Photonics & RF

- Prof. Dr. Christian Schäffer
- PD Dr. Thomas Fickenscher
- Max Rückmann
- Sebastian Kleis
- Alexander Geisler
- Bilal Raza
- Ulrich Herter
- Claus Dehmel
- Rene Marquardt
- Verena Wiehe

Biochemical Sensing
(Proteins, Enzymes, DNA …)
• **Research Topics Photonics**
  – All optical signal processing
  – Optical Equalization
  – Microwave Photonics
  – Optical Performance Monitoring
  – Coherent Receivers for Quantum Communication
  – Machine Learning in Photonics
  – Optical Sensing

• **Research Topics RF & Microwaves**
  – Radar on / with ships
  – Antenna Design onboard ships

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**Research Projects:**

• **SASER Safe and Secure European Routing (BMBF flagship project)**
  – Coherent systems for secure optical communication & Quantum Key distribution

• **Optical Biosensor using Surface Plasmon Resonance**
  – Sensitive detection of specific biochemical molecules (Proteins, Enzymes, DNA …)

• **Optical Signal Processing Silicon Photonics**
  – Optical equalizer and Fourier Transformation for Terabit/s communication systems

• **Radio over Fiber systems for Multigigabit/s wireless Systems**
  – Optical generation and distribution of Multigigabit/s mmwave signals

• **Optical Monitoring in Next Generation Optical Access Networks**
  – Health monitoring of the optical fiber infrastructure in NGOA with >1024 customers

• **Distributed Shipborne Over-The-Horizon-Radar**
  – Simulations including environmental influences on the radar performance.

• **Coexistence of windmills and digital radio links**
Network security on the physical layer
Quantum Key Distribution

- Coherent Systems for Key Generation for Secure Optical Communication

![Diagram](image)

Experimental Results for heterodyne CV-QKD with QPSK

- mean number of photons per symbol \( N_S \)
- post-detection SNR [dB]

Surface Plasmon Resonance Biosensor

- Miniaturized optical probe with power based readout
- Sensing in minimal volumes (< 1 μl) of biochemical analyts for specific:
  - Proteins, Enzymes, DNA...
- Without bulky additional equipment (fluidics, spectrometer, white light sources)
Nonlinear Fourier Transformation

- Proposed optical communication system based on Nonlinear Fourier Transform
- First results will be presented at ECOC 2016


Optical Fourier Transformation for Terabit/s communication systems

- Optical OFDM Demultiplexer in Silicon Photonics
  - Waveguide Layout of fabricated devices
  - Successful demodulation of 14 Gbaud QPSK signals (BER < 10^-4)
Optical Fourier Transformation 2nd Generation

- Realised with IHP’s nanophotonic technology:
  - 220-nm thick Si over 2-μm thick buried oxide
  - 248 nm Deep Ultraviolet lithography (DUV)
  - Plasma source etching
  - Al-based heaters as phase-shifters
  - Bending radius R ~ 5 μm

Chip size: 15 mm²

L. Zimmermann, PIER 2014 [invited]

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Machine learning in Photonics

Nanophotonics: low power laser characterization

- Learning static and dynamic laser parameters from measurements
- Allows for inclusion of laser physics into estimation algorithms

Low output power ⇒ low signal-to-noise ratio
Ultra-sensitive measurements of amplitude and phase noise rate equations

Reference and Lorentzian methods do not provide accurate FM noise. SemiConductor Laser (SCL) Bayesian filtering employs rate equations.

Gigabit/s Wireless Millimeter Wave Communication

- New services like HDTV require high data rates
- Short range communication (< 10m)
- Optical distribution and generation of the microwave carrier between 50 GHz and 300 GHz using optical frequency combs
- Successful error-free wireless transmission of > 10 Gbit/s on a 100 GHz carrier
- First 10Gbit/s wireless transmission in 2007
Optical Monitoring in Next Generation Optical Access Networks

• Health monitoring of the optical fiber infrastructure in NGOA with:
  – >1024 customers
  – 100 km fiber length

Interference with radars and radio links due to reflections/scattering and diffraction (Micro-Doppler effect in backscatter region and frequency deviation in forward scatter region). Safeguard zone dominated by diffraction.

- Development of 2D Fresnel-Kirchhoff Diffraction model for WT forward scattering (fast numerical integration using Babinet's principle) including effect of real ground
- Calculation of dynamic amplitude and phase modulation, Doppler deviation and time-frequency spectrum (point-to-point radio link and radar signals)
- Interference for communication links with higher order modulation schemes:
  - Bit Error Rate (BER)
  - Error vector magnitude and constellation diagram spread
  - OFDM orthogonality

Coexistence of Windpower Parks and Point-to-Point Radio Links

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Distributed Shipborne OTHR

✓ Colocated MIMO Radar with Linear Sparse Receive ARRAY
  • Suppression of grating lobes
  • Long CIT solved by MIMO BF
  • Beat frequency division (FMCW)
  • Fast horizontal displacement and tilt angle compensation

✓ Sea Clutter Canceller BF
  • Superior to STAP
  • Noise reduction in all RD cells
  • Clutter statistics not required

✓ Correlation Detector
  • Superior to CFAR
  • Detection in clutter dominated region
  • Power thresholding not required
  • Detection up to 120 km with 4 W Tx power

Phased Array Verification
Precision Approach Radar PAR-80

Background:
The lifetime of the relocatable radar is going to be further extended. The performance of the phase shifters of the antenna array is crucial for the operability of the radar. To date the functionality of the phase shifters can only be tested when disassembled or by performing test flights.

