building K, 6th floor  
**Lectured by:**  Rik Pintelon, Johan Schoukens, Gerd Vandersteen, Yves Rolain  
**# attendees:**  18 (8 different nationalities) in 2008, 14 (9 different nationalities) in 2010 and 18 (9 different nationalities) in 2011

The department ELEC of the VUB, organized a 4 weeks doctoral school (from the 26th of May till the 20th of June in 2008, from 16th May till the 21st of June in 2009; from the 6th of June till the 2nd of July in 2010 and from 7th of May until 5th of June in 2011) to give an intensive training on advanced modelling and simulation techniques of (non)linear dynamic systems, starting from experimental data. Half of the time has been spent on courses/exercises, the other half on a project to get hands-on experience. The material taught during the courses and exercises has been put into practice during a clearly defined project, in order to get hands-on experience. The course covered the following topics:

- A basic introduction to system identification,  
- Identification of dynamic systems,  
- Measuring and modelling of nonlinear systems,  
- Simulation tools for nonlinear systems,  
- Design and characterization of high-frequency (nonlinear) systems (optional: intended for those with an interest in microwave systems).

The next doctoral school on Identification of Nonlinear Dynamic Systems\(^8\) will be organised in May/June 2012 (from the 21st of May 2012 till the 15th of June 2012). 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 grants 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 20th of February 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: doliva@vub.ac.be or johan.schoukens@vub.ac.be.

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\(^8\)http://wwwtw.vub.ac.be/elec/doctoralschool.htm
4. Bibliography

4.1 BOOKS

b1. Identification of Linear Systems: A Practical Guideline to Accurate Modeling
J. Schoukens, R. Pintelon
The book is concentrated on the problem of accurate modelling of linear time invariant systems. These models can be continuous time (Laplace-domain) or discrete time (Z-domain). The complete experimental procedure is discussed: how to create optimal experiments (optimization of excitation signals), how to estimate the model parameters from the measurements, how to select between different models, etc. These problems are thoroughly discussed in the first section of the book. A profound theoretical development of the proposed identification algorithm is also made in this section. The second part consists of detailed illustrations of the proposed algorithms on practical problems: modelling an electronic, electrical, acoustic, mechanical system. Finally the book is completed with a practical guideline to help the user making the correct choices.
The book is intended for all those dealing with "practical" modelling problems and have to combine measurements and theory. A second group of interested people are those involved with identification theory.

b2. System Identification: A Frequency Domain Approach
Rik Pintelon, Johan Schoukens
How does one model a linear dynamic system from noisy data? This book presents a general approach to this problem, with both practical examples and theoretical discussions that give the reader a sound understanding of the subject and of the pitfalls that might occur on the road from raw data to validated model. The emphasis is on robust methods that can be used with a minimum of user interaction.
System Identification: A Frequency Domain Approach is written for practising engineers and scientists who do not want to delve into mathematical details of proofs. Also, it is written for researchers who wish to learn more about the theoretical aspects of the proofs. Several of the introductory chapters are suitable for undergraduates. Each chapter begins with an abstract and ends with exercises, and examples are given throughout.

4.2 JOURNAL PAPERS (2011)

p388. Improved Variance Estimates of FRF Measurements in the Presence of Nonlinear Distortions Via Overlap
Barbé, K.; Pintelon, R.; Schoukens, J.; Lauwers, L.
The frequency response function (FRF) is a common nonparametric modeling tool in many practical engineering problems used for obtaining insight in the device under test. However, the device often behaves nonlinearly. When nonlinearities are detected, the user wants to find out how large these are with respect to the measurement noise. In this paper, we describe a method, based on an overlap technique and periodic excitations, that accurately estimates the FRF, the level of nonlinear distortion, and the measurement noise using only two periods and two random phase realizations of the input signal.

p389. Finite Record Effects of the Errors-in-Variables Estimator for Linear Dynamic Systems
Barbé, K.; Pintelon, R.; Vandersteen, G
The frequency domain errors-in-variables (EIV) estimator for linear dynamic systems with periodic excitations is generally formulated as a maximum likelihood (ML) estimator, where the estimated input/output noise (co)variances are used. In this paper, we study the finite record influences on the uncertainty of the ML estimator. Furthermore, we discuss when a significant influence can occur and derive a practical method to circumvent this problem without the need of introducing parametric noise models.

More publications of the department ELEC can be found on:
or http://wwwtw.vub.ac.be/elec/Papers%20on%20web/index.html
Robust Tracking in Cellular Networks Using HMM Filters and Cell-ID Measurements

Mussa Bshara, Umut Orguner, Fredrik Gustafsson and Leo Van Biesen

A localization algorithm based on cell identification (Cell-ID) information is proposed. Instead of building the localization decisions only on the serving base station, all the detected Cell-IDs (serving or non-serving) by the mobile station are utilized. The statistical modeling of user motion and the measurements are done via a hidden Markov model (HMM), and the localization decisions are made with maximum a posteriori estimation criterion using the posterior probabilities from an HMM filter. The results are observed and compared with standard alternatives on an example whose data were collected from a worldwide interoperability for microwave access network in a challenging urban area in the Brussels capitol city.

Automatic detection, estimation and validation of harmonic components in measured power spectra: all-in-one approach

K. Barbé and W. Van Moer

The detection of periodic components buried in noise is a general problem in various engineering fields. The amplitudes in the frequency domain of a disturbed signal follow Rice distribution, which is fully described by two parameters. Most methods are restricted to automatically detecting the harmonic components. In this paper, we extend the methodology to detect significant harmonics in measured spectra such that, aside from detection, the magnitude of the harmonic component is also estimated, together with the probability that the harmonic component was incorrectly detected.

On the Polynomial Approximation for Time-Variant Harmonic Signal Modeling

Miroslav Zivanovic and Johan Schoukens

We present a novel approach to modeling time-variant harmonic content in monophonic audio signals. We show that both amplitude and fundamental frequency time variations can be compactly captured in a single time polynomial which modulates the fundamental harmonic component. A correct estimation of the fundamental frequency is assured through the fully automated spectral analysis method (ASA). The best-fit is easily obtained by linear least-squares, given the fact that the set of equations is linear-in-parameters. In contrast to the existing methods, the proposed approach is designed to properly describe harmonic structures in monophonic audio signals under conditions of both amplitude and frequency variations and low signal-to-noise ratios.

Linearizing Oscillometric Blood-Pressure Measurements: (Non)Sense?

Wendy Van Moer, Lieve Lauwers, Danny Schoors, Kurt Barbé

This paper proposes a simplified method to compute the systolic and diastolic blood pressures from measured oscillometric blood-pressure waveforms. Therefore, the oscillometric waveform is analyzed in the frequency domain, which reveals that the measured blood-pressure signals are heavily disturbed by nonlinear contributions. The proposed approach will linearize the measured oscillometric waveform in order to obtain a more accurate and transparent estimation of the systolic and diastolic pressure based on a robust preprocessing technique. This new approach will be compared with the Korotkoff method and a commercially available noninvasive blood-pressure meter. This allows verification if the linearized approach contains as much information as the Korotkoff method in order to calculate a correct systolic and diastolic blood pressure.

Functional Magnetic Resonance Imaging: an improved short record signal model

K. Barbé, W. Van Moer and L. Lauwers

The number of measurement problems for which it is either difficult or expensive to obtain long measurement records is rising. This short-record issue particularly pops up in biomedical measurements. In this paper, we study the problem of modeling fMRI signals used to map brain activity. In this paper, it is shown that, by using a postprocessing technique that is well equipped to handle the short-record problem, either the spatial resolution or the detection accuracy of the active regions can be improved by at least 50%.

Unfolding the frequency spectrum for undersampled wideband data

Charles Nader, Niclas Bjorsell, Peter Handel

In this letter, we discuss the problem of unfolding the frequency spectrum for undersampled wideband data. The problem is of relevance to state-of-the-art radio frequency measurement systems, which capture repetitive waveform based on a sampling rate that violates the Nyquist constraint. The problem is presented in a compact form by the inclusion of a complex operator called the CN operator. The ease-of-use problem formulation eliminates the ambiguity caused by folded frequency spectra, in particular those with lines standing on multiples of the Nyquist frequency that are captured with erroneous amplitude and phase values.
Modelling of the porous anodizing of aluminium: Generation of experimental input data and optimization of the considered mode
Tim Aerts, Els Tourné, Rik Pintelon, Iris De Graeve, Herman Terryn
The current paper considers the interdependency between the current density, the anodic overpotential and the temperature during the porous anodizing of aluminium in a sulphuric acid electrolyte. In contrast to common anodizing experiments, a sequence of increasing current densities is applied to each electrode. As demonstrated, this anodizing approach allows evaluating stationary anodic potentials up to very high current densities without being confronted with anomalous oxide growth. Additionally, anodizing is performed at controlled electrolyte and electrode temperature. Due to its large influence on the electrochemical behaviour, the control of the electrode temperature is important when studying the temperature dependency of the process. Based on the experimental evolutions a macroscopic model is presented, describing the relation between the considered general process parameters. It is demonstrated that a relatively simple expression is capable of well describing the experimental data in the extensive range of temperatures and current densities.

A high-speed on-chip pseudo-random binary sequence generator for multi-tone phase calibration
Liesbeth Gommé, Gerd Vandersteen and Yves Rolain
MEASUREMENT SCIENCE AND TECHNOLOGY, 22 (2011) 075901 (14pp)
An on-chip reference generator is conceived by adopting the technique of decimating a pseudo-random binary sequence (PRBS) signal in parallel sequences. This is of great benefit when high-speed generation of PRBS and PRBS-derived signals is the objective. The design implemented standard CMOS logic is available in commercial libraries to provide the logic functions for the generator. The design allows the user to select the periodicity of the PRBS and the PRBS-derived signals. The characterization of the on-chip generator marks its performance and reveals promising specifications.

Binder Identification by Means of Phantom Measurements
Carine Neus, Wim Foubert, Leo Van Biesen, Yves Rolain, Patrick Boets and Jochen Maes
This paper presents a technique to identify if two twisted pairs (TPs) share the same binder or not, based on single-ended line measurements. If the TPs share the binder only over a certain distance, this length is determined. We first show the challenges of archieving binder identification under normal differential operation. Next, we propose an alternative by measuring two TPs simultaneously in phantom mode. The proposed approach is validated by laboratory measurements.

Frequency-domain weighted non-linear least-squares estimation of continuous-time, time-varying systems
J. Lataire, R. Pintelon
A frequency-domain least-squares estimator is presented for identifying linear, continuous-time, time-varying dynamical systems. The model considered is a linear, ordinary differential equation whose coefficients vary as polynomials in time. A frequency-domain approach is used, thus allowing the user to determine easily the frequency band(s) of interest. It is shown that the bias errors because of windowing and sampling the continuous-time signal can be modelled by a polynomial function of the frequency. The regression matrices of the estimators are shown to be very efficiently computed using the fast Fourier transform algorithm and its inverse. The total least-squares, generalised total least-squares and weighted, non-linear least-squares estimators are constructed. The latter two are shown to be consistent. The estimators are illustrated on simulation and measurement data.

Improved (non-)parametric identification of dynamic systems excited by periodic signals-The multivariate case
R. Pintelon, G. Vandersteen, J. Schoukens, Y. Rolain
Recently [1] a method has been developed to suppress nonparametrically the noise and system transients (leakage errors) in frequency response function and noise co-variance estimates of single-input, single-output systems excited by periodic signals. This paper extends the results of [1] to multiple-input, multiple-output systems where all inputs and outputs are disturbed by noise (i.e. an errors-in-variables frame-work). Two methods are presented: the first starts from multiple experiments with uncorrelated sets of inputs, and makes no assumption about the frequency response matrix (FRM); while the second only requires one single experiment, but assumes that the FRM can locally be approximated by a polynomial. Both methods estimate simultaneously the FRM, the noise level, and the level of the nonlinear distortions. For lightly damped systems, the proposed methods either significantly reduce the experiment duration or, for a given measurement time, significantly increase the frequency resolution of the FRM estimate. If the noise (and/or system) transients are the dominant error sources, then the proposed methods also significantly reduce the covariance matrix of the FRM estimates. The use of the nonparametric noise covariance estimates for parametric transfer function modelling is also discussed in detail.

Guidelines to determine the optimal variables for the MTC measurement by noise analysis
Griet Monteyne, Peter Baeten, Johan Schoukens
In this paper guidelines will be given in order to determine the required measurement time for a specified precision of the Moderator Temperature Coefficient (MTC) estimate by noise analysis. Until now the discussion of the precision of the MTC estimate was neglected. We will study the relation between the precision, the coherence, the amount of temperature sensors and the measurement time. Based on this relation guidelines to determine the optimal measurement time will be given. Simulations in MATLAB will be used to verify the theoretical analysis. Realistic values for the different influencing variables for a specific measurement setup will be given by use of the analysis of a measurement at a Nuclear Power Plant in Belgium.

**Study of the bias of the MTC estimate by noise analysis due to the presence of feedback**
Griet Monteyne, Peter Baeten, Johan Schoukens

This paper discusses the bias of the non-parametric Moderator Temperature Coefficient (MTC) estimate due to the presence of feedback. Up to now the non-parametric estimation of the Frequency Response Function (FRF) is the most commonly used method to estimate the MTC by noise analysis. This estimation method is proportional to the Cross Power Spectral Density between the total neutron flux variation and total temperature variation divided by the auto power spectral density of the total temperature variation. The estimation method is very popular since feedback is considered to be negligible in the frequency band of interest. Unfortunately this is not the case in practice. Measurements at a Nuclear Power Plant in Belgium will be used to confirm that this feedback cannot be neglected. In case of feedback the chosen estimator always results in a biased estimate when there are external neutron flux variations present. It will be seen that the ratio between the external neutron flux and external temperature variation in combination with the amplitude of the feedback determines the bias. The theoretical analysis of the bias is based on a simplified scheme of the MTC measurement setup. A simulation in MATLAB is used to confirm the theoretical results. In order to avoid a biased estimate due to the feedback we will advise to measure the external temperature variation and to use another non-parametric estimator.

**Periodic Time-Series Modeling of Environmental Proxy Records with Guaranteed Positive Growth Rate Estimation**
Veerle Beelaerts, Maite Bauwens, Emma Versteegh, Frank Dehairs, Rik Pintelon

Identifying a periodic time-series model from environmental records, without imposing the positivity of the growth rate, does not necessarily respect the time order of the data observations. Consequently, subsequent observations, sampled in the environmental archive, can be inverted on the time axis, resulting in a non-physical signal model. In this paper an optimization technique with linear constraints on the signal model parameters is proposed that prevents time inversions. The activation conditions for this constrained optimization are based upon the physical constraint of the growth rate, namely, that it cannot take values smaller than zero. The actual constraints are defined for polynomials and first-order splines as basis functions for the nonlinear contribution in the distance-time relationship. The method is compared with an existing method that eliminates the time inversions, and its noise sensitivity is tested by means of Monte Carlo simulations. Finally, the usefulness of the method is demonstrated on the measurements of the vessel density, in a mangrove tree, Rhizophora mucronata, and the measurement of Mg/Ca ratios, in a bivalve, Mytilus trossulus.

**The Use of Nonparametric Noise Models Extracted From Overlapping Subrecords for System Identification**
Kurt Barbé, Johan Schoukens and Rik Pintelon

In this paper, we study the asymptotic properties consistency and asymptotic efficiency) of a frequency-domain errors-in-variables estimator using data extracted from overlapping subrecords. While the classical approach without overlap needs six consecutive periods, we show in this paper that, using overlapping subrecords, consistent estimators can be found with only two periods of the steady state response to a periodic excitation. This is done using overlapping subrecords. Moreover, the system identification procedure developed for data extracted from independent periods is shown to be valid for data extracted from overlapping subrecords. This allows the user to reduce the measurement time considerably without changing the identification procedure.

**Phase Predistortion of a Class-D Outphasing RF Amplifier in 90 nm CMOS**
J. Fritzin, Y. Jung, P.N. Landin, P. Handel, M. Enqvist, A. Alvandpour

This brief presents a behavioral model structure and a model-based phase-only predistortion method that are suitable for outphasing RF amplifiers. The predistortion method is based on a model of the amplifier with a constant gain factor and phase rotation for each outphasing signal, and a predistorter with phase rotation only. The method has been used for enhanced data rates for GSM evolution (EDGE) and wideband code-division multiple-access (WCDMA) signals applied to a Class-D outphasing RF amplifier with an on-chip transformer used for power combining in 90-nm CMOS. The measured peak power at 2 GHz was +10.3 dBm with a drain efficiency and power-added efficiency of 39% and 33%, respectively. For an EDGE 8 phase-shift-keying (8-PSK) signal with a phase error of 3° between the two input outphasing signals, the measured power at 400 kHz offset was -65.9 dB with predistortion, compared with -53.5 dB without predistortion. For a WCDMA signal with the same phase error between the input signals, the measured adjacent channel leakage ratio at 5-MHz offset was -50.2 dBc with predistortion, compared with -38.0 dBc without predistortion.

