Workshop on Mathematical Modelling of Wave Phenomena
- with applications in the power industry

• 23–24 April 2013 • Linnaeus University • Växjö, Sweden
The Workshop on Mathematical Modelling of Wave Phenomena 2013 – with applications in the power industry, is organized jointly by the Linnaeus University and KTH.

Venue, lunches and dinner
Venue: Linnaeus University Campus in Växjö
Workshop meeting room: M1055
Dinner 23/4, 18.00, at Teleborg castle.

Scope of the workshop
The two-day workshop focuses on recent developments and challenges in wave modeling and related inverse problems based on electromagnetic, acoustic or mechanical waves. The workshop brings together applied mathematicians, physicists and engineers on interdisciplinary research issues related to mathematical modelling and numerical simulation of wave phenomena with the additional aim of exploring its applicability in industrial surveillance and monitoring. The workshop specifically emphasizes the possibility to exchange ideas and results that have a potential application in the power industry, and to stimulate new interdisciplinary projects and research activities.

The first day will therefore be devoted to invited talks on the recent developments and challenges in power engineering including manufacturing, surveillance, diagnostics, fault localization and modelling. The second day will be devoted to invited talks on wave modelling and inverse problems with a specific focus on waveguide theory and related modelling issues, Wiener-Hopf techniques, homogenization, spectral problems, deterministic and stochastic analysis of complex media electromagnetics, material modelling and physical limitations.
Organizing committee

- Sven Nordebo, Linnaeus University
- Börje Nilsson, Linnaeus University
- Andreas Ioannidis, Linnaeus University
- Martin Norgren, KTH.
Program Tuesday 23 April

Challenges in power engineering and wave modelling

Morning session, room M1055, Chairman: Sven Nordebo

8.50-9.00 Workshop opening
Smart Grid technologies for Detecting Electrical Equipment Faults, Defects and Weaknesses.
Using Multiple Modes to Reconstruct Conductor Locations in a Cylindrical Model of a Power Transformer Winding.
10.20-10.50 Coffee
10.50-11.30 Jonas Hedberg, ABB Corporate Research, Sweden.
Non-contact High Voltage Measurements: Modeling and On-site Evaluation.
11.30-12.10 Martin Norgren, KTH, Sweden.
Explicit reconstruction of line-currents and their locations in a 2D parallel conductor structure.
Lunch Restaurant Kristina

Afternoon session, room M1055, Chairman: Börje Nilsson

Homogenized Maxwell’s equations as a model for composite materials.
14.10-14.50 Marc Jeroense, ABB AB, Sweden.
Power Cables Industry – a Waveless Future?
14.50-15.20 Coffee
15.20-16.00 Danijela Palmgren, Mats Sjöberg, ABB AB, Sweden.
Armour loss in three-core submarine XLPE cables.
16.00-16.40 Sven Nordebo, Linnaeus University, Sweden.
Modelling and fault localization for HVDC power cables.
18.00 Dinner, Teleborg Castle
# Program Wednesday 24 April

*Challenges in wave modelling and inverse problems*

**Morning session, room M1055, Chairman: Andreas Ioannidis**

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Institution/Location</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.20-10.00</td>
<td>Ana Moura Santos</td>
<td>Technical University of Lisbon, Portugal</td>
<td>Wiener-Hopf operator methods applied to wave diffraction.</td>
</tr>
<tr>
<td>10.00-10.30</td>
<td>Coffee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.30-11.10</td>
<td>Joachim Toft</td>
<td>Linnaeus University, Sweden</td>
<td>Decomposition properties of operators, and Schatten classes.</td>
</tr>
<tr>
<td>11.10-11.40</td>
<td>Gökhan Cinar</td>
<td>Gebze Institute of Technology, Gebze, Kocaeli, Turkey</td>
<td>Wiener–Hopf Analysis on TEM Wave Reflection by a Sudden Area Expansion in a Coaxial Waveguide.</td>
</tr>
<tr>
<td>11.40-12.00</td>
<td>Sinan Aksimsek</td>
<td>Istanbul Kultur University, Istanbul, Turkey</td>
<td>Mode-Matching Analysis of Step Discontinuities in Coaxial Waveguides.</td>
</tr>
<tr>
<td>Lunch</td>
<td>Restaurant Kristina</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Afternoon session, room M1055, Chairman: Martin Norgren**

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Institution/Location</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.30-14.10</td>
<td>Yury V. Shestopalov</td>
<td>Karlstad University, Karlstad, Sweden.</td>
<td>Wave propagation in guides and interaction phenomena.</td>
</tr>
<tr>
<td>14.50-15.20</td>
<td>Coffee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.20-16.00</td>
<td>Daniel Sjöberg</td>
<td>Lund University, Sweden</td>
<td>Determination of material parameters using different sample orientations in hollow waveguides.</td>
</tr>
<tr>
<td>16.00-16.40</td>
<td>Andreas Ioannidis</td>
<td>Linnaeus University, Sweden</td>
<td>Remarks on the time harmonic wave propagation in infinite waveguides.</td>
</tr>
<tr>
<td>16.40</td>
<td>Workshop closure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Smart grid technologies for detecting electrical equipment faults, defects and weaknesses

