

# Signal and Information Processing Laboratory

Prof. A. Lapidoth and Prof. H.-A. Loeliger

## ANNUAL REPORT

**2013**

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# Foreword

The year 2013 began well: I took my first sabbatical from ETH, with visits at UCSD and the University of Toronto. The year continued well: two new PhD students joined our institute, Nour Zalmi (in April) and Annina Bracher (in August). Georg Wilckens defended his PhD thesis in June (and thereafter departed for adventures in Africa). In August, Stefan Moser rejoined our institute as a senior scientist, just in time for the traditional ISI hike. This year, the hike led us to the Hoellgrotten in Baar, and neither a closed trail nor heavy rain could stop us.

On October 24, we organized a reunion of former ISI members in the restaurant Rigiblick. It was great to see so many old friends and former colleagues. On December 12, we met for the traditional ISI dinner in the same restaurant.

However, one person was sorely missed at the reunion: Prof. James L. Massey had passed away in June (at age 79). Jim had meant so much to so many former ISI members, including myself! We remain deeply grateful for the privilege to have known him.

Hans-Andrea Loeliger

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# 1. Personnel

Professor for Information Theory:

**Prof. Amos Lapidoth**

Professor for Signal Processing:

**Prof. Hans-Andrea Loeliger**

Secretaries:

**Rita Hildebrand**  
**Silvia Tempel**

Senior Researcher:

**Dr. Stefan Moser**  
**Dr. Nikolai Nefedov**

Research Assistants:

<b>Jonas Biveroni</b>	Dipl.El.Eng. (left on 30.6.2013)
<b>Annina Bracher</b>	Msc ETH
<b>Lukas Bruderer</b>	MSc ETH
<b>Christoph Bunte</b>	MSc ETH
<b>Neff Sarah</b>	MSc ETH
<b>Christoph Reller</b>	MSc ETH (left on 31.7.2013)
<b>Christian Schürch</b>	MSc ETH
<b>Georg Wilckens</b>	MSc ETH (left on 31.7.2013)
<b>Jiun-Hung Yu</b>	MSc.NCTU Taiwan
<b>Zalmai Nour</b>	MSc ETH

Technical Staff:

**Thomas Schärer**  
**Patrik Strebel**      El.Eng.HTL

## 2. Teaching

### 2.1 Courses

Sem.	Instructors	Title	ETH-No.
5th	Prof. H.-A. Loeliger	Zeitdiskrete und statistische Signalverarbeitung	227-0101
7th	Prof. H.-A. Loeliger	Signal and Information Processing	227-0427
7th	Prof. A. Lapidoth	Applied Digital Information Theory I	227-0417
6th	Prof. A. Lapidoth	Communication and Detection Theory	227-0104
8th	Prof. A. Lapidoth	Information Theory II	227-0420

#### Courses by external Lecturers

7th	Dr. K. Heutschi	Accoustics I	227-0477
8th	Dr. K. Heutschi	Accoustics II	227-0478
8th	Dr. H.P. Schmid	Analog Signal Processing and Filtering	227-0478

### 2.2 Lab Courses (Practica)

5/6th	Practica	Laboratory for "Fundamentals in Electrical Engineering"	227-0095
3rd/4th	Ch. Schürch	Blackfin DSP	PPS
2nd/3rd	Th. Schaerer	EMG Biofeedback Device	PPS

## 2.3 Student Projects

Students	Title	Supervisor
<b>Semester Projects FS 2013</b>		
Lukas Cavigelli Pascal Alexander Hager	Phase-Locked Loops for Harmonic Signals	Christoph Reller Lukas Bruderer
Bojun Cheng	Emission Synthesizer for Road Traffic Noise	Kurt Heutschi Christoph Reller
Michael Tschannen Markus Rempfler	Supervised Learning Algorithms for Vibration Signal Classification	Lukas Bruderer Sarah Neff Christoph Reller
Christian Käslin	Frequency-Domain Methods for Adaptive Dynamometer Measurement Equalization	Lukas Bruderer Nour Zalmai
Daniel Riegger	Signal Envelopes via Hilbert-Transform Inspired Models	Christoph Reller
Patrick Murer Christoph Pfister	“Pulswaage”- Heart Rate Monitoring with a Weighing Scale	Lukas Bruderer Nour Zalmai
Gabriel Gräni	Projective Gaussian Message Passing	Lukas Bruderer
<b>Semester Projects HS 2013</b>		
Lars Palzer	Error exponents for the Gaussian Channel with Intermittent Feedback	Amos Lapidoth Christoph Bunte
Erik Hampus Malmberg	Kalman Filter-Based Phase-Locked Loops for Harmonic Signals	Nour Zalmai Lukas Bruderer

