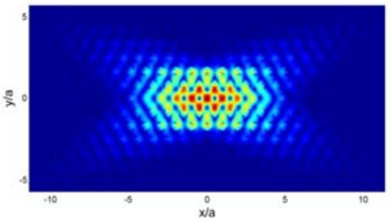
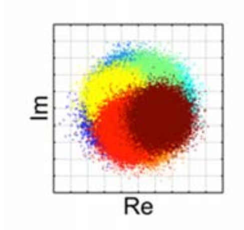


HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

Photonics
&
Radio - Frequency Engineering

Faculty of Electrical Engineering
Helmut-Schmidt-University Hamburg



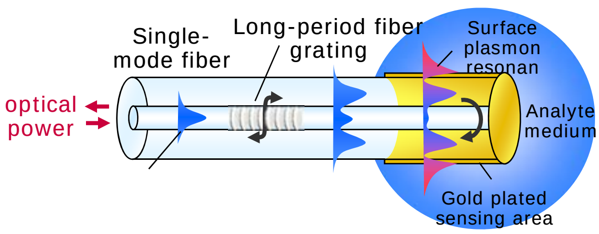
Prof. Dr.-Ing. Christian Schäffer
cgs@hsu-hh.de

Photonics & RF

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

- 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 …)

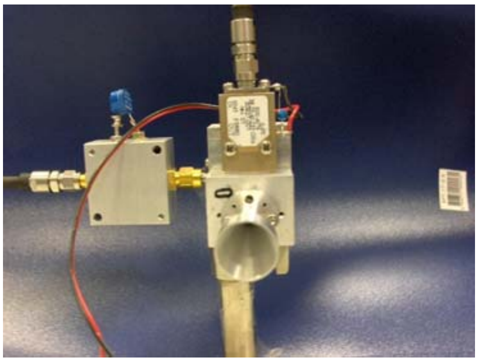


HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

- 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

International Year of Light 2015

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



HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

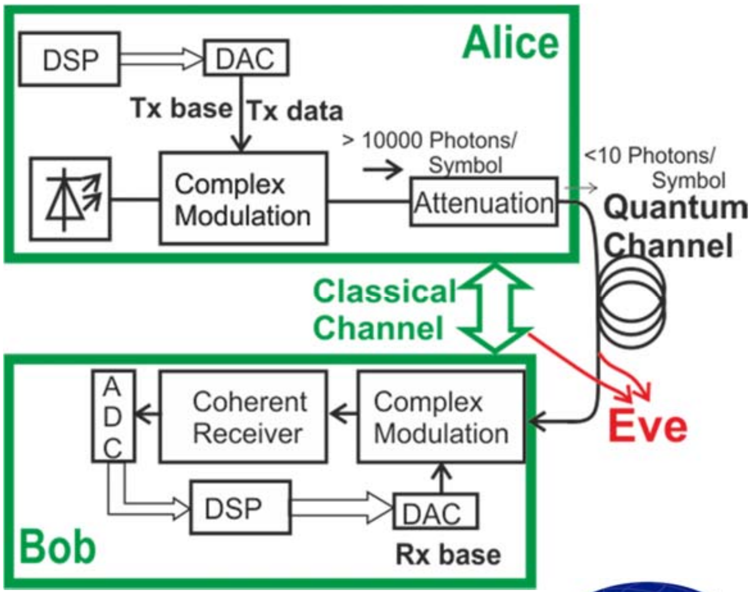
SASER

Research Projects:

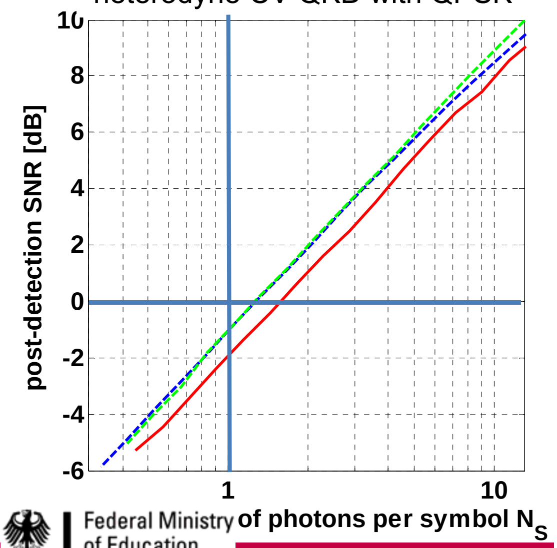
- SASER Safe and Secure European Routing (BMBF flagship project)
  – Coherent systems for secure optical communication & Quantum Key distribution
- Optical Biosensor using Surface Plasmon Resonance
  – Sensitive detection of specific biochemical molecules (Proteins, Enzymes, DNA …)
- Optical Signal Processing 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**