**Single and Piecewise Polynomials for Modeling of Pitched Sounds**
Miro Zivanovic and Johan Schoukens
IEEE Transactions on Audio, Speech, and Language Processing, October 2011 (accepted for publication).

We present a compact approach to simultaneous modeling of non-stationary harmonic and transient components in pitched sound sources. The harmonic and transient components are described by separate models which are built from a common sinusoidal basis modified by a joint action of single and linear piecewise time polynomials respectively. A single polynomial accounts for slow and continuous signal time variations, while various piecewise polynomials can capture fast signal changes on smaller subintervals within the analysis window. The resulting model is linear-in-parameters and the solution to the corresponding linear system of equations provides correct model parameter estimates according to the signal content in the analysis window. The model is extended to deal with mixtures of sounds, where harmonics clustered in a small bandwidth are jointly modeled as a single harmonic. The comparative results suggest that the proposed model outperforms two reference modeling methods in terms of modeling errors and number of parameters.

p407. Optimal multisine excitation design for broadband electrical impedance spectroscopy
B. Sanchez, G. Vandersteen, R. Bragos and J. Schoukens
Measurement Science and Technology, Vol. 22, No. 11, November 2011, 115601 (11pp)
Electrical impedance spectroscopy (EIS) can be used to characterize biological materials in applications ranging from cell culture to body composition, including tissue and organ state. The emergence of cell therapy and tissue engineering opens up a new and promising field of application. While in most cases classical measurement techniques based on a frequency sweep can be used, EIS based on broadband excitations enables dynamic biological systems to be characterized when the measuring time and injected energy are a constraint. Myocardial regeneration, cell characterization in micro-fluidic systems and dynamic electrical impedance tomography are all examples of such applications. The weakness of such types of fast EIS measuring techniques resides in their intrinsic loss of accuracy. However, since most of the practical applications have no restriction over the excitation used, the input power spectrum can be appropriately designed to maximize the accuracy obtained from the measurements. This paper deals with the problem of designing the optimal multisine excitation for electrical bioimpedance measurements. The optimal multisine is obtained by the minimization of the Cramer–Rao lower bound, or what is the same, by maximizing the accuracy obtained from the measurements. Furthermore, because no analytical solution exists for global optimization involving time and frequency domains jointly, this paper presents the multisine optimization approach partially in both domains and then combines the results. As regards the frequency domain approach, a novel contribution is made for the multisine amplitude power spectrum. In the time domain, multisine is optimized by reducing its crest factor. Moreover, the impact on the information and accuracy of the impedance spectrum obtained from using different multisine amplitude power spectra is discussed, as well as the number of frequencies and frequency distributions. The theory is supported by a set of validation measurements when exciting with the optimal and flat multisine signals and compared to a single frequency ac impedance analyzer when characterizing an RC circuit. In vivo healthy myocardium tissue electrical impedance measurements show that broadband EIS based on multisine excitations enable the characterization of dynamic biological systems.

p408. On climate reconstruction using bivalves: Three methods to interpret the chemical signature of a shell
Maite Bauwens, Henrik Ohlsson, Kurt Barbé, Veerle Beelaerts, Frank Dehairs, Johan Schoukens
Computer Methods and Programs in Biomedicine, Vol. 104, No. 2, November 2011, pp. 104-111
To improve our understanding of the climate process and to assess the human impact on current global warming, past climate reconstruction is essential. The chemical composition of a bivalve shell is strongly coupled to environmental variations and therefore ancient shells are potential climate archives. The nonlinear nature of the relation between environmental condition (e.g. the seawater temperature) and proxy composition makes it hard to predict the former from the latter, however. In this paper we compare the ability of three nonlinear system identification methods to reconstruct the ambient temperature from the chemical composition of a shell. The comparison shows that nonlinear multi-proxy approaches are potentially useful tools for climate reconstructions and that manifold based methods result in smoother and more precise temperature reconstruction.

p409. Harmonic Sampling and Reconstruction of Wideband Undersampled Waveforms: Breaking the Code
Charles Nader, Wendy Van Moer, Kurt Barbé, Niclas Björsell, and Peter Händel
IEEE Transactions on Microwave Theory and Techniques, November 2011, Vol. 59, No. 11, pp. 2961-2969
In this paper, a method for measuring wideband waveforms correctly when undersampling is used as a digitizing technique is presented. Two major challenges arise when undersampling wideband waveforms: overlapping of aliased spectral bins of the digitized waveform and ambiguity in spectral bins standing on multiples of the Nyquist frequency. Those challenges are more pronounced when using wideband modulated signals to excite nonlinear devices. The theory behind a correct undersampled measurement is based on the use of an irrational relation between the undersampling frequency and the spectral resolution of the waveform to measure. This is the key to a successful harmonic sampling used today in large-signal network analyzers when wideband modulated waveforms are to be measured. Inverting the problem, such theory is also the solution for reconstructing wideband undersampled waveforms based on a single measurement and with a relatively short record of measured data. It is a solution for RF sampling and cognitive radios where the digital processing is moving toward the antenna of the receiver.

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p410. Spectral analysis of block structured nonlinear systems and higher order sinusoidal input describing functions
Automatica, (2011) 47(12), pp. 2684-2688
When analyzing and modeling dynamical systems in the frequency domain, the effects of nonlinearities need to be taken into account. This paper contributes to the analysis of the effects of nonlinearities in the frequency domain by supplying new analytical tools and results that allow spectral analysis of the output of a class of nonlinear systems. A mapping from the parameters defining the nonlinear and LTI dynamics to the output spectrum is derived, which allows analytic description and analysis of the corresponding higher order sinusoidal input describing functions. The theoretical results are illustrated by examples that show both the use and efficiency of the proposed algorithms.

p411. Extending the Best Linear Approximation to Characterize the Nonlinear Distortion in GaN HEMTs
Mattias Thorsell, Kristoffer Andersson, Guillaume Pailloney, Yves Rolain
In this paper, the best linear approximation (BLA) is extended to include second order nonlinearities. This extension is particularly useful for the analysis of low frequency distortion due to self-mixing. The self-mixing of a modulated signal due to even order nonlinear distortion creates a spectrum around DC as well as around the high order even harmonics. The frequency response at DC can be used to determine long term memory effects such as trapping and self-heating. The extended BLA is extracted for a GaN based HEMT to analyze the low frequency distortion and demonstrate the possibilities with the proposed method.

p412. Parametric Identification of Parallel Hammerstein Systems
Maarten Schoukens, Rik Pintelon, Yves Rolain
This paper proposes a parametric identification method for parallel Hammerstein systems. The linear dynamic parts of the system are modeled by a parametric rational function in the z- or s-domain, while the static nonlinearities are represented by a linear combination of nonlinear basis functions. The identification method uses a three-step procedure to obtain initial estimates. In the first step, the frequency response function of the best linear approximation is estimated for different input excitation levels. In the second step, the power-dependent dynamics are decomposed over a number of parallel orthogonal branches. In the last step, the static nonlinearities are estimated using a linear least squares estimation. Furthermore, an iterative identification scheme is introduced to refine the estimates. This iterative scheme alternately estimates updated parameters for the linear dynamic systems and for the static nonlinearities. The method is illustrated on a simulation and a validation measurement example.

p413. Novel Estimation of the Electrical Bioimpedance using the Local Polynomial Method. Application to In-cycle Myocardium Tissue Impedance Characterization
B. Sanchez, J. Schoukens, R. Bragos, G. Vandersteen
IEEE Transactions on Biomedical Engineering, December 2011, Vol. 58, No. 12, pp. 3376-3385
Classical measurements of myocardium tissue electrical impedance for characterizing the morphology of myocardium cells, as well as cell membranes integrity and intra/extra cellular spaces, are based on the frequency-sweep electrical impedance spectroscopy (EIS) technique. In contrast to the frequency-sweep EIS approach, measuring with broadband signals, i.e., multisinse excitations, enables to collect, simultaneously, multiple myocardium tissue impedance data in a short measuring time. However, reducing the measuring time makes the measurements to be prone to the influence of the transients introduced by noise and the dynamic time-varying properties of tissue. This paper presents a novel approach for the impedance-frequency-response estimation based on the local polynomial method (LPM). The fast LPM version presented rejects the leakage error's influence on the impedance frequency response when measuring electrical bioimpedance in a short time. The theory is supported by a set of validation measurements. Novel preliminary experimental results obtained from real-time in vivo healthy myocardium tissue impedance characterization within the cardiac cycle using multisine excitation are reported.

p414. Nonlinear System-identification of the Filling Phase of a Wet-clutch System
W. D. Widanage, J. Stoev, A. Van Mulders, J. Schoukens and G. Pinte
Control Engineering Practice, Volume 19, Issue 12, December 2011, Pages 1399-1410
The work presented illustrates how the choice of input perturbation signal and experimental design improves the derived model of a nonlinear system, in particular the dynamics of a wet-clutch system. The relationship between the applied input current signal and resulting output pressure in the filling phase of the clutch is established based on bandlimited periodic signals applied at different current operating points and signals approximating the desired filling current signal. A polynomial nonlinear state space model is estimated and validated over a range of measurements and yields better fits over a linear model, while the performance of either model depends on the perturbation signal used for model estimation.

p415. Performance Evaluation of Peak-to-Average Power Ratio Reduction and Digital Pre-Distortion for OFDM Based Systems
Charles Nader, Per Landin, Wendy Van Moer, Niclas Bjorsell, Peter Handel

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c797. On the Use of Laplace and Warburg Variables for Heat Diffusion Modeling
Griet Monteyne and Gerd Vandersteen
10th International Conference on Environment and Electrical Engineering, Rome, Italy, 8-11 May 2011, pp. 1-4
The modeling of heat diffusion phenomena is important to develop optimal control strategies for ground coupled heat pump systems. This paper will discuss different model extraction techniques for such heat diffusion problems, namely using rational transfer function models in both the Laplace and the Warburg domain. The experimental verification is done using measurements on the heat diffusion problem in an isolated bar. The best rational transfer function models in the Laplace variable s and in the Warburg variable ŝ are compared, demonstrating that the Warburg domain has better predicting capabilities when it comes to predicting the lower frequency behavior of the system.

c798. Fast FRF measurement of multivariable systems using periodic excitations
Pintelon, R., G. Vandersteen, J. Schoukens, and Y. Rolain
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 460-465
Classical methods for measuring the frequency response function (FRF) of a multivariable system with \( n \) inputs and \( n \) outputs using periodic excitation signals, either put special conditions on the spectral content of the inputs (no common excited frequencies between each pair of inputs), or require \( n \) experiments with uncorrelated sets of inputs. Since at least 2 consecutive periods should be measured to quantify the noise level on the FRF measurement, the loss in frequency resolution of these classical solutions w.r.t. to random excitations with the same experiment duration is \( 2^n \). To quantify the level of the nonlinear distortions, the FRF measurements should be repeated at least 2 times with independent random phase realisations of the periodic inputs. This increases the loss in frequency resolution further to a factor \( 4^n \). For the same frequency resolution of the FRF measurement, the experiment duration of the classical methods using periodic excitations is \( 2^n \) (linear systems) or \( 4^n \) (nonlinear systems) larger than that for random excitations. In this paper we present a method for measuring the FRF, the noise level, and the level of the nonlinear distortions with a loss in frequency resolution or an increase in measurement time of only a factor 2 compared with random excitations, and this, irrespective of the number of inputs \( n \) and outputs \( n \).

c799. Estimation of nonparametric harmonic transfer functions for linear periodically time-varying systems using periodic excitations
Louarroudi, E., R. Pintelon, J. Lataire, and G. Vandersteen
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 699-704
In this paper a nonparametric estimation procedure is proposed in order to identify continuous (discrete)-time, linear periodically time-varying (LPTV) systems. Further, multisine excitations are applied onto a LPTV system such that the system transient effects may vanish completely when the system is operating in steady state. The key idea is to decompose a LPTV system into an (in)finite series of transfer functions, the so-called harmonic transfer functions (HTF). From an identification point of view, the parallel structure, which consists of a weighted sum of the HTF’s, is truncated to a desirable order. A high quality estimate of the nonparametric HTF’s with its uncertainty embedded in an errors-in-variables framework is then obtained from only one experiment; making use of methods, the so-called indirect learning architecture. The effectiveness of the LPM will be first pointed out through simulations before a real system will be identified. The methodology is then eventually demonstrated on a real-life periodically time-varying electronic system.

c800. On the efficiency loss of the Local Polynomial method for single experiment MIMO Frequency Response Matrix extraction
Vandersteen, G., D. Ugrayumova, Y. Rolain, L. Delocht, R. Pintelon, and J. Schoukens
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 809-813
The estimation the Frequency Response Matrix (FRM) of multiple-input multiple-output (MIMO) Linear Time-Invariant (LTI) systems is often the first step in analyzing, modeling and controlling the system at hand. Recently, the so-
called local-polynomial method (LPM), was developed to extract a nonparametric FRM at all frequency bins out of a single MIMO experiment. This LPM has an efficiency loss when it comes to the variability of the estimated FRM. This paper studies the sources of the efficiency losses in the LPM when using a single experiment to determine the FRM for MIMO systems. A theoretical study of the efficiency shows that a zippered multisine experiment has a low efficiency loss in the LPM when using only a single experiment. This is confirmed using simulation results.

**c801. Design of a Software-Defined Radio for use in the IEEE L- and S-band**
Kevin Voet and Wendy Van Moer
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 563-566
This paper reports on the development and measurements of a software-defined radio front end spanning the IEEE L- and S-band [1]. Specifically, the GPS L1 and 2.4 GHz 802.11 signals are captured by the developed multi-purpose front end. Previous developments have focused on these individual frequency ranges but combining these frequency ranges can be beneficial to several types of applications, e.g. real-time location systems, cognitive radio development and low-cost development platforms. Furthermore, the front end is capable of receiving signals well outside the intended applications due to the flexibility of the design. We present the development of the front end and elaborate on our component choices. After which we discuss and interpret the captured measurements. These outcomes prove that even with modest hardware it is possible to develop and construct a working SDR front end capable of receiving a multitude of signals.

**c802. Characterizing The Out-Of-Band Nonlinear Behaviour Of RF Devices: The Key To Success**
Charles Nader, Wendy Van Moer, Kurt Barbé, Niclas Björsell, Peter Handel
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 790-794
This paper presents the measurement recipe to characterize the out-of-band nonlinear behavior of RF devices when harmonic sampling is used as a digitizing technique. A major challenge to consider when using harmonic sampling is the overlapping of the aliased spectral bins of the digitized waveform. This challenge is more pronounced when using modulated excitation signals. In addition, the excitation signal used should mimic the real behavior of signals used in today's wireless systems. Hence, this paper provides the reader with a tool to select the proper excitation signal, sampling frequency and record length in order to achieve an accurate characterization of the nonlinear behavior of RF devices.

**c803. Transient conditions and overlapping sub-records: an excellent pair for FRF measurements**
Kurt Barbé, Laurent Vanbeylen, Wendy Van Moer
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 804-808
A detailed understanding of a measured system requires some knowledge on the system's behavior at different frequencies. The linear behavior of a system at different frequencies is estimated by the Frequency Response Function FRF). If the system is excited by a periodic multi-frequency signal, the FRF can be obtained by computing the ratio of the discrete Fourier coefficients of the response of the system and of the excitation signal at the excited frequencies. This is a widely applied practical method to measure the system's FRF. However, this non-parametric method may return incorrect results if the system is not operating under steady-state conditions. One way to overcome this problem is by only considering the measurements taken when the system operates under steady state conditions. This significantly increases the measurement time. For expensive measurement problems like biochemical, biomedical and geochemical processes increasing the measurement time is not allowed or simply not possible. This paper proposes a fully non-parametric effective reduction of the system transients based on overlapping sub-records.