Alexander Yu. Khrennikov
PhD of El. Eng., CIGRE member
Federal Grid Company of United Energy System, Moscow, Russia
5a ul. Ak. Chelomeya, 117630 Moscow, Russia
Phone: +7-(495) 7109131, phone/fax: +7-(495) 7104001, e-mail: ak2390@inbox.ru

Abstract
Joint Stock Company “Federal Grid Company of United Energy System” is the operator of the United National Electrical Network of Russia. Extent of the electrical power transmission lines is 121.7 thousand km, a quantity of substations is 805, the class of voltage 220 - 750 kV.

The realized by Federal Grid Company passage to “clever power engineering” (Smart Grid) will make it possible to the development of electrotechnical industry, to monitoring the parameters of electrical equipment, to increase the reliability of electrical power supply.

The most important element of “intellectual of networks” (Smart Grid) are the systems of monitoring the parameters of electrical equipment. Information-measuring systems (IMS) were proposed to use together with rapid digital protection against short-circuit regimes in transformer windings. At the beginning of winding deformations, and also in the case of winding turn-to-turn internal short-circuit the value of inductance $L$ is developed to increase, or to decrease.

The residual winding’s deformations of power transformers during short circuits will be appear practically instantly, without leaving time on the analysis the results of the diagnostic measurements, and requiring as it is possible rapid switch off with the purpose averting or reduction in the scales of future repairing of electrical equipment. Information-measuring system and connected with it protection block were stopped the process of winding destruction.

Also this paper presents an application’s experience of Low Voltage Impulse testing (LVI-testing), some results of the use of Frequency Response Analysis (FRA) to check the condition of transformer windings of electrical equipment. The LVI method and short-circuit inductive reactance measurements are sensitive for detecting such faults as radial, axial winding deformations, a twisting of low-voltage or regulating winding, a losing of winding’s pressing and other.

Typical example of deformation due to radial buckling (deviation of short-circuit reactance measurement $\Delta X_k = +1\%$), example of deformation due to axial shift and damage of pressing system with short-circuit to iron core LV internal winding of 250 MVA /220 kV transformer ($\Delta X_k = +20\%$) are presented. LVI oscillograms of 110 kV winding, including turns of regulating winding, and oscillograms of 6 kV winding of 125 MVA/220 kV/110 kV autotransformer after internal short-circuit at 220 kV substation were illustrated amplitude-frequency differences of C phase, the beginning of winding deformations.

The low voltage impulse testing is a very sensitive and reliable method of deformation’s detections of transformer windings. The LVI oscillograms are a “fingerprint” of transformer.

Diagnostics experience was showed that application of LVI-testing, Frequency Response
Analysis (FRA) and short-circuit reactance measurements (Zk) was be very effective to check the condition of transformer windings of electrical equipment.

Keywords — Intellectual of networks, Smart Grid, Monitoring system, Electrical equipment, Information-measuring system, Frequency Response Analysis, Transformer winding fault diagnostic, Low voltage impulse method, Short-circuit inductive reactance measurement

Non contact high voltage measurements:
modeling and on site evaluation

Jonas Hedberg
ABB Corporate Research, Sweden

Abstract
In the high voltage grid, voltage measurements are made in dedicated voltage transformers. These devices are expensive and insulation failures could impact directly on the system, and even cause a power outage. A non contact measurement technique, on the other hand, does not require a connection to the conductors, and the sensors can therefore be much cheaper by avoiding the need for high voltage insulation.

A capacitive coupling between three measurement electrodes, close to ground, and a high voltage three phase conductor system is used to model and measure the electric field and thereby determine the potentials of the conductors. A 2D model is used for simulations, where the sensors are modeled as ideal, the conductors are modeled in an infinite wire approximation, and the ground plane is approximated as a perfect conductor. For non ideal sensors a transfer function from the potentials on the measurement equipment to the potentials on the conductors is derived as a lumped circuit model.

The L2 norm errors for the amplitude and the phase in the reconstructed signals are calculated and measured for various sensor distances. Simulations show that the sensor distance should not be larger than the conductor distance to mitigate the erroneous effects from distance uncertainties. The optimal sensor distance depends on the quota between the height from the sensors to the conductors and the conductor distance.