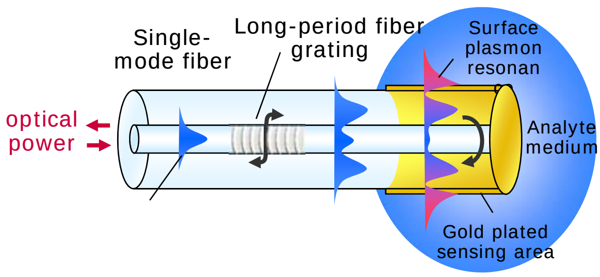
Experimental Results for heterodyne CV-QKD with QPSK



Federal Ministry of Education and Research

Surface Plasmon Resonance Biosensor

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



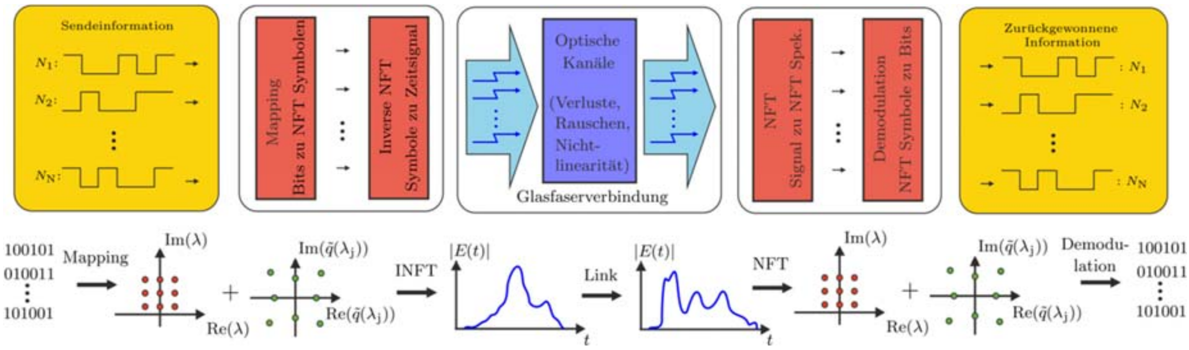
TECHNISCHE UNIVERSITÄT DRESDEN

Deutsche Forschungsgemeinschaft DFG

Nonlinear Fouriertransformation

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

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

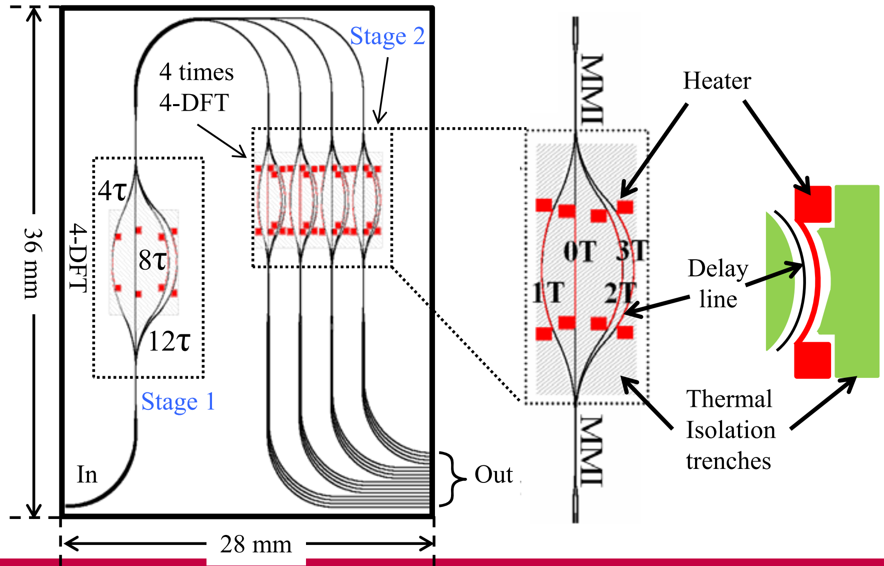


- M. I. Yousefi and F. R. Kschischang, "Information Transmission using the Nonlinear Fourier Transform, Part I-III: Spectrum Modulation," Transaction of information theory, vol. 60, no. 7, pp. 4312-4368, 2014