**c804. Mirrored parallel Hammerstein predistortion for multitone generation**
Kevin Voet, Peter Händel, Niclas Björsell, and Wendy Van Moer
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 814-817
The paper discusses the approach tested for digital pre-distortion of radio frequency vector signal generators, where joint mitigation of impairments is considered stemming from the inphase/quadrature modulator, local oscillator, and power amplifier. A predistorter structure, linear in its parameters, was taken and the parameters were estimated by the least-squares method. The proposed method is validated by demonstrating improvement in the performance of the Rohde & Schwarz SMU200 by about 8 dB reduction in mirror-frequency interference, 17 dB reduction in leakage from the local oscillator, and 6 dB improvement in inter-modulation products. Thus, the tested approach is considered useful for several instrumentation and measurement applications.

**c805. Weighted LS Estimation of Spectral Contents and Periodicity of Signals Comprising Multi-Frequency Components**
M.L.D. Lumori, J. Schoukens, J. Lataire
IEEE International Instrumentation and Measurement Technology Conference - I2MTC, Hangzhou (China), May 10-12, 2011, pp. 686-689
The goal of this paper is to apply the Weighted Least Squares method to accurately estimate the period and spectral contents of a noisy periodic signal that has many frequency components. The signal data record has a total number of periods that is not necessarily an integer, but is greater than two. There is no need for synchronization between the generator and the data acquisition, where the sampling rates may be different and the number of samples per
c806. **Influence of the cuff deflation mode on oscillometric blood pressure measurements**
W. Van Moer and K. Barbé
When performing oscillometric blood pressure measurements, a cuff is wrapped around the upper arm of the patient and inflated until circulation of the blood stops. The blood pressure of the patient is then calculated out of the oscillometric waveform which is measured during the deflation of the cuff. This paper studies the influence of the cuff deflation mode on the oscillometric blood pressure waveform. Or in other words, this paper investigates if there is a difference in accuracy between the oscillometric waveform obtained by deflating the cuff stepwise or in a quasi-linear way.

**c807. Exploring the fractional haemodynamics in fMRI data**
K. Barbé and W. Van Moer
Functional Magnetic Resonance Imaging (fMRI) is one of the more popular non-invasive methods to map the brain. A patient is asked to perform a simple task and based on this simple task the brain is scanned for activation. The brain is partitioned in volume elements or voxels. The current induced in the MRI coils by each voxel due to the changes of the blood flow is measured. These signals per voxel are modeled by a Haemodynamic Response Function (HRF). In practice the HRF is either parametrized in such a way that the desires to keep the model of the HRF as flexible as possible to avoid biased models. The latter implies that the physical interpretation of the parameters is lost. In this paper, we propose to use fractional models or fractional haemodynamics. We show that these models allow physical interpretation of the parameters in the classical way with the additional advantage of retaining maximal flexibility of the model. This allows better fitting the data to the model without the need to increase the model complexity.

**c808. Using Random Phase Multisines to Perform Non-Invasive Glucose Measurements**
O. Olarte, W. Van Moer, K. Barbé, Y. Van Ingelgem, A. Hubin
In this paper a new approach for non-invasive glucose measurements is proposed. The new technique is based on Dielectric Spectroscopy and uses a potentiostat sensor to detect the glucose levels. As an excitation signal, random phase multisines are used. These allow scanning the level of glucose over a wide frequency range. First tests on human albumin clearly show that the phase measurements can detect differences between different glucose concentrations. These results form a very promising basis for the development of a novel non-invasive glucose monitoring sensor.

**c809. Peak-to-Average Power Ratio Reduction Versus Digital Pre-distortion in OFDM-based Systems**
C. Nader, P. Landin, W. Van Moer, P. Händel, N. Björsell and M. Issakson
IEEE International Microwave Symposium 2011, Baltimore, USA, 6-10 June 2011.
In this paper we evaluate the effect of applying peak-to-average power ratio (PAPR) reduction and digital predistortion (DPD) on radio frequency power amplifiers when an orthogonal frequency division multiplexing (OFDM) signal is used. The PAPR reduction method, presented as a convex problem, is based on reshaping the time domain signal by redistributing its energy in the frequency domain, with respect to constraints on in-band and out-of-band errors. The DPD method consists of modeling the behavior of the power amplifier using a parallel Hammerstein model, and then extracting its inverse parameters based on the indirect learning approach. The cases where PAPR and DPD are applied separately and combined, are studied and investigated. Power amplifier figures of merit are evaluated. A good performance is shown when combining both pre-processing techniques up to a certain operating point where DPD performance deteriorates. Solutions to improve the DPD performance at strong compression are suggested.

**c810. On the reuse of DVB-T transmitter infrastructure for DVB-T2**
Francisco Fraile, Charles Nader, Juan Carlos Guerri, and Niclas Björsell
The new DVB-T2 standard was specifically designed to allow the reuse of DVB-T infrastructure if required. This paper presents measurement results that verify the correct performance of a commercial DVB Power Amplifier with DVB T2 waveforms. Furthermore, the paper includes configuration guidelines and performance evaluation of the Tone Reservation PAPR reduction algorithm included in the DVB-T2 standard. PAPR reduction is key technology when reusing DVB-T amplifiers for DVB-T2 transmissions without penalizing amplifier efficiency.

**c811. Experimental validation of a new frequency-domain flutter speed prediction algorithm using a simplified linear aeroelastic model**
M. Van de Walle, T. De Troyer, J. Schoukens

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**Bibliography**

This paper discuses a new flutter speed prediction method. Flutter is a dynamic aeroelastic instability of surfaces exposed to wind, e.g. aircraft wings. Current flight flutter tests trace damping evolution with aircraft speed and then extrapolate these linearly. The critical flutter speed is found when one of the damping ratios becomes zero. The proposed method fits identified modal parameters at different flight speeds to a quasi - steady aerelastic model. The flutter illustrated in this model results from the dependency of the coupled structural aerodynamical damping and stiffness with speed that leads to denominator of that transfer function is a polynomial function of the Laplace variable and extrapolated to other speeds. The damping ratios are predicted using the extrapolated coefficients to estimate the critical flutter speed. As this extrapolation method is physically more justified than the classical linear extrapolation of the damping ratios, the prediction of the flutter speed will be more reliable. Moreover, the identification process is ideally suited to the frequency domain, so state-of-the-art frequency-domain identification algorithms can be used. The proposed approach is tested with actual wind tunnel data acquired from a cantilevered wing setup and compared to caiscalssical prediction methods.

c812. Frequency domain based friction compensation, industrial application to transmission electron microscopes
Friction is a performance limiting factor in many industrial motion systems. Correct compensation or control of friction and other nonlinearities is generally difficult. Apart from the complex nature of friction, compensation of even the most basic type of friction, Coulomb friction, is non trivial. Most available tuning methods rely on time domain measurements and are often unable to distinguish between nonlinear effects of friction and that of for example linear viscous damping. Furthermore, the sensitivity of time domain data to the influence of friction is too low for correct tuning in many of the high precision motion applications currently used in industry. In this paper a frequency domain method is introduced that allows fast and high accuracy tuning of controller parameters when the closed loop system is subject to nonlinear influences. This methodology is applied to optimally compensate friction in a high precision motion stage of a transmission electron microscope. Theoretical and experimental results are presented and related to time domain performance to illustrate the advantage of frequency domain tuning over time domain tuning.

c813. Detecting and analyzing non-linear effects in respiratory impedance measurements
Clara Ionescu, Johan Schoukens and Robin De Keyser
2011 American Control Conference on O’Farrell Street, San Francisco, CA, USA, June 29- July 01, 2011, pp. 5412-5417
This article describes the nonlinear effects in the respiratory impedance and in the related measurement instrumentation during the forced oscillation technique (FOT) measurements. First, the principle of FOT measurements and nonlinear variance analysis is explained. Two methods are considered to detect nonlinear effects: a robust method and a fast method. These methods are employed to compare the nonlinear distortions in a prototype device and a commercial device, respectively. The identification signal for the respiratory impedance is optimized to reduce the nonlinear distortions. Finally, the nonlinear effects are measured in the respiratory impedance. A set of lung function tests are performed in several groups of patients with various lung conditions (healthy, asthma, cystic fibrosis, smoking). Based on the measured data from the patients, the corresponding nonlinear distortions can be quantified and evaluated for classification purposes.

c814. Spectral analysis of block structured nonlinear systems
Proceedings 18th IFAC World Congress, Milano (Italy), Aug. 28-Sept. 2. 2011, pp. 4416-4420
It is a challenge to investigate if frequency domain methods can be used for the analysis or even synthesis of nonlinear dynamical systems. However, the effects of nonlinearities in the frequency domain are non-trivial. In this paper analytical tools and results to analyze nonlinear systems in the frequency domain are presented. First, an analytical relationship between the parameters defining the nonlinearity, the LTI dynamics and the output spectrum is derived. These results allow analytic derivation of the corresponding higher order sinusoidal input describing functions (HOSIDF). This in turn allows to develop novel identification algorithms for the HOSIDFs using identification experiments that apply broadband excitation signals, which significantly reduces the experimental burden previously associated with obtaining the HOSIDFs. Finally, two numerical examples are presented. These examples illustrate the use and efficiency of the theoretical results in the analysis of the effects of nonlinearities in the frequency domain and broadband identification of the HOSIDFs.

c815. Frequency Domain Errors-In-Variables Identification of a Time-Varying, Discrete Time System
J. Lataire, R. Pintelon
Proceedings 18th IFAC World Congress, Milano (Italy), Aug. 28-Sept. 2. 2011, pp. 13110-13114
This paper considers the parametric identification of single-input single-output, linear, discrete-time, time-varying systems. The model equation is a linear ordinary difference equation with coefficients varying as polynomials in time. The model equation is formulated exactly in the frequency domain. Based on this equation a consistent estimator is constructed within an errors-in-variables framework. The estimator is illustrated on a simulation example.
applications, where the System dynamics are intended to be studied. can be extended to understand various unsolved problems in a wide range of biomedical and electrochemical applications, where the System dynamics are intended to be studied.

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**Initializing Wiener-Hammerstein Models Based on Partitioning of the Best Linear Approximation**
Jonas Sjoberg, J. Schoukens
Proceedings 18th IFAC World Congress, Milano (Italy), Aug. 28-Sept. 2., 2011, pp. 11177-11181

This paper describes a new algorithm for initializing and estimating Wiener-Hammerstein models. The algorithm makes use of the best linear model of the system which is split in all possible ways into two linear sub-models. For all possible splits, a Wiener-Hammerstein model is initialized which means that a nonlinearity is introduced in between the two sub-models. The linear parameters of this nonlinearity can be estimated using least-squares. All initialized models can then be ranked with respect to their fit. Typically, one is only interested in the best one, for which all parameters are fitted using prediction error minimization. The paper explains the algorithm and the consistency of the initialization is stated. Computational aspects are investigated, showing that in most realistic cases, the number of splits of the initial linear model remains low enough to make the algorithm useful. The algorithm is illustrated on an example where it is shown that the initialization is a tool to avoid many local minima.

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**Frequency domain total least squares identification of linear, periodically time-varying systems from noisy input-output data**
Louarroudi, E., J. Lataire, and R. Pintelon
Proceedings 18th IFAC World Congress, Milano (Italy), Aug. 28-Sept. 2. 2011, pp. 13115-13120

This paper presents an extension of the well known linear time invariant identification theory to Linear, Periodically Time-Varying (LPTV) systems. The considered class of systems is described by ordinary differential equations with coefficients that vary periodically over time, making use of multisines both for excitations as well as for the time-varying system parameters. To solve the model equation, an efficient frequency domain simulator is built and is compared with the classically time integration solvers. Further, a frequency domain identification algorithm is proposed within an errors-in-variables stochastic framework. This approach determines a parametric model for the LPTV-system from noisy input-output data. The developed estimation theory is also verified on a simulation example.

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**Information inequality for estimation of transfer functions: main results**
T. Ivanov, B.D.O. Anderson, P.-A. Absil and M. Gevers
Proceedings 18th IFAC World Congress, Milano (Italy), Aug. 28-Sept. 2. 2011, pp. 9959-9965

In this paper we derive a canonical lower bound for the autocovariance function of any unbiased transfer-function estimator. As a generalization of the Cram’er-Rao bound, the Cram’er-Rao kernel that we define can be derived without parametrizing the model set. The Cram’er-Rao kernel is thus one of the cornerstones for experiment design formulations that do not depend on the choice of coordinates.

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**Constrained time-variant signal modeling for identifying colliding harmonics in sound mixtures**
M. Zivanovic, and J. Schoukens
Proceedings of the 19th European Signal Processing Conference (EUSIPCO 2011), Barcelona, Spain, August 29-September 2, 2011

We present a general approach to identifying time-variant colliding harmonics in pitched steady-state monophonic sound mixtures. Each sound is described by a linear-in-parameter quasi-harmonic model which captures properly instantaneous time variations of the non-stochastic sound energy. The model parameters corresponding to colliding harmonics are estimated on the basis of multiple-solution cost function L2 minimization with regularization. The major advantage against the state-of-the art methods is that no additional information about the underlying sounds in the mixture is needed. A comparative study shows that the proposed method performs significantly better than an existing algorithm for separation of monaural pitched sounds from a mixture.

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**In-cycle myocardium tissue impedance characterization using multisine broadband Electrical Impedance Spectroscopy**
Sánchez, B., Vandersteen, G., Bragós, R. and Schoukens, J.
33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Boston, USA. August 30th - September 3rd, 2011, pp. 2518-2521

Measurements of myocardium tissue impedance during the cardiac cycle have information about the morphology of myocardium cells as well as cell membranes and intra/extra cellular spaces. Although the variation with time of the impedance cardiac signal has information about the myocardium tissue activity during the cardiac cycle, this information has been usually underestimated in the studies based on frequency-sweep Electrical Impedance Spectroscopy (EIS) technique. In these cases, the dynamic behavior was removed from the impedance by means of averaging. The originality of this research is to show the time evolution of in-vivo healthy myocardium tissue impedance during the cardiac cycle, being measured with a multisine excitation at 26 frequencies (1 kHz - 1 MHz). The obtained parameters from fitting data to a Cole model are valid indicators to explain the time relation of the systolic and diastolic function with respect to the myocardium impedance time variation. This paper presents a successful application of broadband Impedance Spectroscopy for timevarying impedance monitoring. Furthermore, it can be extended to understand various unsolved problems in a wide range of biomedical and electrochemical applications, where the System dynamics are intended to be studied.
c821. Influence of the multisine broadband excitation amplitude design for Electrical Impedance Spectroscopy biomedical applications

Sánchez, B., Bragós, R. and Vandersteen, G.
33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Boston, USA. August 30th - September 3rd, 2011, pp. 3975-3978
Electrical Impedance Spectroscopy (EIS) is a powerful tool to collect data from many biological materials in a wide variety of applications. Body composition fluid or tissue and organ state monitoring are just some examples of these applications. While the classical EIS is based on frequency sweep, the EIS technique using broadband excitations allows to acquire simultaneous impedance spectrum data. The strength and weakness of broadband EIS relies on the fact that it enables multiple Electrical Bio-Impedance (EBI) data collection in a short measuring time but at the cost of losing impedance spectrum accuracy. In general, there is a relationship between the broadband excitation time/frequency properties and the final EBI’s accuracy obtained. This paper studies the influence of the multisine broadband excitation amplitude’s design over the EBI accuracy by means of the resultant Noise-to-Signal Ratio (NSR) obtained when measuring with a custom impedance analyzer. Theory has been supported by a set of validation experiments.

c822. A Parallel Bit Removal Greedy Algorithm for Multiuser 4G OFDM-based Systems

Heman Cordova, Leo Van Biesen
Bit and power allocation remains a challenge in multiuser multicarrier systems though optimal and suboptimal algorithms have been proposed. In this paper, we optimize the multiuser bit removal greedy algorithm by allowing removing bits in parallel, so reducing the computation time of the algorithm and making it attractive for real implementations. It has been proved that the proposed algorithm converges faster than both the traditional multiuser greedy algorithm and the multiuser bit removal greedy algorithm. This is another approach in comparison to other centralized and distributed algorithms like Optimum Spectrum Balancing (OSB) and Convex Approximation Distributed Spectrum Balancing (CA-DSB).

c823. A novel Approach for Impedance Spectrum Estimation: the Local Polynomial Method