Measurements show, in accordance with the theory, that the sensor distance should not be larger than the conductor distance. To reduce the amplitude and phase shift errors the sensors should be placed close to the ground. For applied load resistances there is a tradeoff between amplitude and phase shift errors. Additionally, higher load resistances attenuate higher frequencies. Measurements have verified that this technique is capable of detecting high harmonics and transients. The relatively low cost and the movability makes this method highly applicable for quick diagnostics on many locations in a grid, where the data can be evaluated on site using computer based scripts.

Wiener Hopf operator methods applied to wave diffraction

A.Moura Santos
Dep. of Mathematics, I.S.T., Technical University of Lisbon

Abstract
In this talk, I will try to present a review of operator methods to treat boundary value
problems in connection to diffraction of waves. The applications include different geometries of diffraction screens that range from half planes to gratings. The boundary conditions can be of different kind: Dirichlet, Neumann, mixed type, or even oblique derivative type.

We start to seek for weak solutions of the Helmholtz equation, together with boundary-transmission conditions on the screen and translate the boundary value problem into a linear operator equation. From the mathematical point of view, we deal mostly with Wiener Hopf and Toeplitz operators with Fourier symbols that constitute matrix functions defined in certain classes.

The next step is to give an overview of useful factorization methods of matrix functions relative to a curve with emphasis on explicit Wiener Hopf factorization and a factorization issued from the solution of a Riemann Hilbert problem. The first factorization applies to some boundary value problem on the half plane, and the latter works in the case of certain boundary value problem on a two dimensional grating. Both factorizations allow, under certain conditions, to construct explicit inverses for the Wiener Hopf and Toeplitz operators, respectively, and therefore solve the corresponding boundary value problem.

**Decomposition properties of operators and schatten classes**

Joachim Toft
Department of Mathematics, Linnaeus University, Sweden
joachim.toft@lnu.se

Abstract. It is well-known that any integral operator $T_K$ with its kernel $K$ in the Schwartz space $\mathcal{S}(\mathbb{R}^{2d})$ can be written as $T_{K_1} \circ T_{K_2}$, where both $K_1$ and $K_2$ belong to $\mathcal{S}(\mathbb{R}^{2d})$. We give a proof of this. Furthermore, we show that similar facts hold if $\mathcal{S}$ is replaced by the smaller Gelfand-Shilov space $S_s$, $s \geq 1/2$, i.e. if $T_K$ with $K \in S_s(\mathbb{R}^{2d})$, then we prove that $T_K = T_{K_1} \circ T_{K_2}$, for some $K_1, K_2 \in S_s(\mathbb{R}^{2d})$. We use this to prove that for any (quasi-)Banach spaces $\mathcal{B}_1$ and $\mathcal{B}_2$ such that

$$S_s(\mathbb{R}^d) \subseteq \mathcal{B}_1, \mathcal{B}_2 \subseteq S'_s(\mathbb{R}^d), \quad (\mathcal{S}(\mathbb{R}^d) \subseteq \mathcal{B}_1, \mathcal{B}_2 \subseteq \mathcal{S}'(\mathbb{R}^d)),$$

and $K \in S_s(\mathbb{R}^{2d})$ ($K \in \mathcal{S}(\mathbb{R}^{2d})$), then $K$ belongs to $\mathcal{S}_p(\mathcal{B}_1, \mathcal{B}_2)$, the set of Schatten-von Neumann operators from $\mathcal{B}_1$ to $\mathcal{B}_2$ of order $p \in (0, \infty]$.

Finally, by similar technique we show that if

$$\frac{1}{p_0} = \frac{1}{p_1} + \frac{1}{p_2}, \quad p_0, p_1, p_2 \in (0, \infty],$$

and $K$ belongs to the modulation space $M^{p_0}(\mathbb{R}^{2d})$, then $T_K = T_{K_1} \circ T_{K_2}$, for some $K_1 \in M^{p_1}(\mathbb{R}^{2d})$ and $K_2 \in M^{p_2}(\mathbb{R}^{2d})$. We use this to prove that if $a \in M^p(\mathbb{R}^{2d})$ with $p \in (0, 2]$, then $T_K \in \mathcal{S}_p(L^2(\mathbb{R}^d), L^2(\mathbb{R}^d))$.

The present talk is based on two scientific project. The first one is a joint project between J. Toft, A. Kheifnikov, B. Nilsson and S. Nordebo. The second one is a joint project between K. Gröchenig and J. Toft.
Wave propagation in guides and interaction phenomena: Introduction to the mathematical theory of intertype interaction

Yury Shestopalov
Karlstad University, Sweden
youri.shestopalov@kau.se

Abstract
We give a short introduction to the spectral theory of open structures including some mathematical aspects of modeling the interaction of oscillations and waves in electromagnetics and acoustics. The problems in question are considered in terms of the analysis of the spectral and various critical points (CPs) of multi-parameter operator-valued functions (OVFs), in particular, integral and infinite-matrix (summation) OVF s, when some of the operator parameters are varied.