**Master Theses 2013**

Ismail Celebi	Adaptive Filtering with MIMO Crosstalk Cancellation Applied to 3-D Force Sensor Signals	Sarah Neff Lukas Bruderer
Nour Zalmi	Likelihood Filtering for Pulse Detection and Pulse Learning	Christoph Reller Lukas Bruderer Sarah Neff

## 3. Research

### 3.1 General Research Areas

The Signal and Information Processing Lab focusses on research and teaching in the following areas:

#### **Information Theory and Coding**

Information theory, error correcting codes, and their application to communication systems. Current topics:

- Combined source-channel coding for multi-access networks
- Multi-access channels with noisy feedback
- Network coding
- Capacity of fading channels
- Broadcasting correlated sources
- Multi-path channels
- Interference networks
- Optical channels
- Error correcting codes
- Monte Carlo algorithms and numerical information theory

#### **Digital Signal Processing**

Current topics:

- State-space methods in signal processing
- Fundamentals and applications of graphical models (factor graphs)
- Feature detection filters

#### **Analog and Hybrid Signal Processing**

Current topics:

- Digital-to-analog conversion and analog-to-digital conversion
- Joint synchronization and decoding



## 3.2 Current Research Topics

### Prof. Amos Lapidoth (Information Theory)

#### The Free-Space Optical Intensity Channel at Low SNR

Free-space optical intensity channels are used to model infrared communication in an environment with strong ambient light. Hence of particular interest is the capacity at low SNR. We derive the asymptotic growth of the channel capacity at low SNR under average and/or peak power constraints.

#### On Multipath Fading Channels at High SNR

We study a discrete-time, non-coherent, multipath fading channel where the number of paths finite. The focus is on capacity at high signal-to-ratios (SNR). In particular, we investigate the capacity pre-loglog, defined as the limiting ratio of capacity to loglog SNR as SNR tends to infinity.

#### Multipath Channels of Unbounded Capacity

We investigate the capacity of discrete-time, non-coherent, multipath fading channels. We study conditions under which channel capacity is unbounded in the allowed transmit power.

#### The Poisson Channel at Low Input Powers

We study the asymptotic capacity at low input powers of an average-power limited or an average- and peak-power limited discrete-time Poisson channel. We consider channels whose dark currents are proportional to the input powers as well as channels whose dark currents are constant.

#### Wyner's Interference Network with Side-Information at Transmitters and Receivers

We consider a linear interference network modeling the communication in wireless cellular systems. For this network we explore a duality regarding transmitter side-information (cognition of other transmitters' messages) and receiver side-information (observation of other receivers' signals).

#### The Poisson Channel with Side Information

We study the capacity of the peak-limited Poisson channel with spurious counts whose positions are given a-causally as side-information to the transmitter but not to the receiver.

#### Coding for a Noisy Feedback Link

We study communication in the presence of a *noisy* feedback link. We assume that the feedback is active, so the noise on the feedback link can be combatted using coding. We study specific coding schemes as well as fundamental limits that hold for all coding schemes.

#### The Multiple Access Channel with Causal State Information

We study a state-dependent two-to-one multiple access channel (MAC), where the state sequence is available as side-information to the transmitters but not to the receiver. We consider two scenarios depending on whether the state sequence is known strictly causally or causally.

## **Prof. H.-A. Loeliger (Signal Processing)**

### **State-Space Methods in Statistical Signal Processing**

Most of our work in signal processing is based on linear state space models. Using IIR (infinite impulse response) models decouples the model order from the sampling rate and allows effortless transitions between discrete time and continuous time. We have extended such models to pulse-like (wavelet-like) signals that are localized anywhere in time. For given observations and unknown localization, the corresponding model likelihood is then itself a function of time, i.e., a signal. The computation of such a likelihood signal leads to the concept of a likelihood filter (or feature detection filter), a generalization of a matched filter.

In parallel with the development of this approach, we have applied it to applications including joint symbol synchronization and matched filtering, detection of seismic waves, analysis of biomedical signals, gesture detection using the magnetic sensor in smartphones, and many more.

Likelihood filters (feature detection filters) can also be cascaded into a new sort of neural network that works naturally with multichannel signals at multiple time scales. The exploration of this new approach has only just begun.

### **Fundamentals and Applications of Factor Graphs**

Factor graphs are a graphical notation for system models and algorithms in a large variety of fields including error correcting codes, signal processing, statistical physics, linear algebra, and more. We find factor graphs to be very helpful in most of our research work, and we continue to develop the approach. Recent progress includes localized state space models (see above), and factor graphs for joint probability distributions in quantum systems with many variables.