Sánchez, B., Vandersteen, G., Bragós, R. and Schoukens, J.
International Workshop on Impedance Spectroscopy (IWIS), Chemnitz, Germany, September 28-30, 2011
Measuring the Electrical Impedance steady-state response of a time varying system by Impedance Spectroscopy is not always useful especially when the dynamic behavior itself is pretended to be characterized. In contrast to the frequency-sweep EIS approach, measuring with wide band spectral signals enables to reduce the measuring time. Nevertheless, the measurements are prone to the influence of the transients introduced by the system dynamics. This paper presents a novel approach for impedance frequency response estimation, based on the Local Polynomial Method (LPM). The theory presented is supported by a set of simulations, which show the improvement in accuracy of the impedance spectrum estimation with respect to the classical spectral estimation methods based on auto/cross correlation using windows.

c824. Measuring and modeling techniques for RF devices

K. Voet, W. Van Moer and N. Bjørseth
RF Measurement Technology Conference 2011, Gävle, Sweden, 4-5 October 2011
Good nonlinear models require good nonlinear measurements. Hence, accurately measuring the nonlinear behavior of a DUT is very important. Recently, some measurement instruments capable of measuring the nonlinear behavior of RF systems have been developed. All of these instruments have their advantages and disadvantages. Hence, it is important to guide the user in his choice of the most appropriate nonlinear measurement technique for the considered application.

c825. Identifying a Wiener system using a variant of the Wiener G-Functionals

Koen Tiels and Johan Schoukens
50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC11), Orlando, FL, USA, December 12-15, 2011
This paper concerns the identification of nonlinear systems using a variant of the Wiener G-Functionals. The system is modeled by a cascade of a single input multiple output (SIMO) linear dynamic system, followed by a multiple input single output (MISO) static nonlinear system. The dynamic system is described using orthonormal basis functions. The original ideas date back to the Wiener G-functionals of Lee and Schetzen. Whereas the Wiener G-Functionals use Laguerre orthonormal basis functions, in this work Takenaka-Malmquist orthonormal basis functions are used. The poles that these basis functions contain, are estimated using the best linear approximation of the system. The approach is illustrated on the identification of a Wiener system.

c826. A state-space view on locally-stable, globally-unstable nonlinear models driven by Gaussian burst inputs

Laurent Vanbeylen, Anne Van Mulders and Johan Schoukens
50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC11), Orlando, FL, USA, December 12-15, 2011

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In this paper, the behaviour of nonlinear dynamic systems driven by stationary random excitations is studied from a model-based perspective – i.e. starting from a perfect knowledge of the system under study and its driving random input – over a finite time interval (a burst excitation is assumed). For a given discrete-time nonlinear state-space model operating in the neighbourhood of a stable equilibrium, a "blow-up" is seen as the event of escaping out of a region of attraction. Based on Laplace integration, a method is outlined to approximate a future state’s probability density function (pdf) at low excitation amplitudes. Inspection of this pdf can reveal additional insights into the complex behaviour of an abstract state-space model, compared with the simulation approach. The probability of staying inside the region of attraction (viz. obtaining a bounded operation subject to an input active in a finite time interval) can be obtained by integration of this pdf. The state pdf estimation is illustrated with numerical Monte-Carlo simulation experiments.

**c827. User friendly Box-Jenkins identification using nonparametric noise models**

J. Schoukens, Y. Rolain, G. Vandersteen, R. Pintelon

50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC11), Orlando, FL, USA, December 12-15, 2011

The identification of SISO linear dynamic systems in the presence of output noise disturbances is considered. A nonparametric Box-Jenkins approach is studied: the parametric noise model is replaced by a nonparametric model that is obtained in a preprocessing step, and this without any user interaction. The major advantage for the user is that i) one method can be used to replace the classical ARX, ARMAX, OE, and Box-Jenkins models; ii) no noise model order should be selected. This makes the identification much easier to use for a wider public; iii) a bias on the plant model does not create a bias on the noise model. The disadvantage of the proposed nonparametric approach is a small loss in efficiency with respect to the optimal parametric choice. These results are illustrated on a series of well selected problems.

**c828. The Local Polynomial Method for nonparametric system identification: improvements and experimentation**

M. Gevers, R. Pintelon and J. Schoukens

50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC11), Orlando, FL, USA, December 12-15, 2011, pp. 4302-4307

The Local Polynomial Method (LPM) is a recently developed procedure for nonparametric estimation of the Frequency Response Function (FRF) of a linear system. Compared with other nonparametric FRF estimates based on windowing techniques, it has proved to be remarkably efficient in reducing the leakage errors caused by the application of Fourier transform techniques to non periodic data. In this paper we propose a modification of the LPM that takes account explicitly of constraints between the coefficients of the polynomials at neighbouring frequencies. This new variant contributes a new and significant reduction in the Mean Square Error of the FRF estimates. We also discuss the effects of the various design parameters on the accuracy of the estimates.

**c829. Parametric MIMO parallel Wiener identification**

M. Schoukens and Y. Rolain

50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC11), Orlando, FL, USA, December 12-15, 2011

4.4 **ABSTRACTS (2011)**

**a228. Modelling and identification: progress and new challenges**

Michel Gevers

Presentation of plenary lecture at 30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.

Modelling and identification has seen enormous progress and paradigm shifts over the last 40 years. The systems and control community has played a major role in these developments. And yet, the task of modelling and identification still represents the major cost in any advanced control project. It is still viewed as a difficult problem that must be left to the experts. So this raises the questions: what progress has been accomplished? what exactly are the bottlenecks? what are the new challenges?

This talk will first outline the major steps accomplished over this 40-year period. It will then focus on the new challenges which can be encapsulated in one major goal: reduce the cost of the identification. This focus on the reduction of the modelling and identification cost is quite recent and takes on several different forms. The cost can be reduced by tuning the model to the application for which it is intended (e.g. control application), by reducing the experiment time, by reducing the model complexity, by optimizing the data collection experiment (optimal experiment design), by producing methods and algorithms that rely as little as possible on the expertise of the user.

**a229. Errors-in-variables Identification of a Class of Time-varying Systems**

John Lataire and Rik Pintelon

30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011

In this research, the parametric identification of a class of time-varying systems is investigated. The model considered is a parallel connection of LTI systems, weighted by time-varying functions. The identification procedure is formulated in the frequency domain within an errors-in-variables framework.
Bounded operation of unstable nonlinear models under small random burst excitations
Vanbeylen Laurent, Van Mulders Anne, Schoukens Johan
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
A large class of nonlinear plants can be very well approximated via the family of polynomial state-space models (with a polynomial state evolution in the state and input). It has good black-box approximation capabilities, and the model can be obtained from input-output measurements via a least-squares data-fitting approach [1]. The problem is that no stability guarantees are given for the obtained nonlinear model; only the underlying linear dynamics are easy to analyse. It is therefore desirable to investigate (automatically) how a given state-space model behaves under a given random input when no stability information is given. Moreover, an unstable system's state can stay within a given bounded region for very long periods of time and with a high probability. In this work, we propose a method that allows one to estimate the probability density function (pdf) of a future state, given the (smooth) state space equation, the initial state and the nature of the random input, consisting of a Gaussian term with known power spectrum and a known deterministic term. Other possible applications include the analysis of the start-up behaviour of nonlinear oscillators, the investigation of physical (white-box) models, and controlled nonlinear plants with random noise on top of the deterministic reference signal.

Unraveling polynomial nonlinear state-space models into Wiener-Hammerstein blocks
Anne Van Mulders, Laurent Vanbeylen and Johan Schoukens
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
Suppose that one wants to identify a model of a Wiener-Hammerstein system. A Wiener-Hammerstein system consists of two linear dynamic subsystems that are separated by a static nonlinearity. Several models can be considered as an option: block-structured models, but also black box models. A drawback of the block-structured models is the difficulty to determine initial estimates. Especially the model orders of the two linear blocks are unknown beforehand. When using black box models, the nonlinearity will pop up in a natural way at a suitable place during the optimisation and the user does not have to bother about the model orders of the linear blocks. Our goal is to transform a black box model into a block-structured model. This last model is easier to interpret than the first one, which contains no easily accessible information about the structure of the system.

Combining system identification and machine learning: a fast procedure for the initialization of nonlinear state-space models
Anna Marconato, Johan Schoukens, Jonas Sjoberg, Johan Suykens
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
In this work we address the problem of obtaining good starting values for the identification of nonlinear state-space models.

MIMO parallel Hammerstein identification
Maarten Schoukens & Yves Rolain
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
An identification method for multiple input multiple output parallel Hammerstein systems is proposed. It is a generalization of the method proposed for the case of single input single output. The MIMO parallel model captures coupled nonlinearities, and power-dependent dynamics (e.g. moving resonance). The restriction is that the structure only allows nonlinear systems with a dominant input nonlinearity (e.g. RF power amplifiers).

Piezoelectric Tactile Sensor System for the Estimation of the Mechanical Characteristics of Biological Tissues
David Oliva Uribe, Jörg Wallaschek and Johan Schoukens
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
The aim of this work is to develop a tool able to assist neurosurgeons with the difficult task of delineation of tumour boundaries during brain surgery. Resection of brain tumours depends on different technologies and surgeons skills. As a first step, brain tumours can be localized using pre-operative imaging techniques like MRI which provides the surgeon with an exact localization of the tumour and its borders. Although the information provided by MRI is sufficient to carry out the surgical procedure, during operation, a brain shift is occurred when the skull is opened due to the loss of pressure and fluids. At this point, the surgeon loses the exact position of the tumour leading to a new search based on visual and tactile impressions, relying the attainment of the resection, on surgeon’s senses and experience.

Identification of distillation columns using multisine excitation
D. Ugryumova, G. Vandersteen, R. Pintelon, B. Huycck, J. Bonilla, F. Logist and J. Van Impe
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
Distillation is nowadays a widely used separation technique. A high purity separation is achieved by increasing the number of trays (or the column height) or by increasing the energy consumption. To make the distillation process more efficient in view of economical reasons, the energy consumption can be reduced through better modeling techniques and control strategies. A popular ‘online’ control strategy is model predictive control (MPC) that needs a good model of the system in order to predict and optimally excite the system. The goal is therefore to find a model of the distillation column that gives a good description of the system and is not too computationally involved. A physical model of a distillation column is often too complex for ‘online’ simulation. Therefore, we want to find a relatively simple mathematical model of the distillation column, which is good enough to be used for MPC.
a236. **Identifying a Wiener system using a variant of the Wiener G-Functionals**
Koen Tiels en Johan Schoukens
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
The Wiener G-Functionals (see Figure 1) can describe a large class of nonlinear systems [1]. In this figure $F_k$ are linear dynamic systems and $g(x_1, \ldots, x_{n+1})$ is a multivariate polynomial function. In the original settings the $F_k$'s were selected to be Laguerre orthogonal basis functions. In this work we will replace the Laguerre basis functions by the Takenaka-Malmquist orthonormal basis functions (see section 2). This allows us to tune the basis functions to the dynamics of the system to be modelled. We will illustrate the new approach on the identification of a Wiener system as shown in Figure 2. It can be observed that this system can be exactly modelled by the proposed Wiener G-Functional.

a237. **Mirrored parallel Hammerstein predistortion for multitone generation**
Kevin Voet, Peter Händel, Niclas Bjorsell, and Wendy Van Moer
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
The evolution of digital signal processing enables cost-efficient trade-offs between performance boosting by digital operations and cost-reduction by reducing the requirements on the analog hardware. In this work, the authors consider digital predistortion of radio frequency vector signal generators (VSGs) by means of parametric frequency-dependent modeling of the inverse of the nonlinear artifacts, including artifacts from in-phase (I) and quadrature (Q) modulation, leakage from the local oscillator (LO), and power amplifier.

a238. **Comparison of Rational Heat Diffusion Model in Laplace and Warburg Variable**
G. Monteyne, Gerd Vandersteen, Clara Verheist, Lieve Helsen
30th Benelux Meeting on System and Control, Lommel, Belgium, March 15-17, 2011.
Optimal control strategies for HVAC systems using borehole thermal energy storage aim at minimizing the primary energy use, while guaranteeing thermal comfort in the building on short term and a thermal balance of the ground on long term. To check the thermal balance of the ground, heat diffusion phenomena need to be modeled. In the present study different model extraction techniques for such heat diffusion problems are discussed, namely using rational transfer function models in both the Laplace and the Warburg domain. The experimental verification is based on temperature measurements of the heat diffusion in an isolated bar. The best rational transfer function models in the Laplace variable $s$ and in the Warburg variable $\jmath\omega$ are compared, demonstrating that the Warburg domain has better predicting capabilities when it comes to predicting the lower frequent behavior of the system.

a239. **Nonparametric Identification of Linear Periodically Time-Varying Systems using periodic inputs**
Ebrahim Louarroudj, John Lataire en Rik Pintelon
30th Benelux Meeting on System and Control, Lommel, Belgium, March 15-17, 2011.
This abstract deals with the extension of the nonparametric identification of linear time invariant (LTI) systems to systems that might evolve periodically over time. Linear periodically time-varying (LPTV) systems could appear in a lot of engineering applications (cyclic phenomena, multi-rate sampling, speeding up LTI experiments, etc.). A concise methodology for estimation nonparametrically LPTV systems in practice is given below. It is possible to obtain high quality estimates with their corresponding uncertainty, using multi-input single-output (MISO) LTI algorithms that have been recently developed for periodic excitations [1].

a240. **Frequency domain based nonlinear feed forward design for friction compensation**
Rijlaardsdam, D., Nuij, P., Schoukens, J., Steinbuch M
30th Benelux Meeting on System and Control, Lommel, Belgium, March 15-17, 2011.
A frequency domain based method for controller design for nonlinear systems is presented. In a case study, this method is applied to optimally design a feed forward friction compensator for an industrial motion stage in a transmission electron microscope. It is shown that the frequency domain approach yields a tool to fast and easily design friction control in practice with improved detection sensitivity and orthogonal tuning of the controller parameters, while providing a well-defined notion of optimal performance.

a241. **Analysis of the biological composition of fresh water lakes by measuring and modelling**
Diane De Coster, Gerd Vandersteen, Yves Rolain, Ludwig Triest
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
To avoid blooming of algae, online monitoring of the density is necessary because the system is dynamic and even chaotic. Biomass growth monitoring is a very useful tool to predict blooming in fresh water lakes. This work is a step towards an online monitoring setup for this growth. We present a model that is able to identify fluorescense peaks of algae to distinguish different groups of algae.

a242. **A bottom up approach to non-invasive glucose measurements**
Oscar J. Olarte, Wendy Van Moer, Kurt Barbé and Yves Van Ingelgem
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.
There are 150 millions of Diabetic Patients around the world and the World Health Organization expects 300 million by 2025. The intensive insulin therapy (iit) improves the conditions and prognostic of the patient but increases the risk of hypoglycaemic events [1]. Therefore, close monitoring of glucose is highly recommended such that the level of glucose can be kept close as possible into the normal range. Actually the standard for home monitoring is based on a finger-prick blood samples procedure which is time-consuming, painful and offers only intermittent samples. Developing a non-invasive glucose system (NI-GS) would improve the glucose monitoring as required by the iit.
Earlier attempts to generate a similar application have failed. They have not achieved the technical or clinical requirements, due to the lack of a solid background on the measurements, concept, poor use of information, or have not taken into account external factors that could affect the sensor behaviour. [2] [3]. This project will focus on the development of a NI-GS based on bio-impedance measurements, which are well-known in electrical engineering. The impedance value at the frequencies where glucose molecules resonate is proportional to the glucose level in the blood. This work will include the implementation of digital pre-distortion to obtain a more realistic and workable glucose measurement concept. The development will be split up into two complementary stages: 1. A well-founded measurement technique and 2. The hardware development.

**a243. Nonlinear System Identification of the Filling Phase of a Wet Clutch System**
W.D. Widanage, J. Stoev, A. Van Mulders and J. Schoukens
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.

The work presented illustrates how the choice of input perturbation signal and experimental design improves the derived model of the dynamics of a wet clutch system. The relationship between the applied current signal and resulting pressure in the filling phase of the clutch is established based on bandlimited periodic signals applied at different current operating points and signals approximating an ideal filling signal. A polynomial nonlinear state space model (PNLSS) is estimated and validated over a range of measurements and yields better fits over a linear model, while the performance of either model depends on the perturbation signal used for model estimation. A wet clutch is a mechanical device that transmits torque from an input axis to an output axis via fluid friction. An electro-hydraulic pressureregulated proportional valve regulates the pressure inside the clutch which brings about the engagement of the piston with the friction plates. A model describing the relation between the current applied to the valve and the resulting pressure during the filling stage of the clutch is required to bring about a smooth engagement using either iterative learning control or model predictive control.