Project task:
Verification of individual phase shifter performance with antenna array assembled. Development of automated PC controlled measuring equipment.

Funding:
Bundesamt für Wehrtechnik und Beschaffung, Koblenz
Safe and Secure European Routing

- **BMBF Project SASER**
- Network security on the physical layer
  Quantum Key Distribution
- **Coherent Systems for Key Generation for Secure Optical Communication**
- **Coherent Systems I**
  - BPSK realization of a B 92 protocol
  - LO transmission with TDM & POL multiplex
- **Coherent Systems II**
  - M-PSK modulation
  - LO at the receiver site
  - LO free running

Coherent Systems for Key Generation I

Secure communications using a quantum channel

Information advantage based on quantum properties
- Non-orthogonality of coherent states (Heisenberg uncertainty)
- Single Photon or Entanglement

A key is not transmitted but **generated after** the quantum state transmission by **interactive reconciliation** via the classical channel

Coherent Technologies: State of the Art QKD System B92

Transmitter
- Rep. rate: 5 MHz
- Pulse width: 17 ns
- Extinction: >25 dB

Receiver
- PBS
- Phase Shifter
- Balanced Receiver

Error Correction CASCADE Protocol

P. Jouguet et al., Nature Photonics, 2013

CASCADE Protocol –Simulation-

- Simulation of CASCADE modules for Alice and Bob via a reflected Ethernet Connection

JESUS MARTINEZ-MATEO: “DEMYSTIFYING THE INFORMATION RECONCILIATION PROTOCOL CASCADE”
Quantum Information and Computation, Vol. 15, No. 5&6 (2015) 0453

State of the Art QKD System B 92

- Remote heterodyne for relaxing the requirement on the coherence of the laser field
- Power of the remote Local Oscillator (LO) given by the shot noise limit of the coherent receiver
- Manage crosstalk issues between LO and quantum signal with polarization and time division multiplex
- Error correction with Cascade
- Can we move the LO to the receiver?
Coherent Technologies II:
M-PSK Transmission

Here: transmission of faint $M$-PSK modulated laser pulses

$$\alpha_k = a \exp(j2\pi k/M)$$
$$\beta_k = \eta |\alpha_k|$$

$\eta$: channel transmittance

Attenuation to enhance quantum uncertainty (non-orthogonality)

Mutual Information between Alice and Bob

$M$-PSK

Hard decision case
Bob decides immediately $\beta \rightarrow l$

$$I_{AB,\text{hard}}(l) = \log_2(M) + \sum_{k=0}^{M} p(k|l) \log_2[p(k|l)]$$
$$I_{AB,\text{hard}} = \sum_{l=0}^{M} p(l)I_{AB}(l)$$

Soft decision case
Bob keeps continuous value $\beta$

$$I_{AB,\text{soft}}(\beta) = \log_2(M) + \sum_{k=0}^{M} p(k|\beta) \log_2[p(k|\beta)]$$
$$I_{AB,\text{soft}} = \int p(\beta)I_{AB}(\beta)\,d\beta$$
**M-PSK scheme system proposal and experiment**

Heterodyne detection
Free running LO and A/D at SNR < 0 dB
Combined linewidth ~200 kHz
Unsuppressed carrier
Transmission of clock

Experimental Results

Direct evaluation of \( I_{AB,\text{hard}} \)
- ~2 dB penalty
  - quantum efficiency (~1 dB)
  - thermal noise (~0.5 dB)
  - lowest power
    0,1 photons/symbol

Experimental raw key-rate
- feed back results to num. optimization
  But: penalty can serve as worst-case estimator

\( N_{Rx} \): number of photons per symbol

\( dB N = 10 \cdot \log_{10}(N_{Rx}) \)
Co-existence of quantum channel and WDM channel(s)

- No influence to be seen with one strong interferer

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Conclusion & Outlook

- $M$-PSK scheme for secure key distribution introduced
  - Eve uses perfect coherent Rx
  - Eve gets all the channel loss

- Theoretical Key-rates calculated
  - >100 km possible at reasonable key-rates ($>10^{-3}$ bit/symbol)
  - 16-PSK seems a good choice

- Realization possible with standard components!

- Further investigation: coexistence in a multichannel environment
References

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