Optical Fourier Transformation for Terabit/s communication systems

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

- Optical OFDM Demultiplexer in Silicon Photonics
  - Waveguide Layout of fabricated devices
  - Successful demodulation of 14 Gbaud QPSK signals (BER < 10^{-4})

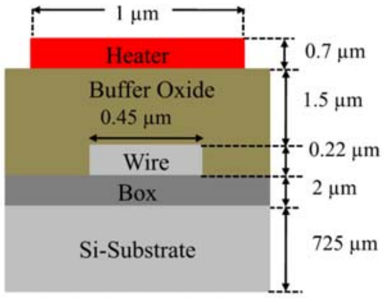


OFDM: orthogonal frequency division multiplexing

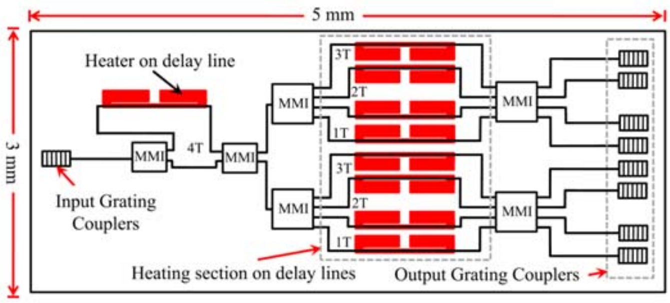
Deutsche Forschungsgemeinschaft DFG

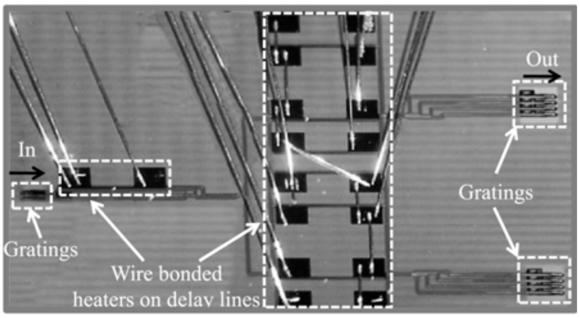
Optical Fourier Transformation 2nd Generation

- 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



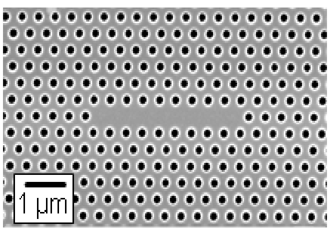


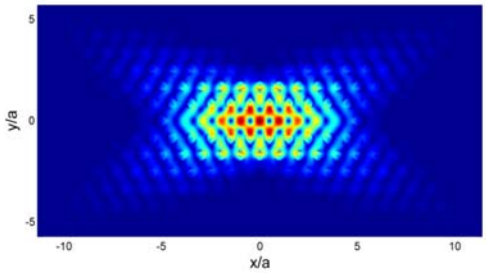
Chip size: 15 mm²

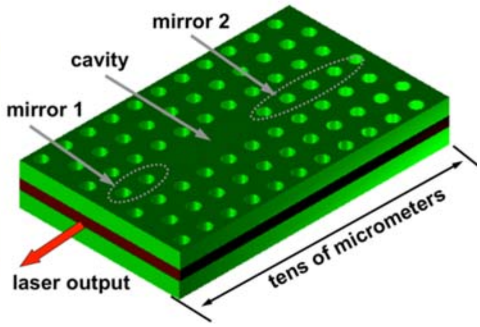
L. Zimmermann, PIER 2014 [invited]

Machine learning in Photonics

Nanophotonics: low power laser characterization[3]