**a244. Nonparametric Identification of Linear Periodically Time-Varying Systems using periodic inputs**
E. Louarroudi, R. Pintelon, J. Lataire and G. Vandersteen
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.

This abstract deals with the extension of the nonparametric identification of linear time invariant (LTI) systems to systems that might evolve with strong spectral modifications, i.e., systems with periodic time-varying (LPTV) coefficients. The paper provides a methodology for estimation of linear periodically time-varying (LPTV) systems in practice is given below. It is possible to obtain high quality estimates with their corresponding uncertainty, using multi-input single-output (MISO) LTI algorithms that have been recently developed for periodic excitations.

**a245. Interpolation-based Modeling of MIMO LPV systems**
Jan de Caigny, Juan F. Camino, Rik Pintelon and Jan Swevers
30th Benelux Meeting on Systems and Control, Lommel, Belgium, March 15-17, 2011.

A new technique is presented to estimate linear parameter-varying (LPV) state-space models for multiple-input multiple-output (MIMO) systems whose dynamic depends on multiple time-varying parameters, called scheduling parameters. The technique is based on the interpolation of linear time-invariant (LTI) models estimated for constant values of the scheduling parameters. The proposed technique yields LPV models that have a homogeneous polynomial dependency on the scheduling parameter that takes values in the multi-simplex. The potential of the technique is demonstrated through a numerical simulation using an analytic mass-spring-damper system.

**a246. Evolved Harmonic sampling: a tool to reduce the digital bandwidth requirement of RF receivers**
Charles Nader, Wendy Van Moer, Kurt Barbé, Niclas Björssell, Peter Händel and Zhiyang Zhao

High interest arise in measuring wideband signals for applications in cognitive radio’s, multiband systems and also in testing nonlinear devices such as radio frequency (RF) power amplifiers. However such task is challenging due to technology limitation. Today’s current generation of RF receivers has a limitation in their digital bandwidth, i.e. sampling rate, based on a high resolution, available analog bandwidth, and reasonable cost. Hence RF engineers strive to measure the waveform by violating the Nyquist-Shannon sampling constraint, and apply algorithms to reconstruct the original wide-band data. Such procedure is not straightforward due to information overlapping in the undersampled spectrum caused by aliasing of birds higher than the Nyquist frequency will alias back to the first Nyquist band with ambiguities in there amplitude and phase information. In this paper, we will introduce an evolved harmonic sampling to measure and reconstruct wide-band waveforms. Harmonic sampling is well known in the field of large signal network analysis. However, implementing such theory is not an obvious procedure certainly for wide-band modulated signals and dense spectra. In this work, we will present a method that for any bandwidth and resolution frequency, it will overcome the required sampling frequency and number of samples that avoid overlapping in the aliased spectra as well as avoid ambiguities in critical tones.

**a247. Overview of Synergetic OFDM Crest Factor Reduction and Digital Pre-Distortion for RF PAs**
Per Landin, Charles Nader, Wendy Van Moer, Niclas Björssell, Magnus Isaksson and Peter Händel
Digital baseband pre-distortion (DDPD) is used to linearize nonlinear RF PAs, crest factor reduction (CFR) to increase the maximum output power level of RF PAs. Together they result in increased output power with maintained, or even, better linearity. This paper discuss some of the techniques for DPD and CFR methods currently under investigation. Measured results for a class-AB PA using OFDM signals indicate a possibility to increase the power added efficiency (PAE) by at least 15%-points, from 30% to 45% and a power output increase of 6 dB while maintaining specified ACLR requirements.

**a248. Nonlinear measurement instruments - A comparative study**
Kevin Voet, Wendy Van Moer, Niclas Björsell and Peter Händel
Good nonlinear models require good nonlinear measurements. Hence, accurately measuring the nonlinear behaviour of a device-under-test is very important. Recently, some measurement instruments capable of measuring the nonlinear behaviour of RF systems have been developed. All of these instruments have their advantages and disadvantages. Hence, it is important to guide the user in his choice of the most appropriate nonlinear measurement technique for the considered application.

**a249. The Application of Odd Random Phase Electrochemical Impedance Spectroscopy (ORP EIS) in Biological Sensing Applications**
S. Verguts, O. Olarte, Y. Van Ingelgem, K. Barbé, W. Van Moer, E. Lauwers, B. Landuyt, and A. Hubin
220th ECS Meeting & Electrochemical Energy Summit, Boston, USA, 9-14 October 2011
As it provides information about processes taking place at multiple time scales in one single experiment, electrochemical impedance spectroscopy (EIS) is traditionally used to unravel reaction mechanisms in electrochemical reactions, batteries, fuel cells, corrosion processes and other applications. In these cases, the impedance is recorded as a function of the frequency. The spectrum that is generated is subsequently analyzed to gather information over the system studied. Responses in different zones of the spectrum can then be related to specific process or components of the system, e.g. the electrochemical double layer, an organic layer, a charge transfer reaction or diffusion. These identifications are however based on a preceding study of these phenomena, resulting in an electrically equivalent representation of the phenomenon. Due to the power if EIS to investigate complex systems, more and more application s in the field of biology and medicine emerge. EIS serves as the basis for analytical sensors, in medical imaging, in cell culture monitoring or is used in a biomass monitor.

## 4.5 WORKSHOPS (2011)

**w143. Converting a polynomial nonlinear state-space model into a block-structure**
Anne Van Mulders, Laurent Vanbeylen and Johan Schoukens
IUAP/PAI DYSCO study day at Colonster, University of Liège, May 12th, 2011

**w144. Weighted LS Estimation of Spectral Contents & Periodicity of Signals Comprising Multi-Frequency Components**
Mikaya LD Lumori, Johan Schoukens, John Lataire
IUAP/PAI DYSCO study day at Colonster, University of Liège, May 12th, 2011
Using an initial least squares estimate, the WLS method computes the noise variance and the spectral contents of a noisy periodic signal that has more than two periods (non-integer) and many frequency components. The generator and the data acquisition are not synchronized, i.e. the sampling rates may differ and the number of samples per period may not be an integer. The WLS method tunes the period length, such as to minimize the leakage.

**w145. Design, realization and measurement of a CMOS Phase Locked Loop (PLL) to study its nonlinear performance**
Maulik Jain and Gerd Vandersteen
IUAP/PAI DYSCO study day at Colonster, University of Liège, May 12th, 2011

**w146. Multisine Excitation for a Piezoelectric Tactile Differentiation Sensor System for Biological Tissues and Phantoms**
David Oliva Uribe, Johan Schoukens, Jörg Wallaschek
The International Workshop on Piezoelectric Materials and Applications (IWPMA 2011) and 6th Annual Energy Harvesting Workshop, The Hotel Roanoke & Conference Center, Roanoke, Virginia, USA, August 7-11, 2011
Resection of brain tumors rely on the correct use of different technologies and surgeons skills. In a first step, a tumor can be localized using pre-operative imaging techniques like MRI Magnetic Resonance Imaging) which provides the surgeon with an exact localization of the tumor and its borders. Even though the information provided by MRI is enough to carry out the surgical procedure, brain shift phenomenon is unavoidable when the skull is opened, leading to the lost of the position of the tumor. At this critical stage, the neurosurgeon is coerced to start a new search based
on visual and tactile impressions, where the attainment of the resection will hinge on surgeon’s senses and experience. Consequently, the availability of tactile sensors with higher sensitivity than surgeon’s tactile capabilities may improve more securely tumor resection in guided brain neurosurgery. In previous work (Oliva Uribe et al., 2009), we have reported our efforts in the development of a tactile sensor using a piezoelectric bimorph for brain tissue differentiation. The tactile sensor system uses one of the layers of the bimorph to generate vibrations and the other one is used to sense changes in the mechanical conditions of the contact load. Preliminary experiments were carried out on tissue gelatin phantoms with slightly different differences in their mechanical properties. For these experiments, frequency sweep measurements were performed when the spherical sensor’s tip was in contact with a sample. Although the tactile sensor was able to detect minimal differences in gelatin gel phantoms, the measurement time was considerable long (approximately 2 mins). In order to have a reliable instrument that can be used in surgical procedures, it is necessary to enhance the capabilities of the tactile sensor system. This contribution presents a comparison of measurements performed on a series of tissue phantoms using multisine excitations and standard frequency sweep response. The improvement in measurement time and accuracy using multisine excitation, as well as the advantages and disadvantages of the implementation of this technique are discussed. In addition, recommendations and further steps to provide the sensor system with the function to characterize the mechanical properties by the estimation of viscoelastic parameters using system identification techniques are introduced.

**w147. Identification of systems with localized nonlinearity: from state-space to block-structured models**

Anne Van Mulders, Laurent Vanbeylen, Johan Schoukens

Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

The goal of this work is to join the benefits of block-structured models with those of nonlinear state-space models. In general, a block-structure is more sparse and yields extra physical insight, while nonlinear state-space models are very flexible (with a high number of parameters and nearly no insight). In order to maximally preserve the flexibility of the state-space model, the considered block-structure entails several simpler structures. The chosen structure can e.g. describe Wiener, Hammerstein, Wiener-Hammerstein and nonlinear feedback structures. The static nonlinearity is assumed to be polynomial. In fact, the chosen block-structure is the most general discrete-time representation of a system with one, SISO, polynomial, static nonlinearity. The approach is to first distill the static nonlinearity out of a more general polynomial state-space model. Next, a MIMO linear dynamic part can easily be identified, yielding extra structural insight.

**w148. Parameter reduction of a Wiener model using the best linear approximation**

Koen Tiels en Johan Schoukens

Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

A Wiener model can describe a large class of nonlinear systems. The dynamics of the system are modeled by a set of orthonormal basis functions, while the nonlinearity is modeled by a multivariate polynomial. Often, this polynomial contains a lot of terms. In this work we propose to replace one of the basis functions by the best linear approximation of he system. In this way the number of relevantly contributing terms in the multivariate polynomial is reduced. Simulation results on a Wiener system show a major reduction of the number of parameters, while the rms error on the simulated output is still reasonable.

**w149. Under modeling and Border effect of Local Polynomial method**

Griet Monteyne, Diana Ugryumova and Gerd Vandersteen

Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

A non-parametric system identification method, the Local Polynomial (LP) method, was recently developed to remove the leakage errors, determine a non-parametric model of the linear part of the system, and estimate the covariance matrix of the additive noise. The transient response in time domain translates to leakage in the frequency domain, which causes errors in the frequency response function (FRF) estimation. The LP method assumes that the transient and the FRF are smooth functions of frequency, while the excitation is assumed to be a rough function of the frequency (e.g. random noise or random phase multisine). This enables the separation of the transient and the FRF by locally approximating both by a polynomial function of the frequencies. In this way, a significant part of the leakage can be removed. At the same time, interpolation errors are introduced by both the transient and the FRF polynomials. The interpolation errors are significant where the transient and/or FRF fluctuate fast, and hence demand a high order polynomial approximation. The order of the polynomial and the considered frequency interval, on which the polynomials are estimated, are controlled by the user. In most cases, this frequency interval can be chosen symmetrical around the frequency line at which the transient and/or FRF are estimated. At the borders, e.g. around DC, there are not enough frequency lines available, and hence the frequency interval becomes asymmetric. This poster discusses the non-parametric FRF estimate obtained using the LP method. The focus is put on the increase of the estimated variance of the FRF estimate at the border. This increase is caused by the under modeling of the transient/FRF at the border. The estimated variance does not only contain the true variance but also a bias error due to under modeling. This bias error, and thus the estimated variance, can be decreased by increasing the order of the polynomial estimate. Another solution exists in decreasing the amount of frequency lines used for the estimation of the polynomial. However, the amount of frequency lines always needs to be at least as large as the amount of parameters for the polynomial estimate. That is why we propose to use all the frequency lines (excited as well as non-excited) and estimate the FRF and transient at the same time. In this way the total amount of frequency lines remains large enough for estimating the parameters while the amount of excited frequency lines decreases. That is why the bias of the FRF estimate vanishes and thus the estimated variance decreases at the border in the latter case. The variance increases slightly at all the frequency lines. This increase in variability is, however, negligible compared
Comparison of some efficient black- and grey-box nonlinear model structures
Laurent Vanbeylen
Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

In nonlinear system identification, it is well-known that the richness of the model class determines the model's performance on real-life data. The model description should therefore capture the most common forms of nonlinear effects, such as nonlinear feedback. In this poster, different, sometimes barely studied, black- and grey-box candidate nonlinear dynamic model structures will be presented, comparing the flexiblity, the parameter-parsimony, the physical insight and the open identification challenges. Both state-space and block-structured representations will be highlighted.

One-step identification of parallel Hammerstein systems
Maarten Schoukens, Yves Rolain, Gerd Vandersteen
Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

Hammerstein systems consist of a static nonlinearity connected in tandem to a linear time invariant (LTI) system. These systems are used to model nonlinear systems for which the nonlinearity is present mainly at the input such as power amplifiers, chemical processes and physiological systems. In some systems, different signal paths are present, each with different nonlinearities and different dynamics. Or some systems have a dynamical behavior depending on the applied input power. In those cases a Hammerstein model suffers from a lack of general applicability. Such systems can be better modeled by replacing the single Hammerstein model by a more general structure consisting of a parallel connection of Hammerstein systems.

On the use of Neural Networks and Support Vector Machines for the identification of nonlinear state space models
Anna Marconato and Johan Schoukens
Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

This poster discusses the application of regression methods from the machine learning community to the identification of nonlinear state space models. In this approach, linear modeling techniques are used to capture system dynamics, and the remaining nonlinear terms are identified separately. This combines the best of two worlds. On one hand the linear identification theory is very well suited to model dynamic systems, while on the other hand the methods from the machine learning community are very powerful tools to model multidimensional static nonlinear functions. By combining these two methodologies, an approximated static version of the problem is solved, so that one does not have to deal with the recursion in the state equation. A two step initialization procedure is proposed. First the dynamics of the system are modeled with the Best Linear Approximation, resulting in a linear state space model, then a simplifed problem is obtained by estimating the nonlinear states. This can be done by solving a Least Squares problem or, alternatively, by means of Kalman filtering. Several possibilties can then be considered to estimate the nonlinearities in the model. This work focuses on the use of Neural Networks and Support Vector Machines as regression tools, and analyses advantages and drawbacks of the two methods. Finally, all parameters of the initialized nonlinear model are optimized, e.g. by means of a Levenberg-Marquardt algorithm.

Non-parametric identification of Weakly Nonlinear Periodically Time-Varying Systems
Ebrahim Louarroudi, Rik Pintelon, John Lataire
Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011

Although the identification framework of linear time-invariant (LTI) systems covers a vast number of applications, there exist still circumstances where the linear and time-invariant conditions are not fulfilled. Time-varying systems, in particular Periodically Time-Varying (PTV), could be found in a lot of engineering applications such as biochemical processes, mechanical system, electronic circuits etc. In this poster multisine excitations (periodic signals) are applied to a PTV system; since this kind of excitation signals allows us to discriminate between the noise and the nonlinear distortion from a single experiment. We start with the class of systems having a linear PTV behavior, which can be arbitrarily well approximated under mild conditions by a parallel structure consisting of a finite number of weighted LTI systems, the so-called Harmonic Transfer Functions (HTF). Making use of a polynomial approximation of the HTFs in the frequency domain, the evolution of the time-varying dynamics, described by the concept of the instantaneous transfer function (ITF), is then estimated in an output-error framework and this from only one single experiment. Afterwards we extend the methodology to PTV systems with a weakly nonlinear behavior. This can be done through the replacement of the HTFs by the Best Linear Approximation BLA) of the HTFs plus an additional disturbance source ys(t), called the stochastic nonlinear distortion, that captures the nonlinearities. Moreover, non-linear distortion levels and the noise floor are provided as well. The developed non-parametric estimator is demonstrated on a real-life weakly nonlinear periodically time-varying device under test (an electronic circuit).

A class of broad band excitation designed and applied for nonlinear system identification: A wet-clutch application
W.D. Widanage, J. Schoukens
The poster presents a range of broadband signals and their advantages for nonlinear identification. They belong to the class of signals called multisine signals and offer great design flexibility, such as the frequency content, signal amplitude levels or the amplitude distribution. Depending on the particular nonlinear application these attributes can be effectively designed to drive the system into a dynamic region of interest while maintaining within any operating constraints. Three signals designs are illustrated which are the random phased multisine, positively skewed multisine and crest factor optimised multisine. Further when measuring for identification, the signals can be combined with a nominal control signal of the system to enrich and model its finer dynamics. All these signals were made use of to effectively identify the pressure dynamics of a wet-clutch system.