### **Monte Carlo Algorithms and Numerical Information Theory**

Many hard computational problems in information theory and statistical estimation can be addressed with Monte Carlo techniques. We have been continuing to enlarge the scope of such algorithms, e.g., to computing the partition function of Markov random fields at low temperature using factor graph duality.

### **Error Correcting Codes**

Our present interest is in a new perspective on decoding algorithms for Reed-Solomon codes (and similar codes), and on combining ideas from Reed-Solomon codes and polar codes.

### **Analog Computation and Analog-to-Digital Conversion**

We have a long-standing interest in analog computation and analog circuits for information processing. Our recent research in this area has focused on analog-to-digital converters. However, many of our likelihood filters (see above) are easily implementable as analog circuits.

### 3.3 Publications

- Molkaraie M., Loeliger H.-A. “Partition function of the Ising model via factor graph duality”, *IEEE International Symposium on Information Theory*, Istanbul, Turkey, July 7 – 12, 2013.
- Hung J., Loeliger H.-A. “Reverse Berlekamp-Massey decoding”, *IEEE International Symposium on Information Theory*, Istanbul, Turkey, July 7 – 12, 2013.
- Nefedov N. “Structure of Communities and its evolution in mobile social networks”, *NetSci Satellite Symposium on State-Topology Coevolution in Adaptive Networks (STCAN)*, Copenhagen, Denmark, June 3 – 7, 2013.
- Nefedov N. “Analysis of Communities Evolution in Dynamic Social Networks”, *Complex Networks IV*, vol. 476, pp. 39 – 36, Springer Verlag, Berlin.
- Molkaraie M., Loeliger H.-A. “Monte Carlo algorithms for the partition function and information rates of two-dimensional channels”, *IEEE Transactions on Information Theory*, vol. 59, no. 1, pp. 495 – 503, January 2013.
- Loeliger H.-A., Reller Ch. “Signal Processing with Factor Graphs: Beamforming and Hilbert Transform”, *Information Theory and Applications Workshops, (ITA)*, San Diego, CA., Feb. 10 – 15, 2013.
- Bunte Ch., Lapidoth A. “On the Average-Listsize Capacity and the Cutoff Rate of Discrete Memoryless Channels with Feedback”, *IEEE Information Theory Workshop (ITW)*, Sevilla, Spain, September 9 – 13, 2013.
- Bunte Ch., Lapidoth A. “Source Coding, Lists, and Rény Entropy”, *IEEE Information Theory Workshop (ITW)*, Sevilla, Spain, September 9 -13, 2013.
- Khisti A., Lapidoth “Multiple Access channels with intermittent feedback and side information”, *IEEE International Symposium on Information Theory*, Istanbul, Turkey, July 7 – 12, 2013.
- Lapidoth A., Bunte Ch. “The Honey-Do Problem Revisited: Sources with Memo-Mismatch, and a Divergence”, *Workshop on Information Theory, Communication Coding*, Haifa, Israel, December 29, 2013.
- Bunte Ch., Lapidoth A., Samorodnitsky A. “The zero-undetected-error capacity of the low-noise cyclic triangle channel”, *IEEE International Symposium on Information Theory*, Istanbul, Turkey, July 7 – 12, 2013.
- Lapidoth A., Steinberg Y. “The multiple-access channel with causal side information: common state”, *IEEE Transactions on Information Theory*, vol. 59, no.1, pp. 32 – 50, January 2013.

- Lapidoth A., Steinberg Y. “The multiple-access channel with causal side information: double state”, *IEEE Transactions on Information Theory*, vol. 59, no. 3, pp. 1379 – 1393, March 2013.
- Koch T., Lapidoth A. “At low SNR, Asymmetric Quantizers are Better”, *IEEE Transactions on Information Theory*, pp. 2592 – 2596, ISBN 978-1-4577-0596-0, 2011.
- Lapidoth A. Wang L. “The State-Dependent Semideterministic Broadcast Channel”, *IEEE Transactions on Information Theory*, vol. 59, issue 4, pp. 2242 – 2251, April 2013.