Interaction of oscillations in a cylindrical slotted resonator whose cross section is formed by two rectangular domains is taken as an example. We reduce the initial boundary eigen value problem for the Helmholtz equation or Maxwell equations to Fredholm integral equations with logarithmic singularity or to infinite systems with respect to the unknown Fourier coefficients of the solution.

It turns out that some CPs of the OVF are associated with the points where one or several eigenvalues of partial domains merge. We demonstrate that interaction of oscillations occur in this case; namely, the electromagnetic field distributions become unstable with respect to small variations of certain parameters of the structure (geometric, permittivity etc.) in the vicinities of critical values.

Mathematical modelling of phenomena in resonance scattering and generation of oscillations for nonlinear layered media

Lutz Angermann 1, Yury V. Shestopalov 2 and Vasyl V. Yatsyk 3
1 TU Clausthal, Clausthal-Zellerfeld, Germany
2 Karlstad University, Karlstad, Sweden
3 O. Ya. Usikov Institute for Radiophysics and Electronics NASU, Kharkov, Ukraine

Abstract
Nonlinear dielectrics with controllable permittivity are subject of intense studies and begin to find broad applications, for instance in device technology and electronics. Based on a model of resonance scattering and generation of waves on an isotropic nonmagnetic nonlinear layered dielectric structure, which is excited by a packet of plane waves, we compare two numerical algorithms - the preset field approximation and the self-consistent method for simulating various effects of the fields at multiple frequencies. The mathematical model consists of a system of boundary-value problems of Sturm-Liouville type and of an equivalent system of one-dimensional nonlinear Fredholm integral equations of the second kind. Various effects caused by the nonlinearity of the structure were investigated using analytical and numerical techniques [1] - [3]. It could be observed that only the self-consistent approach ensures the physically important law of the balance of energy. The results principally indicate how to control the generated field by means of the intensity of
the exciting field. In particular, they offer the possibility of designing a frequency multiplier and other electrodynamic devices containing nonlinear dielectrics with controllable permittivity.

Acknowledgement
This work was partially supported by the Visby Program of the Swedish Institute and by the joint Russian-Ukrainian RFBR-NASU grant no. 12.02.90425-2012.

References
Participants and e-mail

- Sinan Aksimsek, Istanbul Kultur University, Istanbul, Turkey, s.aksimsek@iku.edu.tr
- Anders Andersson, Jönköping University, Sweden, anders.andersson@jth.hj.se
- Lutz Angermann, TU Clausthal, Clausthal-Zellerfeld, Germany, lutz.angermann@tu-clausthal.de
- Thomas Biro, Jönköping University, Sweden, thomas.biro@jth.hj.se
- Gökhan Cinar, Gebze Institute of Technology, Turkey, gcinar@gmail.com
- Mariana Dalarsson, KTH, Sweden, mardal@kth.se
- Stefan Gustafsson, Linnaeus University, Sweden, stefan.h.gustafsson@lnu.se
- Jonas Hedberg, ABB AB, Corporate Research, Sweden, jonas.hedberg@se.abb.com
- Andreas Ioannidis, Linnaeus University, Sweden, andreas.ioannidis@lnu.se
- Marc Jeroense, ABB AB, Sweden, marc.jeroense@se.abb.com
- Nicklas Johansson, ABB AB, Corporate Research, nicklas.johansson@se.abb.com
- Alexander Khrennikov, Federal Grid Company of United Energy System, Moscow, Russia, ak2390@inbox.ru
- Andrei Khrennikov, Linnaeus University, Sweden, andrei.khrennikov@lnu.se
- Roya Nikjoo, KTH, Sweden, royasn@kth.se
- Börje Nilsson, Linnaeus University, Sweden, borje.nilsson@lnu.se
- Sven Nordebo, Linnaeus University, Sweden, sven.nordebo@lnu.se
- Martin Norgren, KTH, Sweden, mnorgren@kth.se
- Danijela Palmgren, ABB AB, Sweden, danijela.palmgren@se.abb.com
- Ana Moura Santos, Technical University of Lisbon, Portugal, amoura@math.ist.utl.pt
- Yury Shestopalov, Karlstad University, Karlstad, Sweden, shestop@hotmail.com
- Daniel Sjöberg, Lund University, Sweden, Daniel.Sjoberg@eit.lth.se
- Mats Sjöberg, ABB AB, Sweden, mats.l.sjoberg@se.abb.com
- Ioannis Stratis, National and Kapodistrian University of Athens, Greece, istratis@math.uoa.gr
- Joachim Toft, Linnaeus University, Sweden, joachim.toft@lnu.se
- Niklas Wellander, FOI, Sweden, niklas.wellander@foi.se
- Vasyly Yatsyk, O. Ya. Usikov Institute for Radiophysics and Electronics NASU, Kharkov, Ukraine, vasyl.yatsyk@rambler.ru