**w155. Frequency Domain Errors-In-Variables Identification of a Time-Varying, Discrete Time System**
John Lataire, Rik Pintelon
Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011
This poster discusses the parametric identification of single-input single-output, linear, discrete-time, time-varying systems. The model equation is a linear ordinary difference equation with polynomial coefficients that vary in time. The model equation is formulated exactly in the frequency domain. Based on this equation a consistent estimator is constructed within an errors-in-variables framework. The estimator is illustrated on a simulation example.

**w156. On the use of multisine excitation for a piezoelectric tactile sensor system for tissue differentiation**
D. Oliva Uribe, J. Schoukens and J. Wallaschek
Presentation of poster at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011
Resection of brain tumors is a very difficult task. Even though the information provided by imaging systems like MRI is enough to conduct successfully this surgical procedure, a brain shift occurs when the skull is opened leading to the lost of the exact position of the tumor. At this point a neurosurgeon has to decide what and where to cut based only on visual and tactile impressions. In consequence, the availability of a tactile sensor with higher sensitivity than human senses, could improve the quality of this crucial surgical procedure. We have developed a tactile sensor using a piezoelectric bimorph for brain tissue differentiation. The proposed sensor system relies on the evaluation of the frequency response function to identify changes in the mechanical conditions when the sensor is in contact with brain tissue. First experiments carried out on tissue gelatin phantoms with slightly different mechanical properties, showed that is possible to detect even minimal differences but the measurement time was considerable long (approximately 2 mins) using standard frequency sweep response. In order to have a reliable instrument that can be used in surgical procedures, it is necessary to enhance the capabilities of the tactile sensor system. The present work reports our last efforts to improve the measurement procedure using multisine excitation and comparing with standard frequency sweep response. Time and accuracy using multisine excitation are improved radically. In addition, further steps to provide the sensor system with the function to characterize the mechanical properties by the estimation of viscoelastic parameters using system identification techniques are presented.

**w157. User friendly Box-Jenkins identification using nonparametric noise models**
J. Schoukens, Y. Rolain, G. Vandersteen, R. Pintelon, M. Gevers
Presentation at the European Research Network on System Identification workshop (ERNSI 2011), Nice (France), 25-28 September 2011
The identification of SISO linear dynamic systems in the presence of output noise disturbances is considered. A ‘nonparametric’ Box-Jenkins approach is studied: the parametric noise model is replaced by a nonparametric model that is obtained in a preprocessing step, and this without any user interaction. The major advantage for the user is that i) one method can be used to replace the classical ARX, ARMAX, OE, and Box-Jenkins models; ii) no noise model order should be selected. This makes the identification much easier to use for a wider public; iii) a bias on the plant model does not create a bias on the noise model; iv) improved convergence for the numerical optimization procedure. The disadvantage of the proposed nonparametric approach is a small loss in efficiency with respect to the optimal parametric choice. These results are illustrated on a series of well selected problems.

**w158. 24 years of IAP involvement**
Michel Gevers
Presentation of a brief plenary lecture at the IUAP/PAI DYSCO workshop, Leuven-Heverlee, Thermotechnisch Instituut, November 29, 2011.

**w159. Under-modeling of Local Polynomial method**
Griet Monteyne, Diana Ugryumova and Gerd Vandersteen
Poster presentation at the IUAP/PAI DYSCO workshop, Leuven-Heverlee, Thermotechnisch Instituut, November 29, 2011.
A non-parametric system identification method, the Local Polynomial (LP) method, was recently developed to remove the leakage errors, determine a non-parametric model of the linear part of the system, and estimate the covariance matrix of the additive noise. The transient response in time domain translates to leakage in the frequency domain, which causes errors in the frequency response function (FRF) estimation. The LP method assumes that the transient and the FRF are smooth functions of frequency, while the excitation is assumed to be a rough function of the frequency (e.g. random noise or random phase multisine). This enables the separation of the transient and the FRF.
by locally approximating both by a polynomial function of the frequencies. In this way, a significant part of the leakage can be removed. At the same time, interpolation errors are introduced by both the transient and the FRF polynomials. The interpolation errors are significant where the transient and/or FRF fluctuate fast, and hence demand a higher order polynomial approximation. The order of the polynomial and the considered frequency interval, on which the polynomials are estimated, are controlled by the user. In most cases, this frequency interval can be chosen symmetrically around the frequency line at which the transient and/or FRF are estimated. At the borders, e.g. around DC, there are not enough frequency lines available, and hence the frequency interval becomes asymmetric. This poster discusses the non-parametric FRF estimate obtained using the LP method. The focus is put on the increase of the estimated variance of the FRF estimate at the border. This increase is caused by the under modeling of the transient/FRF at the border. The estimated variance does not only contain the true variance but also a bias error due to under modeling. This bias error, and thus the estimated variance, can be decreased by increasing the order of the polynomial estimate. Another solution exists in decreasing the amount of frequency lines used for the estimation of the polynomial. However, the amount of frequency lines always needs to be at least as large as the amount of parameters for the polynomial estimate. That is why we propose to use all the frequency lines (excited as well as non-excited) and estimate the FRF and transient at the same time. In this way the total amount of frequency lines remains large enough for estimating the parameters while the amount of excited frequency lines decreases. That is why the bias of the FRF estimate vanishes and thus the estimated variance decreases at the border in the latter case. The variance increases slightly at all the frequency lines. This increase in variability is, however, negligible compared to the decrease of the bias at the border. A simple simulated SISO system with added white noise is used to illustrate this problem.

w160. **One-Step Identification of Parallel Hammerstein Systems**

Maarten Schoukens, Yves Rolain

Poster presentation at the IUAP/PAI Dysco workshop, Leuven-Heverlee, Thermotechnisch Instituut, November 29, 2011.

Hammerstein systems consist of a static nonlinearity connected in tandem to a linear time invariant (LTI) system. These systems are used to model nonlinear systems for which the nonlinearity is present mainly at the input such as power amplifiers, chemical processes and physiological systems. In some systems, different signal paths are present, each with different nonlinearities and different dynamics. Or some systems have a dynamical behavior depending on the applied input power. In those cases a Hammerstein model suffers from a lack of general applicability. Such systems can be better modeled by replacing the single Hammerstein model by a more general structure consisting of a parallel connection of Hammerstein systems.

### 4.6 PRESENTATIONS ORGANISED BY THE DEPT. ELEC (2011)

1. Modeling and pre-distortion of RF power amplifiers
   Magnus ISAKSSON, University of Gävle, Center for RF Measurement Technology (Sweden), March 29th, 2011

2. Obtaining Maximum Likelihood Estimates via the Expectation Maximisation Algorithm
   Adrian Wills, University of Newcastle (Australia), April 1st, 2011

   An important step when identifying a system based on observations is the selection of parameter values from a class of models. Typically, this step involves curve fitting, where parameter values are computed via optimising an objective function that reflects "closeness" of fit between the model output and the observed outputs. One such objective function is the Maximum Likelihood criteria, which arguably has several attractive properties. Among the available methods for computing a Maximum-Likelihood estimate, this talk will discuss the Expectation Maximisation (EM) algorithm, which is specifically designed for this task. In order to make the ideas concrete, the talk will explore the identification of linear discrete time-invariant, multi-input multi-output state-space model estimation from both time and frequency data using EM. Some extensions to non-linear model estimation will be discussed and the talk will conclude with some open questions regarding EM for parameter estimation.

3. Measurement fundamentals
   Allesandro Ferrero, Politecnico di Milano (Italy), July 8th, 2011

   Nowadays, we are surrounded by measuring instruments and we use them several times a day, very often unconsciously and unaware of their complexity and accuracy. Despite instruments influence our life and have a big part in our commercial transactions (when we refuel our car we have to trust the fuel meter for the money we pay for the fuel), we usually don't pay too much attention to the accuracy of the instruments we use, nor we consider if their operating principle is based on a suitable model. Too often, even in our technical activities, we limit ourselves to simply reading an instrument, instead of making a measurement. This lecture is aimed at investigating the fundamentals of the measurement science, and, through the definition of a model of the measuring activity, finding an answer to the two basic questions of metrology: why do we measure? and for what do we use our measurement results? The defined model shows also the limits of the measurement science, so that the uncertainty concept will be introduced and the main contribution to uncertainty will be defined.

4. Development of advanced excitation signals and sampling techniques for improved RF system performance
   Niclas BJÖRSELL, University of Gävle, Center for RF Measurement Technology (Sweden), November 7th, 2011
5. Fast measurements of slow processes
Ivan Markovsky, the University of Southampton (UK), November 10th, 2011
Motivated by an application in metrology for speed up of measurement devices, the following problem is considered: given output observations of a stable linear time-invariant system with known dc-gain, generated by a step input, find the input. If a model of the data generating process is available, the input estimation problem is solved as an equivalent state estimation problem for an autonomous system. Otherwise, the input estimation problem is reduced to standard system identification problems: identification from step response data and autonomous system identification. The link to autonomous system identification suggests a data-driven solution, i.e., an algorithm for computation of the input value without identifying a representation of the system. The data-driven algorithm requires only a solution of a linear system of equations and is computationally more efficient and easier to implement in real-time than the alternative solutions based on system identification. Applications of the generic problem considered are presented and the effectiveness of the methods proposed in the paper is demonstrated in specific examples.

6. Parametric MIMO parallel Wiener identification
Maarten Schoukens, VUB-ELEC, December 8th, 2011
This paper proposes a parametric identification method for multi-input multi-output parallel Wiener systems. The linear dynamic parts of the system are modeled by a parametric rational function in the continuous or discrete time variable, while the static nonlinearities are represented by a linear combination of nonlinear basis functions. The identification method uses a three step procedure to obtain initial estimates. In the first step, the frequency response matrix of the best linear approximation is estimated for different input excitation levels. In the second step, the power dependent dynamics are decomposed over a number of parallel orthogonal branches. In the last step, the static nonlinearities are estimated using a linear least squares estimation. Finally both linear and nonlinear parameters are estimated together using a nonlinear optimization procedure. The method is illustrated on a simulation example.

7. Piezoelectric ultrasonic systems - Research at the Institute of Dynamics and Vibration Research, Leibniz University of Hannover
Jörg Wallaschek, the University of Hannover (Germany), December 20th, 2011
Prof. Dr.-Ing. Jörg Wallaschek, Director of the Institute of Dynamics and Vibration Research of the University of Hannover, is Full Professor in Mechanical Engineering and Mechatronics with more than 20 years of experience. He is expert in the areas of mechanical design of actuators using smart materials, piezoelectric actuators, vibration engineering and intelligent automotive lighting systems. For over 15 years he has successfully conducted R&D projects for German companies like Siemens, Hella, Bosch and Continental.
Prof. Wallaschek has 50 industrial patents, more than 150 scientific articles and 14 contributions in scientific books. During his career, internationalization has been a priority for him; therefore he has built an extensive network of professional contacts with universities in the United States, Europe and Asia. His experience in teaching and training of young researchers is extensively demonstrated by the 30 PhDs students he has successfully graduated.

4.7 PATENTS

1. TDR Based Transfer Function Estimation of Local Loop
Tom Bostoen, Patrick Boets, Leo Van Biesen, Thierry Pollet and Mohamed Zekri
European Patent Office, Application No./Patent No. 01400832.0-1246

2. Method and Apparatus for Identification of an Access Network by Means of 1-Port Measurements
Tom Bostoen, Thierry Pollet, Patrick Boets, Mohamed Zekri and Leo Van Biesen

3. Method and Apparatus for Identification of an Access Network by Means of 1-Port Measurements
Tom Bostoen, Thierry Pollet, Patrick Boets, Mohamed Zekri and Leo Van Biesen

4. Method for Matching an Adaptive Hybrid to a Line
Tom Bostoen, Patrick Boets, Leo Van Biesen and Thierry Pollet
European Patent Office, Application No./Patent No. 03292891.3

5. Interpretation system for interpreting reflectometry information
T. Vermeiren, Tom Bostoen, Leo Van Biesen, Frank Louage, Patrick Boets

6. Interpretation system for interpreting reflectometry information
T. Vermeiren, Tom Bostoen, Leo Van Biesen, Frank Louage, Patrick Boets

7. Localisation of Customer Premises in a Local Loop Based on Reflectometry Measurements
Bibliography

Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

8. Localisation of Customer Premises in a Local Loop Based on Reflectometry Measurements
Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

10. Signal Pre Processing for Estimating attributes of transmission Line
Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

11. A method for determining bit error rates
Vandersteen Gerd, Verbeeck Jozef, Rolain Yves, Schoukens Johan, Wambacq Piet, Donnay
Stephane

12. A method for determining signals in mixed signal systems
Wambacq Piet, Vandersteen Gerd, Rolain Yves, Dobrovolny Petr

4.8 DOCTORAL DISSERTATIONS

PhD1. Etude de la Production et des Conditions de Propagation d'Ondes de Choc Crus par
       un Plasma de Decharge
Jean Renneboog
Doctoral Dissertation, Universit Libre de Bruxelles, 1967
Promoter: P. Baudoux (ULB)

PhD2. Bijdrage tot het Verwekken en Meten van Nauwkeurig Bepaalde Fazeverschuivingen
Alain Barel
Doctoral Dissertation, Vrije Universiteit Brussel, April 1976
Judging-committee: G. Maggetto (VUB), Verlinden (VUB), Hoffman (RUG), C. Eugène (UCL)
Promoter: J. Renneboog (VUB)

PhD3. Maximum Informatie Extractie door middel van een Optimaal Frequentie Domein
       Experiment
Guy Vilain
Doctoral Dissertation, Vrije Universiteit Brussel, March 1983
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), J. Cornelis (VUB), C. Eugène (UCL), Kerkhof, J. Vereecken
(VUB), G. Vansteenkiste (VUB)
Promoter: J. Renneboog (VUB)

PhD4. Foutdetectie op Electrische Lijnen met behulp van een Digitale Behandeling van
       het Reflectogram
Leo Van Biesen
Doctoral Dissertation, Vrije Universiteit Brussel, April 1983
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), Baert (RUG), C. Eugène (UCL), Goossens, Kirschvinck, J.
Tiberghien (VUB)
Promoter: J. Renneboog (VUB)