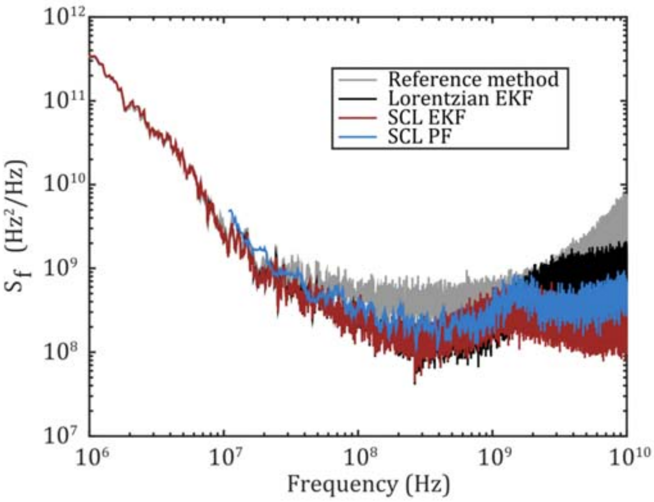


- Learning static and dynamic laser parameters from measurements
- Allows for inclusion of laser physics into estimation algorithms

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

[3] M. Piels, JLT, 2015

Frequency noise spectra nanolaser[3]

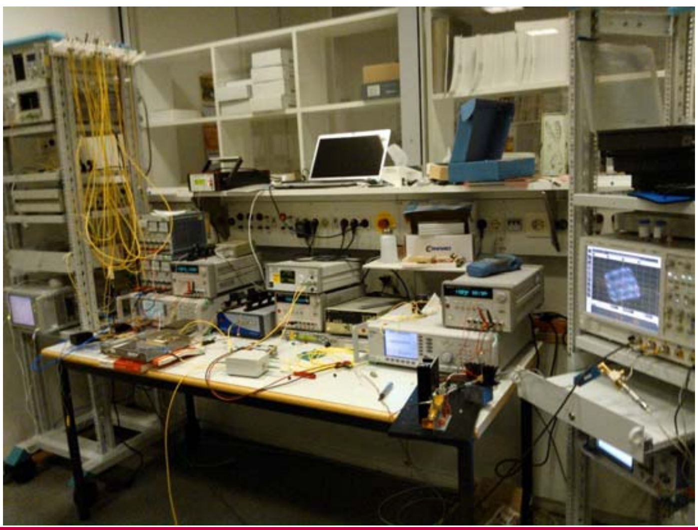


Reference and Lorentzian methods do not provide accurate FM noise
SemiConductor Laser (SCL) Bayesian filtering employs rate equations

[3] M. Piels, JLT, 2015

Gigabit/s Wireless Millimeter Wave Communication

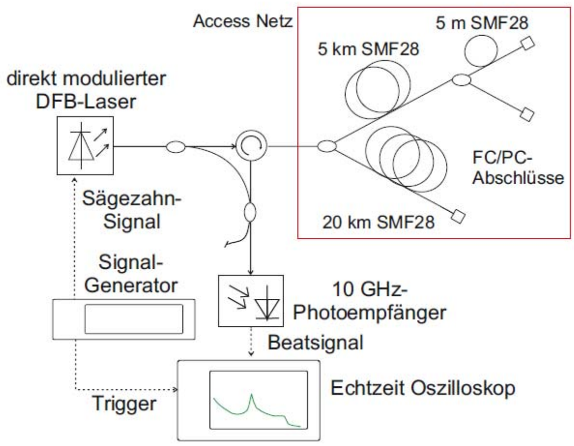
- New services like HDTV require high data rates
- Short range communication (< 10m)
- Optical distribution and generation of the microwave carrier between 50 GHz and 300 GHz using optical frequency combs
- Successful error-free wireless transmission of > 10 Gbit/s on a 100 GHz carrier
- First 10Gbit/s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



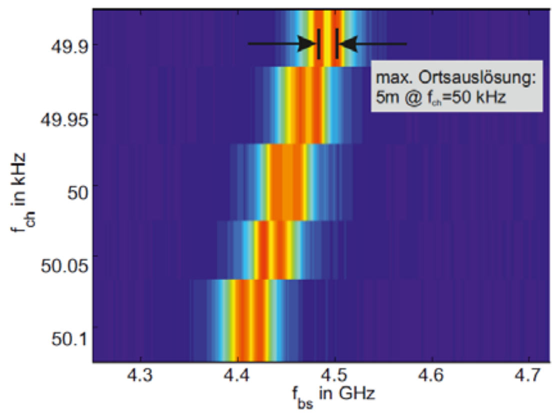
Federal Ministry of Education and Research

Optical Monitoring in Next Generation Optical Access Networks

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



High resolution coherent FMCW System



Federal Ministry of Education and Research

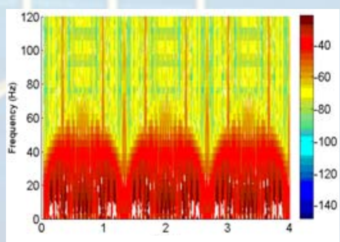
Coexistance of Windpower Parks and Point-to-Point Radio Links

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.