## 3.4 Completed PhD Theses

WILCKENS Georg

**Digital Estimation of Continuous-Time Signals Using Factor Graphs**

*ETH-Diss. Nr. 21292*

Referee: Prof. Hans-Andrea Loeliger

Co-examiner: Prof. Dr. Hanspeter Schmid, Fachhochschule Nordwestschweiz, Windisch

## 4. Trips and Talks

### 4.1 Participation in Conferences and Meetings

Lapidoth Amos	Information Theory and Applications Workshop, San Diego, USA, February 9 – 14.
Lapidoth Amos	IEEE International Symposium on Information Theory, Istanbul, Turkey, July 7 – 12.
Lapidoth Amos	IEEE Information Theory Workshop, Sevilla, Spain, September 9 – 13.
Lapidoth Amos	University of Maryland, Maryland, USA, October 3 – 10.
Lapidoth Amos	Technion-Israel Institute of Technology, Haifa, Israel, December 25 – January 1, 2014.
Bunte Christoph	IEEE International Symposium on Information Theory, Istanbul, Turkey, July 7 – 12.
Bunte Christoph	IEEE Information Theory Workshop, Sevilla, Spain, September 9 – 13.
Loeliger H.A.	9 <sup>th</sup> Int. ITG Conference on Systems, Communications and Coding (SCC 2013), Munich, Germany, January 21 – 24.
Loeliger H.A.	Information Theory and Applications Workshops, San Diego, USA; February 9 – 14.
Loeliger H.A.	IEEE International Symposium on Information Theory, Istanbul, Turkey, July 7 – 12.
Loeliger H.A.	Dagstuhl Workshop on Coding Theory, Schloss Dagstuhl, Wadern, Germany, August 25 – 30.
Bruderer Lukas	Information Theory and Applications Work Shop, San Diego USA, February 9 – 14.
Bruderer Lukas	University of Linköping, Linköping, Sweden, September 18 – 22.
Bruderer Lukas	7 <sup>th</sup> Workshop on Advanced Information Processing for Wireless Communication Systems, Aalborg, Sweden, November 14 - 15.
Reller Christoph	Information Theory and Applications Work Shop, San Diego, USA, February 9 – 14.
Yu Jiun Hung	IEEE International Symposium on Information Theory, Istanbul, Turkey, July 7 – 12.
Yu Jiun Hung	Dagstuhl Workshop on Coding Theory, Schloss Dagstuhl, Wadern, Germany, August 25 – 30.
Nefedov Nikolai	CompleNet, 4 <sup>th</sup> Workshop on Complex Networks, Berlin, Germany, March 13 – 15.
Nefedov Nikolai	NetSci Kopenhagen, June 3 – 6.

## 4.2 Presentations by Institute Members Not Listed under 3.3

- Loeliger H.A. “Statistical state space models and likelihood filtering”, 9<sup>th</sup> Int. ITG Conference on Systems, Communications and Coding (SCC 2013), Munich, Germany, January 21 – 24.
- Loeliger H.A. “From likelihood filtering to quantum probabilities”, University of California, San Diego, USA, March 12.
- Loeliger H.A. “Topics in statistical modeling and signal processing with state space models”, University of Toronto, Canada, May 28.

## 4.3 Invited Lectures and Seminars

- 14.05.2013 **Dr. Sergey Loyka**, University of Ottawa, Ontario, Canada  
“On Optimal Signaling over Secure MIMO Channels”
- 22.08.2013 **Dr. Michèle Wigger**, Telecom ParisTech, Paris, France  
“New Schemes and Achievable Rates for Broadcast Channels with Rate-Limited Feedback”
- 26.08.2013 **Prof. Edmond Yeh**, Northeastern University, Boston, USA  
“Polar Codes and Pricing via Quantization”
- 16.09.2013 **Dr. Christian Schlegel**, Dalhousie University, Halifax, Canada  
“Promise and Reality of Joint Detection in Coordinated and Random Access Communications Systems”
- 27.09.2013 **Alberto Monina**, University of Lugano  
“Fast computation of channel capacity”
- March – June 2013 **Dr. Nikolai Nefedov**  
“Complex networks analysis: clustering methods”

## 5. Service Activities

### 5.1 Conference Organization

**Prof. Loeliger** Co-Chair, 2013 Dagstuhl Workshop in Coding Theory

**Prof. Lapidath** Chair, 2013 International Zurich Seminar on Communications

### 5.2 Other Service Activities and Society Memberships

**Prof. Lapidath** Fellow of the IEEE

Member of the IMS Institute of Mathematical Statistics.  
Bethesda, USA

Research Affiliate in the Research Laboratory of Electronics  
RLE) at the Massachusetts Institute of Technology (MIT)

Member of the Center for Communication and Information  
Technologies (CCIT), Technion, Haifa, Israel

**Prof. Loeliger** Chair, IEEE Switzerland Chapter on Digital Communication  
Systems