PhD5. Parameterestimatie in Lineaire en Niet-Lineaire Systemen met Behulp van
       Digitale Tijdsdomein Metingen
Johan Schoukens
Doctoral Dissertation, Vrije Universiteit Brussel, February 1985
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), P. Eykhooff (TU Eindhoven), C. Eugène (UCL), Hoffman
(RUG), Spriet (RUG), O. Steenhaut (VUB), G. Vansteenkiste (VUB)
Promoter: J. Renneboog (VUB)
| PhD6. | **Active Microstrip Antennas**  
Russell Deamly  
Doctoral Dissertation, Vrije Universiteit Brussel, June 1987  
Judging-committee: G. Maggetto (VUB), L.P. Ligthart (TU Delft), O. Steenhaut (VUB), G. Szymanski (Tech. University of Poznan), J. Tiberghien (VUB), A. Van De Capelle (KUL)  
Promoters: J. Renneboog (VUB), A. Barel (VUB) |
|---|---|
| PhD7. | **Analysis and Application of a Maximum Likelihood Estimator for linear Systems**  
Rik Pintelon  
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), P. Eykhoff (TU Eindhoven), A. van den Bos (TU Delft), J. Vandewalle (KUL)  
Promoters: J. Renneboog (VUB), J. Schoukens (VUB) |
| PhD8. | **Time Division Multiplexing in Optical Fiber Networks**  
Danny Sevenhans  
Doctoral Dissertation, Vrije Universiteit Brussel, June 1988  
Judging-committee: G. Maggetto (VUB), P. Kool (VUB), E. Stijns (VUB), R. Blondel (Université de Mons), P. Bulteel (Atea), C. Eugène (UCL), Baert (RUG)  
Promoters: J. Renneboog (VUB), A. Barel (VUB) |
| PhD9. | **Design of Optimal Input Signals with Minimal Crest Factor**  
Edwin Van der Ouderaa  
Judging-committee: G. Maggetto (VUB), F. Delbaen (VUB), P. Eykhoff (TU Eindhoven), R. Pintelon (VUB), J. Renneboog (VUB), A. van den Bos (TU Delft), J. Vandewalle (KUL)  
Promoter: J. Schoukens (VUB) |
| PhD10. | **Channel Multiple Access Protocols for a Hydrological Multihop Packet Radio Network**  
Thomas J. Odhiambo Afullo  
Doctoral Dissertation, Vrije Universiteit Brussel, June 1989  
Judging-committee: G. Maggetto (VUB), L. Van Biesen (VUB), J. Tiberghien (VUB), P. Van Binst (VUB), A. Van Der Beken (VUB)  
Promoter: A. Barel (VUB) |
| PhD11. | **Steady-State Analysis of Strongly Nonlinear Circuits**  
Eli Van Den Eijnde  
Promoter: J. Schoukens (VUB) |
| PhD12. | **Knowledge-Based Spectral Estimation**  
James Ambani Kulubi  
Judging-committee: G. Maggetto (VUB), R. Pintelon (VUB), A. Barel (VUB), W. Verhelst (VUB), O. Steenhaut (VUB), Hoffman (RUG)  
Promoter: L. Van Biesen (VUB) |
| PhD13. | **Radar Cross Section Reduction using Multiple - Layer Strip Gratings**  
Gert Van Der Plas  
Judging-committee: G. Maggetto (VUB), R. Van Loon (VUB), A. Van de Capelle (KUL), D. De Zutter (RUG), P. Deligne (UCL)  
Promoters: A. Barel (VUB), E. Schweicher (KMS) |
| PhD14. | **Automated Diagnosis for Arbitrary Digital Circuits**  
Patrick Bakx  
Judging-committee: G. Maggetto (VUB), M. Goossens (VUB), A. Barel (VUB), M. Verlinden (VUB), V. Jonckers (VUB), P. Vandeloo (UA)  
Promoter: L. Van Biesen (VUB) |
| PhD15. | **Measuring Nonlinear Systems - A Black Box Approach for Instrument Implementation**  
Marc Vanden Bossche  
Doctoral Dissertation, Vrije Universiteit Brussel, June 1989  
Judging-committee: G. Maggetto (VUB), R. Pintelon (VUB), A. Barel (VUB), W. Verhelst (VUB), O. Steenhaut (VUB), Hoffman (RUG)  
Promoter: L. Van Biesen (VUB) |
Judging-committee: G. Maggetto (VUB), R. Pollard (T.U. Leeds), P. Eykhoff (TU Eindhoven), D. De Zutter (RUG), Rik Pintelon (VUB), D. Ritting (Hewlett Packard - USA)
Promoters: A. Barel (VUB), J. Schoukens (VUB)

PhD16. Identification of Multi-Input Multi-Output Systems using Frequency-Domain Models
Patrick Guillaume
Doctoral dissertation, Vrije Universiteit Brussel, June, 1992
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), M. Van Overmeire (VUB), P. Eykhoff (TU Eindhoven), M. Gevers (UCL), J. Vandewalle (KUL)
Promoters: J. Schoukens (VUB), R. Pintelon (VUB)

Hugo Van hamme
Doctoral dissertation, Vrije Universiteit Brussel, June, 1992
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), M. Vanden Bossche (Hewlett Packard Belgium), A. van den Bos (TU Delft), B. De Moor (KUL), L. Ljung (University of Linköping)
Promoters: R. Pintelon (VUB), J. Schoukens (VUB)

PhD18. Identification of Linear Systems from Amplitude Information only
Yves Rolain
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), F. Delbaen (VUB), P. Eykhoff (TU Eindhoven), A. van den Bos (TU Delft), K. Godfrey (Univ. of Warwick, UK), J. Vandewalle (KUL)
Promoters: J. Schoukens (VUB), R. Pintelon (VUB)

PhD19. The Use of the Method of Moments in Designing NMR Antennas
Guido Annaert
Doctoral dissertation, Vrije Universiteit Brussel, December, 1993
Judging-committee: G. Maggetto (VUB), R. Van Loon (VUB), R. Luympaert (VUB-AZ), R. Turner, C. De Waele (RUG), P. Van Hecke (AGFA-GEVAERT NV.), M. Lumori (VECO)
Promoters: A. Barel (VUB), M. Osteaux (VUB-AZ)

Luc Peirlinckx
Doctoral dissertation, Vrije Universiteit Brussel, June 1994
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), L. Bjørnø (TU Denmark), P. De Wilde (VUB), H. Leroy (KULAK), J. Van Campenhout (UG), J.P. Sessarego (CNRS-LMA, France)
Promoters: L. Van Biesen (VUB), R. Pintelon (VUB)

PhD21. Radar Cross Section Calculations of Three-Dimensional Objects, Modelled by CAD
Isabelle De Leeneer
Judging-committee: G. Maggetto (VUB), V. Stein, D. De Zutter (UG), A. Van De Capelle (KUL), R. Van Loon (VUB)
Promoters: A. Barel (VUB), E. Schweicher (KMS)

PhD22. Design and Realization of Low Crest Factor Broadband Microwave Excitation Signals
Tom Van den Broeck
Doctoral Dissertation, Vrije Universiteit Brussel, September 1995
Judging-committee: G. Maggetto (VUB), J. Tiberghien (VUB), L. Martens (UG), R. Pollard (University of Leeds), M. Vanden Bossche (Hewlett Packard Belgium)
Promoters: A. Barel (VUB), J. Schoukens (VUB)

PhD23. Accurate Experimental Modelling of Bounded Wave Propagation in Viscoelastic Materials
Dayu Zhou
Doctoral Dissertation, Vrije Universiteit Brussel, October 1995
Judging-committee: G. Maggetto (VUB), P. Guillaume (VUB), L. Bjørnø (TU Denmark), H. Leroy (KULAK), M. Lumori (VECO), J.P. Sessarego (CNRS-LMA, France), I. Varettenico (VUB)
Promoters: L. Van Biesen (VUB), L. Peirlinckx (VUB)
PhD24. Calibration of a Measurement System for High Frequency Nonlinear Devices
Jan Verspecht
Doctoral Dissertation, Vrije Universiteit Brussel, November 1995
Judging-committee: G. Maggetto (VUB), J. Schoukens (VUB), A. Cardon (VUB), M. Vanden Bossche (Hewlett Packard, Belgium), L. Martens (RUG), B. Nauwelaers (KUL), U. Lotz, A. Roddie, R. Pintelon (VUB), I. Veretennicoff (VUB)
Promoter: A. Barel (VUB)

PhD25. Performance with dielectric resonators at microwave frequencies for studying the pairing state in high-Tc superconductors
Andrei Mourachkine
Judging-committee: W. Van Rensbergen (VUB), G. Van Tendeloo (VUB), J. Drowart (VUB), N. Klein (IFF, Julich), V. Gasumyants (St. Petersburg)
Promoters: A. Barel (VUB), S. Tavernier (VUB), R. Deltour (ULB)

Gerd Vandersteen
Doctoral dissertation, Vrije Universiteit Brussel, April 1997
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), M. Gevers (UCL), L. Ljung (University of Linköping), A. van den Bos (TU Delft), J. Vandewalle (KUL)
Promoters: R. Pintelon (VUB), J. Schoukens (VUB)

PhD27. Frequency Domain Identification of Transmission Lines from Time Domain Measurements
Patrick Boets
Judging-committee: G. Maggetto (VUB), A. Cardon (VUB), A. Barel (VUB), M. Goossens (VUB), R. Pintelon (VUB), D. Baert (RUG), C. Eugène (UCL), J. Capon (Belgacom), J. Verspecht (Hewlett Packard, Belgium)
Promoter: L. Van Biesen (VUB)

PhD28. Nonparametric Identification of Nonlinear Mechanical Systems
Stefaan Duym
Judging-committee: G. Maggetto (VUB), R. Pintelon (VUB), A. Barel (VUB), J. Vandewalle (KUL), J. Swevers (KUL), K. Worden (Univ. of Sheffield)
Promoters: J. Schoukens (VUB), M. Van Overmeire (VUB)

PhD29. Design of Digital Chebyshev Filters in the Complex Domain
Rudi Vuerinckx
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), F. Grenez (ULB), I. Kollár (TU Budapest), McClellan (Georgia Institute of Technology), R. Pintelon (VUB), W. Verhelst (VUB)
Promoters: J. Schoukens (VUB), Y. Rolain (VUB)

PhD30. Caching in Dataflow-Based Instrumentation & Measurement Environments
Eli Steenput
Doctoral dissertation, Vrije Universiteit Brussel, October 1999
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), M. Goossens (VUB), E. Dierickx (VUB), H. Spoelder (Vrije Universiteit Amsterdam), E. Petriu (SITE-Ottawa)
Promoters: Y. Rolain (VUB), J. Schoukens (VUB)

PhD31. Standstill Frequency Response Measurement and Identification Methods for Synchronous Machines
Jef Verbeeck
Judging-committee: G. Maggetto (VUB), J. Vereecken (VUB), A. Barel (VUB), J. Deuse (Tractebel), I. Kamwa (Institut de Recherche d'Hydro-Québec), J.C. Maun (ULB), J. Schoukens (VUB)
Promoters: R. Pintelon (VUB), Ph. Lataire (VUB)

PhD32. Nonlinear Identification with Neural Networks and Fuzzy Logic
Jürgen Van Gorp
Doctoral dissertation, Vrije Universiteit Brussel, August 2000
Judging-committee: G. Maggetto (VUB), A. Barel (VUB), G. Horváth (Budapest University of Technology and Economics), P. Kool (VUB), Y. Rolain (VUB), J. Sjöberg (Chalmers University of Technology, Göteborg), J. Suykens (KUL)
Promoters: J. Schoukens (VUB), R. Pintelon (VUB)
PhD33. **Patient and staff dosimetry in diagnostic radiology**  
Jessica Pages Pulido  
Doctoral dissertation, Vrije Universiteit Brussel, September 2000  
Judging-committee: A. Hermanne (AZ-VUB), J. Vereecken (VUB), P. Van den Winkel (VUB-cyclotron), M. Osteaux (AZ-VUB), H. Thierens (Universiteit Gent), M.A.O. Thijssen (St. Radboud Ziekenhuis Nijmegen), H. Mol (AZ-VUB), M. Sonck (VUB-cyclotron)  
Promoters: R. Van Loon (VUB)

PhD34. **Experimental Study of the Wave Propagation Through Sediments and the Characterization of its Acoustical Properties by Means of High-Frequency Acoustics**  
Steve Vandenplas  
Judging-committee: G. Maggetto (VUB), J. Vereecken (VUB), A. Barel (VUB), L. Bjerre (Technical University of Denmark), J.P. Sessarego (CRNS-Marseille), O. Leroy (KULAK), L. Peirlinckx (Phonetics Topographics)  
Promoter: L. Van Biesen (VUB)

PhD35. **High Spatial Resolution Experimental Modal Analysis**  
Steve Vanlanduit  
Judging-committee: G. Maggetto (VUB), R. Arruda (Univ. Est. de Campinas, Brazil), A. Barel (VUB), R. Pintelon (VUB), J. Swevers (PMA - KU Leuven), M. Van Overmeire (VUB), H. Van der Auweraer (LMS International)  
Promoters: J. Schoukens (VUB), P. Guillaume (VUB)

PhD36. **Development of New Measuring and Modelling Techniques for RFICs and their Nonlinear Behaviour**  
Wendy Van Moer  
Doctoral Dissertation, Vrije Universiteit Brussel, June 2001  
Judging-committee: G. Maggetto (VUB), J. Vereeeken (VUB), R. Pollard (Univ. of Leeds, UK), D. Van Hoenacker (Univ. Catholique de Louvain), J. Schoukens (VUB)  
Promoters: Yves Rolain (VUB), Alain Barel (VUB)

PhD37. **Spectral and Kinetic Analysis of Radiation Induced Optical Attenuation in Silica: Towards Intrinsic Fibre Optic Dosimetry?**  
Borgermans Paul  
Judging-committee: G. Maggetto (VUB), J. Vereeeken (VUB), R. Pollard (Univ. of Leeds, UK), D. Van Hoenacker (Univ. Catholique de Louvain), J. Schoukens (VUB)  
Promoter: Alain Barel (VUB)

PhD38. **Multi-Carrier Modulation with Reduced Peak to Average Power Ratio**  
Zekri Mohamed  
Doctoral Dissertation, Vrije Universiteit Brussel, February 2002  
Judging-committee: G. Maggetto (VUB), J. Vereeeken (VUB), A. Barel (VUB), J. Tiberghien (VUB), P. Boets (VUB), G. Vanhoutte (Belgacom), S. Popescu (Polytechnic Univ. of Bucharest)  
Promoter: L. Van Biesen

PhD39. **Parametric Modeling and estimation of ultrasonic bounded beam propagation in viscoelastic media**  
Bey Temsamani Abdellatif  
Doctoral Dissertation, Vrije Universiteit Brussel, February 2002  
Judging-committee: G. Maggetto (VUB), J. Vereeeken (VUB), A. Barel (VUB), D. Van Hemelrijck (VUB), L. Peirlinckx (Phonetic-Topographics, Ieper), O. Leroy (KULAK), Lef Bjørn (Technical University of Denmark, Lyngby (DK)), Jean-Pierre Sessarego (Laboratoire d’Acoustique et de Mecanique, CRNS, Marseille (F))  
Promoter: L. Van Biesen

PhD40. **Measurement and modelling of the noise behaviour of high-frequency nonlinear active systems**  
Geens Alain  
Doctoral Dissertation, Vrije Universiteit Brussel, May 2002  
Judging-committee: G. Maggetto (VUB), J. Vereeeken (VUB), R. Pollard (University of Leeds, UK), D. Van Hoenacker (UCL), J.C. Pedro (Universidade de Aveiro, Portugal), A. Barel (VUB)  
Promoter: Y. Rolain

PhD41. **Model Based Calibration of D/A Converters**  
Vargha Balázs  
Doctoral Dissertation, Vrije Universiteit Brussel, June 2002
PhD42. Frequency Response Function Measurements in the Presence of Non-Linear Distortions
Kenneth Vanhoenacker
Doctoral Dissertation, Vrije Universiteit Brussel, June 2003
Judging-committee: G. Maggetto (VUB), J. Vereecken (VUB), A. Barel (VUB), B. Bell (NIST, USA), I. Kollar (TUB, Hungary), Y. Rolain (VUB), G. Vandersteen (VUB-IMEC)
Promoters: Johan Schoukens, István Zoltan (TUB)

PhD43. Identification of Nonlinear Systems using Interpolated Volterra Models
József G. Nmeth
Doctoral Dissertation, Vrije Universiteit Brussel, June 2003
Judging-committee: A. Barel (VUB), T. Dobrowiecki (Budapest University of Technology and Economics), M.P. Kennedy (University College Cork), R. Pintelon (VUB)
Promoters: Johan Schoukens, István Kollár (TUB)

PhD44. Identification of block-oriented nonlinear models
Philippe Crama
Doctoral Dissertation, Vrije Universiteit Brussel, June 2004
Judging-committee: G. Maggetto (VUB), J. Vereecken (VUB), P. Guillaume (VUB), L. Ljung (Linköping Universitet, Sweden), M. Verhaegen (TU D, The Netherlands), J. Vandewalle (KUL), A. Barel (VUB), R. Pintelon(VUB)
Promoters: Johan Schoukens, Y. Rolain

PhD45. Identification of the Time Base in Environmental Archives
Fjo De Ridder
Doctoral Dissertation, Vrije Universiteit Brussel, December 2004
Judging-committee: W. Baeyens (VUB), A. Barel (VUB), A. Berger (UCL), Ph. Lataire (VUB), G. Munhoven (Université de Liège), D. Paillard (Centre d’Etudes de Saclay, Orme des Merisiers, France), J. Schoukens (VUB), J. Vandewalle (KUL), J. Vereecken (VUB)
Promoters: R. Pintelon, Frank Dehairs

PhD46. Optimisatie van patiënt dosissen, gekoppeld aan beeldkwaliteit, in de vasculaire radiologie
Lara Struelens
Doctoral Dissertation, Vrije Universiteit Brussel, January 2005
Judging-committee:
Promoter: R. Van Loon, co-promotors: H. Bosmans (KUL), F. Vanhavere (SCK-CEN)