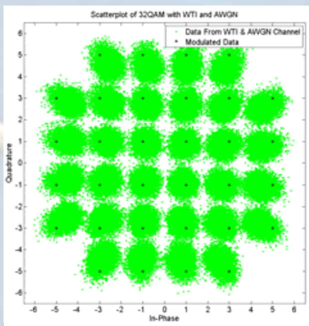
✓ Development of 2D Fresnel-Kirchhof Diffraction model for WT forward scattering (fast numerical integration using Babinets principle) including effect of real ground

✓ 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



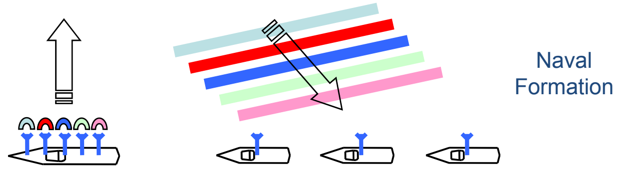
Time-Frequency Spectrum



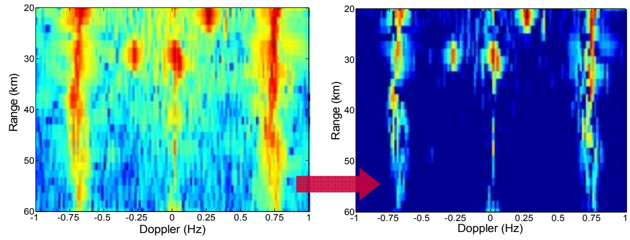
Constellation Diagram

Distributed Shipborne OTHR

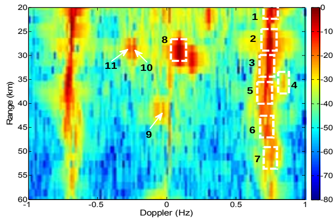
- ✓ Colocated MIMO Radar with Linear Sparse Receive ARRAY
  - Suppression of grating lobes
  - Long CIT solved by MIMO BF
  - Beat frequency division (FMCW)
  - Fast horizontal displacement and tilt angle compensation



- ✓ 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.

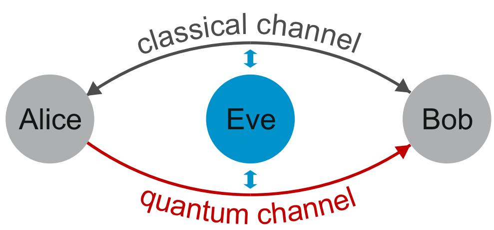
Funding:
Bundesamt für Wehrtechnik und Beschaffung, Koblenz

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**

Federal Ministry of Education and Research

Coherent Systems for Key Generation I
Secure communications using a quantum channel



quantum state transmission
error correction
privacy amplification
use key to encrypt classical channel

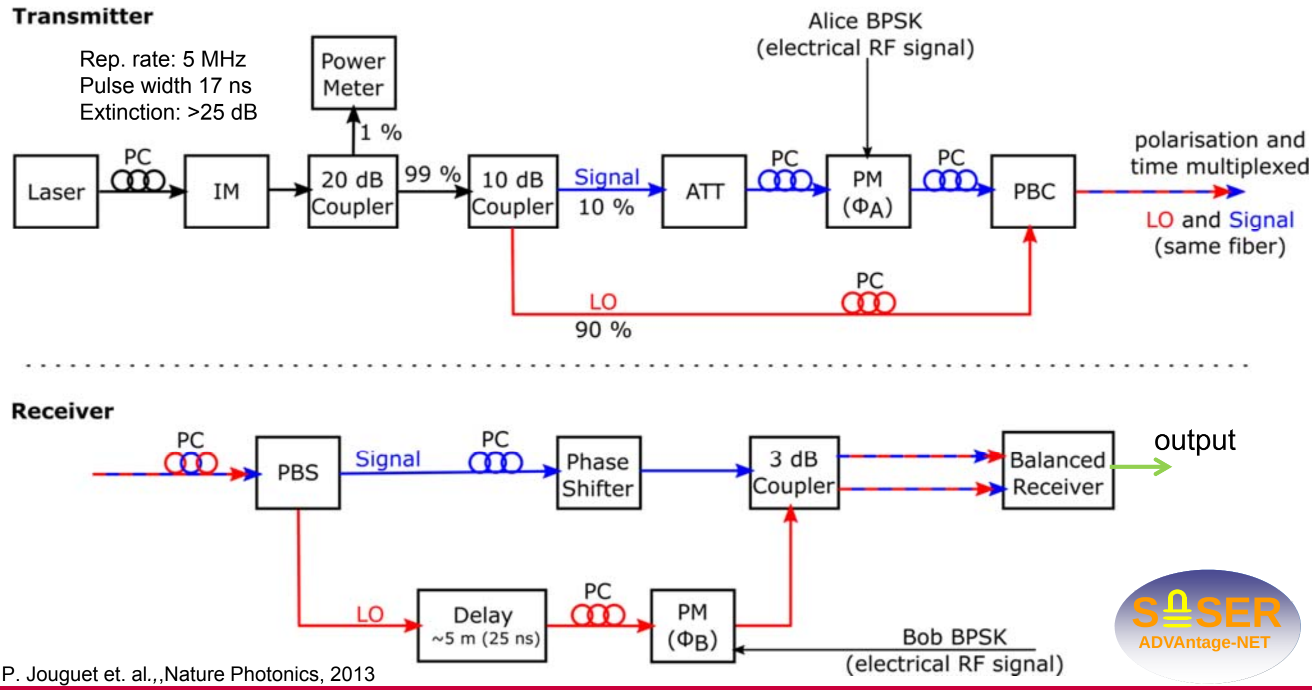
Information advantage based on quantum properties

- 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

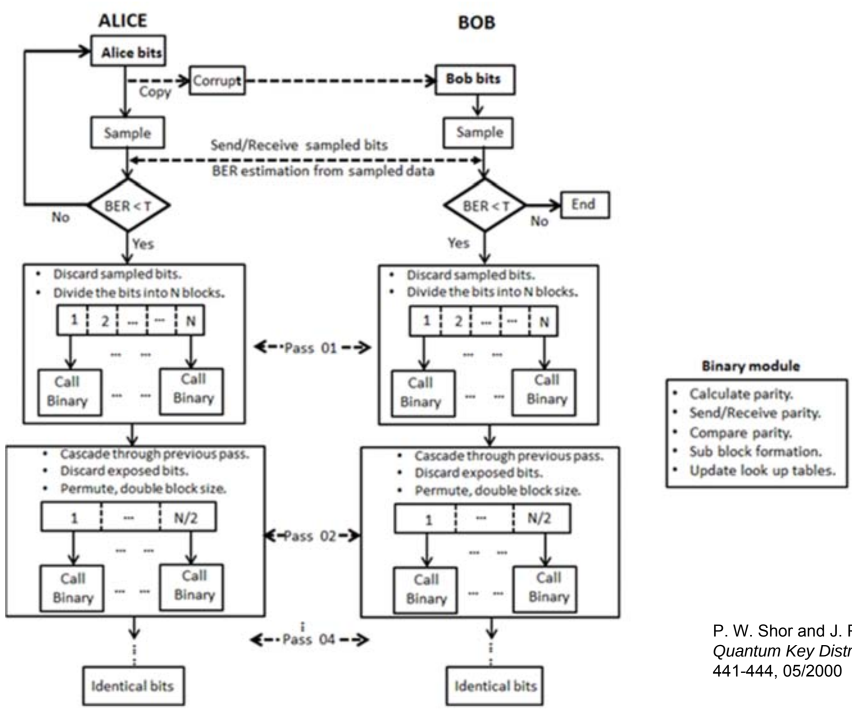
G. van Assche, *"Quantum-Cryptography and Secret-Key Distillation,"* Cambridge University Press, 2006