PhD47. Modelling, Designing and Developing a Multidisciplinary Geodatabase GIS with the Implementation of RDBMS in conjuction with CAD and different GIS applications for the development of Coastal/Marine Environment
Tesfazghi Ghebre Egziabeher
Doctoral Dissertation, Vrije Universiteit Brussel, September 2005
Judging-committee: E. Vandijck (VUB), F. Canters (VUB), A. Barel (VUB), S. Wartel (Royal Belgian Institute of Natural Sciences), L. Peirlinckx (Phonetics Topographies, Belgium)
Promoters: L. Van Biesen and Marc Van Molle (Geography dept., fac. of Sciences)

PhD48. Modeling of Substrate Noise Impact on CMOS VCOS on a Lightly-Doped Substrate
Charlotte Soens
Promoters: M. Kuijk, Y. Rolain, P. Wambacq,

PhD49. Evaluation of deep-sub-quarter micron CMOS technology: low noise amplifiers, oscillators and ESD reliability
Dimitri Linten
Promoters: Y. Rolain, P. Wambacq and M. Kuijk
Judging-committee: G. Maggetto, J. Vereecken, A. Barel, M.I. Natarajan (Mentor IMEC), I. Smedes (Philips Semiconductors), M. Tiebout (Infineon)

PhD50. Verification and Correction of Test Signals with a Spectrum Analyzer
Daan Rabijns
Doctoral Dissertation, Vrije Universiteit Brussel, March 2006
Promoters: G. Vandersteen, J. Schoukens
Judging-committee: P. Lataire, J. Vereecken, L. Van der Perre (IMEC), V. Öwall (Lund University, Sweden), W. Van Moer

PhD51. Impact and Mitigation of Analog Impairments in Multiple Antenna Wireless Communications
Jian Liu
Promoters: A. Barel, J. Stiens, G. Vandersteen
Judging-committee: P. Lataire, J. Vereecken, L. Van der Perre (IMEC), V. Öwall (Lund University, Sweden), W. Van Moer

PhD52. Development and evaluation of a numerical method for the identification of a physical system described by a partial differential equation: a case study
Kathleen De Belder
Promoters: R. Pintelon, J. Schoukens
Judging-committee: Ph. Lataire, J. Vereecken, J. Swevers (KUL), P. Guillaume, H. Van der Auweraer (LMS International), H. Sol, P. Roose (Cytec)

PhD53. Contributions to Large-Signal Network Analysis
Frans Verbeyst
Promoter: Y. Rolain
Judging-committee: J. De Ruyck, Jean Vereecken, Alain Barel, Don DeGroot (CCNi Measurement Services, Andrews University, Michigan, USA), Rik Pintelon, Roger Pollard (University of Leeds, UK), Johan Schoukens, Steve Vnlanduit

PhD54. Contribution to severe weather and multimodel ensemble forecasting in Belgium
David Dehenauw
Doctoral Dissertation, Vrije Universiteit Brussel, November 2006
Promoters: A. Barel, H. Declerck

PhD55. A system identification view on two aquatic topics: phytoplankton dynamics and water mass mixing
Anouk de Brauwere
Promoters: Willy Baeyens, Johan Schoukens
Judging-committee: Robert Finsey, Frank Dehairs, Rik Pintelon, An Smeyers-Verbeke, Joos Vandewalle (KUL), Eric Deleersnijder (UCL), Karline Soetaert (NIOO-KNAW), Johannes Karstensen (University of Kiel)

PhD56. Ultra-Wideband transceiver for low-power low data rate applications
Julien Ryckaert
Promoters: Yves Rolain, Piet Wambacq (IMEC)
Judging-committee: Annick Hubin, Rik Pintelon, Gerd Vandersteen, J. Rabaey (University of Berkley, USA), M. Tiebout (Infineon Germany), Christof Debaes, C. Desset (IMEC)

PhD57. Measuring, modeling and realization of high-frequency amplifiers
Ludwig De Locht
Promoters: Yves Rolain, Gerd Vandersteen
Judging-committee: Annick Hubin, Rik Pintelon, Wendy Van Moer, Danielle Vanhovenacker (UCL), Andrea Ferrero (Politecnico di Torino), Christof Debaes (VUB), Marc Vanden Bossche (NMDG Engineering)

PhD58. Body Area Communications: Channel characterization and ultra-wideband system-level approach for low power
Andrew Fort
Promoters: Leo Van Biesen, Piet Wambacq (IMEC)
Judging-committee: Annick Hubin, R. Pintelon, G. Vandersteen, Y. Hao (Univ. of London), C. Desset (IMEC)

PhD59. Algorithms for identifying guaranteed stable and passive models from noisy data
Tom D’Haene
Promoter: Rik Pintelon
Judging-committee: Gert Desmet, Jean Vereecken, Patrick Guillaume, Paul Van Dooren (UCL), Tom Dhaene (UGent), Martine Olivi (INRIA), Gerd Vandersteen

PhD60. Identification of Nonlinear Systems Using Polynomial Nonlinear State Space Models
Johan Paduart
Promoters: Johan Schoukens, Rik Pintelon
Judging-committee: Annick Hubin, Jean Vereecken, Steve Vanlanduit, Lennart Ljung (Linköping University), Jan Swevers (KUL), Yves Rolain

PhD61. GSM-based Positioning: Techniques and Application
Nico Deblauwe
Doctoral Dissertation, Vrije Universiteit Brussel, June 2008
Promoters: Leo Van Biesen, Prof. Dr. Claudia Linnhoff-Popien (Ludwig-Maximilians-Univ. Munchen)
Judging-committee: Dirk Lefeber, Rik Pintelon, Peter Schelkens, Wendy Van Moer, Luc Vandendorpe (Université Catholique de Louvain), Luc Martens (Universiteit Gent), Fredrik Gustafsson (Linköping University)

Anna Marconato
Doctoral Dissertation, Vrije Universiteit Brussel - Università degli Studi di Trento, March 2009
Promoters: Prof. Dario Petri, Johan Schoukens, Bruno Caprice
Judging-committee: Annick Hubin, Gerd Vandersteen, Michel Verleysen (UCL), Davide Anguita (University of Genova), Anne Nowé

PhD63. A framework for the analysis and modelling of substrate noise
Stephane Bronckers
Doctoral Dissertation, Vrije Universiteit Brussel, June 2009
Promoters: G. Van der Pias, G. Vandersteen
Judging-committee: A. Hubin, voorzitter, R. Pintelon, P. Wambacq, M. Nagat, (Kobe University, Japan), F.J. Clément, (Coupling Wave Solutions, France), W. Schoenmaker (Magwel, Belgium)

PhD64. Identification and use of nonparametric noise models extracted from overlapping subrecords
Kurt Barbé
Doctoral Dissertation, Vrije Universiteit Brussel, September 2009
Promoters: Rik Pintelon, Johan Schoukens
Judging-committee: Annick Hubin, Patrick Guillaume, Gerd Vandersteen, Lennart Ljung (Linköping University), Jérôme Antoni (Univ. de Technologie de Complègne), Joos Vandewalle (KULeuven), Steve Vanlanduit

PhD65. Model Fitting in Frequency Domain Imposing Stability of the Model
László Balogh
Doctoral Dissertation, Vrije Universiteit Brussel, October 2009
Promoters: Rik Pintelon, István Kollár (TUBudapest)
Judging-committee: Johan Schoukens, Patrick Guillaume, Joos Vandewalle (KULeuven), Steve Vanlanduit, Barnabás Garay (TUBudapest)

PhD66. CMOS building blocks for 60 GHz Phased-Array receivers
Karen Scheir
Promoters: Piet Wambacq, Yves Rolain)
Judging-committee: A. Hubin, R. Pintelon, G. Vandersteen, J. Long (TUDelft, Nederland), K. Halonen (Helsinki University of Technology, Finland), C. Debaes

PhD67. Localization in wireless networks and co-existence of broadband services
Muska Bshara
Doctoral Dissertation, Vrije Universiteit Brussel, June 2010
Promoter: Leo Van Biesen
Judging-committee: J. Tiberghien, R. Pintelon, P. Schelkens (IBBT), F. Gustafsson (linkoping Universitet), G. Vandersteen, P. Boets (Alcatel-Lucent-Bell), L. Vandendorpe (UCL)

PhD68. Advanced calibration and Instrumentation setups for nonlinear RF devices
Liesbeth Gommé
Doctoral Dissertation, Vrije Universiteit Brussel, August 2010
Promoter: Yves Rolain
PhD69. **A Bayesian Model To Construct A Knowledge Based Spatial Decision Support System For The Chaguana River Basin**  
Indira Nolivos Alvarez  
Doctoral Dissertation, Vrije Universiteit Brussel, October 2010  
Promoters: Leo Van Biesen, Pilar Cornejo (ESPOL, Ecuador)  
Judging-committee: J. Tiberghien, R. Pintelon, W. Bauwens, Pedro Girao (Universidade Tcnica de Lisboa), Rony Swennen (KUL), Ann Now

PhD70. **Best Linearized models for RF systems**  
Koen Vandermot  
Doctoral Dissertation, Vrije Universiteit Brussel, October 2010  
Promoter: Yves Rolain  
Judging-committee: W. Bauwens, R. Pintelon, D. Vanhoenacker (UCL), T. Dhaene (Universiteit Gent), M. Vanden Bossche (NMDG Engineering)

PhD71. **Time series reconstruction of environmental proxy records**  
Veerle Beelaerts  
Doctoral Dissertation, Vrije Universiteit Brussel, January 2011  
Promoter: Rik Pintelon, Frank Dehairs  
Judging-committee: W. Bauwens, H. Terryn, J. Schoukens, J. Vandewalle (KUL), G. Munhoven (Université de Liège), D. Paillard (Lab. des Sciences du Climat et de l’environnement, Centre de Saclay, France), M. Elskens

PhD72. **Multirate Cascaded $\Sigma$S Converters for Wireless Applications**  
Lynn Bos  
Doctoral Dissertation, Vrije Universiteit Brussel, January 2011  
Promoters: G. Vandersteen, Dr, ir. J. Ryckaert  
Judging-committee: P. Guillaume, H. Terryn, P. Wambacq, P. Rombouts (Universiteit Gent), K. Makinwa (Delft University of Technology), B. Murmann (Stanford University)

PhD73. **Use and modeling of overtone resonances in FBAR resonators operating at RF frequencies**  
Mohamed Reda Amin El-Barkouky  
Doctoral Dissertation, Vrije Universiteit Brussel, January 2011  
Promoter: Y. Rolain, P. Wambacq  
Judging-committee: D. Lefeber, H. Terryn, G. Vandersteen, B. Otis (University of Washington, Seattle, USA), J. Vandewalle (KUL)

PhD74. **Nonlinear and Dynamical Models for Temperature Reconstructions from Multi Proxy Data In Bivalve Shells**  
Maite Bauwens  
Doctoral Dissertation, Vrije Universiteit Brussel, March 2011  
Promoters: Johan Schoukens and Frank Dehairs  
Judging-committee: Alan Wanamaker (Iowa State University, USA), Luc André (ULB-MRAC), Fjo De Ridder, Rik Pintelon, Willy Baeyens, Mark Elskens

PhD75. **Reflectometric Analysis of Transmission Line Networks**  
Carine Neus  
Doctoral Dissertation, Vrije Universiteit Brussel, March 2011  
Promoters: Leo Van Biesen, Yves Rolain  
Judging-committee: Annick Hubin, Ludwig De Locht, Patrick Boets (Alcatel-Lucent, Belgium), Luc Martens (U-Gent), Tomas Nordström (FTW Telecommunication Research Center Vienna, Austria)

PhD76. **Frequency Domain Measurement and identification of Linear, Time-varying Systems**  
John Lataire  
Doctoral Dissertation, Vrije Universiteit Brussel, March 2011  
Promoter: Rik Pintelon  
Judging-committee: Jérome Antoni (Université Complègne, France), Lennart Ljung (University of Linköping, Sweden), Paul Van den Hof (Delft University of Technology, The Netherlands), Johan Schoukens, Patrick Guillaume, Herman Terryn, Steve Vanlanduit.

PhD77. **Nonlinear dynamic systems: blind identification of block-oriented models, and instability under random inputs**  
Vanbeylen Laurent  
PhD78. Study of 3D position determination of the interaction point in monolithic scintillator blocks for PET

Zhi Li
Promoters: Stefaan Tavernier, Gerd Vandersteent
Judging-committee: Johan Schoukens, Michel Defrise, Karl Ziemons (University of Aachen, Germany), Jose Perez (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain)

PhD79. Some practical applications of the best linear approximation in nonlinear block-oriented modelling

Lieve Lauwers
Promoter: Johan Schoukens
Judging-committee: Gert Desmet, Herman Terryn, Kurt Barbé, Keity Godfrey (University of Warwick), Joos Vandewalle (KULeuven), Steve Vanlanduit

PhD80. Design and evaluation of channel models for DSL applications

Wim Foubert
Doctoral Dissertation, Vrije Universiteit Brussel, November 2011
Promoters: Leo Van Biesen and Yves Rolain

4.9 THESIS TOT HET BEHALEN VAN HET AGGREGAAT VAN HET HOGER ONDERWIJS

1. System Identification. A Frequency Domain Modeling Approach
Johan Schoukens
Geaggregeerde van het hoger onderwijs, Vrije Universiteit Brussel, 1991
Judging-committee: G. Maggetto (VUB), G. Baron (VUB), G. Vansteenkiste (VUB), P. Eykhoff (TU Eindhoven), A. van den Bos (TU Delft), J. Vandewalle (KUL), M. Gevers (UCL)
Promoters: J. Renneboog (VUB), A. Barel (VUB)

2. Frequency Domain Identification of Linear Time Invariant Systems
Rik Pintelon
Geaggregeerde van het hoger onderwijs, Vrije Universiteit Brussel, 1994
Judging-committee: G. Maggetto (VUB), A. Cardon (VUB), G. Baron (VUB), P. Eykhoff (TU Eindhoven), M. Gevers (UCL), A. van den Bos (TU Delft), J. Vandewalle (KUL), G. Van Steenkiste (RUG)
Promoter: A. Barel (VUB)
5. Location of the university (VUB) and the dept. ELEC

Getting to the department ELEC of the “Vrije Universiteit Brussel”

5.1 ARRIVAL BY CAR:

Take the “Ring” and exit at the crossing with the motorway E411 direction centre of Brussels. At the end of the motorway, take the viaduct (go straight on), and at the second traffic lights, turn on right (“Triomflaan”), the VUB is situated on the left side of this road, starting from entrance 6 (see next map).

5.2 FROM THE BRUSSELS NATIONAL AIRPORT AT ZAVENTEM:

Brussels International Airport is at Zaventem, 14 km from the city centre.

- Information can be obtained by phone: Tel +32 2 753 42 21 / +32 2 723 31 11
- Flight information: Tel +32 900 70 000 (7 a.m. - 10 p.m.)
- www.brusselsairport.be

From the airport, every 20 minutes the rail shuttle quickly takes you to the North Station in the centre of Brussels. At the North Station (“Bruxelles Nord”), you take the train to Etterbeek (direction Etterbeek or Louvain La Neuve) and get off the train in Etterbeek, which is 10 min.
walking distance from the VUB. You only pay € 6.90 for a first class ticket, and € 5.30 for a second class ticket (a taxi or cab from airport to the University is about € 50.00).

More information and timetables of the Belgian railways: www.b-rail

5.3 FROM BRUSSELS SOUTH AIRPORT (CHARLEROI)

Situated to the south of Brussels, approximately 60 km away, Brussels-South Charleroi airport mainly houses low-cost airlines. www.charleroi-airport.com

A bus links Charleroi Brussels-South and the Gare du Midi railway station in Brussels more than 20 times a day.

The timetables are organised to coincide with Ryanair airline flights.

- Brussels to Charleroi: The shuttle departure point is situated at the junction of rue de France and rue de l'Instruction (follow "Thalys" exit at the Gare du Midi station).
- Charleroi to Brussels: shuttle departs 30 minutes after the Ryanair airline flight arrives at the airport. One-way ticket fare: 10.00 € (tickets are sold inside the shuttle)

5.4 ARRIVAL BY TRAIN:

Change in “Bruxelles Nord” and take the train to Etterbeek (direction Etterbeek or Louvain La Neuve)

www.b-rail.be
5.5 ARRIVAL BY SUBWAY (€ 1.80/JUMP-TICKET):

Take line 5 direction "Hermann-Debroux" and get off at "Petillon", which is also 10 min. walking distance from the VUB.

- 1 single fare JUMP (purchased outside vehicle) 1,80 €
- 1 single fare JUMP (purchased inside vehicle) 2,00 €

More information about Brussels subway: www.stib.be

The dept. ELEC is located in building K, 6th floor.