Coherent Technologies:
State of the Art QKD System B92



P. Jouguet et. al.,,Nature Photonics, 2013

Error Correction CASCADE Protocol

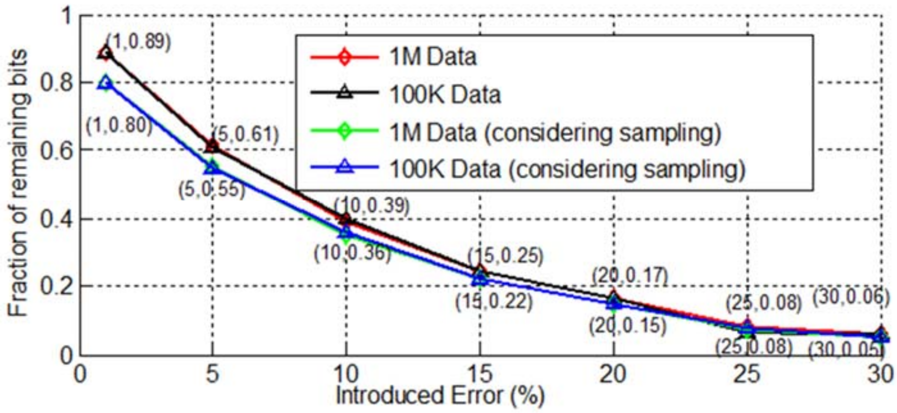


P. W. Shor and J. Preskill, *Simple Proof of Security of the BB84 Quantum Key Distribution Protocol*, Phys. Rev. Lett., vol. 85, pp. 441-444, 05/2000

CASCADE Protocol –Simulation-

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

- 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

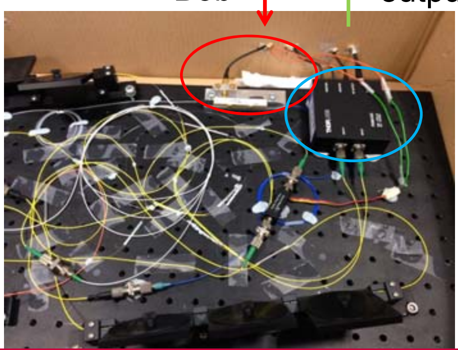
State of the Art QKD System B 92

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

- 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?

Alice

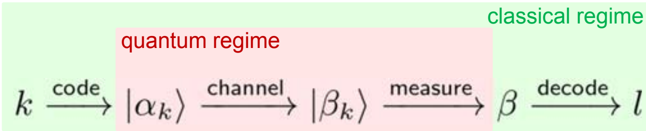
Bob output



SASER ADVAntage-NET

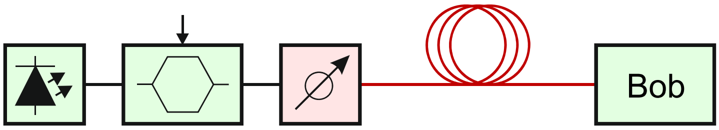
Coherent Technologies II:
M-PSK Transmission

Here: transmission of faint M- PSK modulated laser pulses



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

η: channel transmittance



Attenuation to enhance quantum uncertainty (non-orthogonality)

SASER ADVAntage-NET

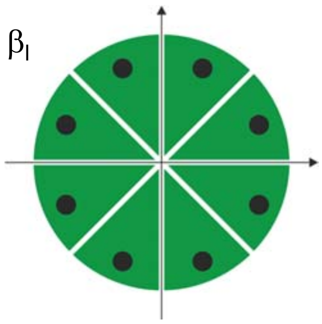
Mutual Information between Alice and Bob

M -PSK

Hard decision case

Bob decides immediately $\beta \rightarrow l$

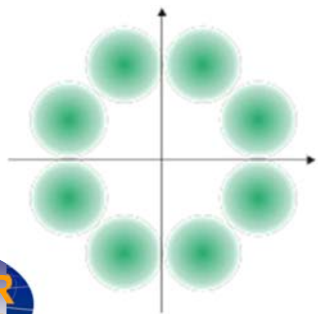
$$I_{\mathrm{AB,hard}}(l) = \log_2(M) + \sum_{k=0}^{M} p(k|l) \log_2[p(k|l)]$$
$$I_{\mathrm{AB,hard}} = \sum_{l=0}^{M} p(l) I_{\mathrm{AB}}(l)$$



Soft decision case

Bob keeps continuous value β

$$I_{\mathrm{AB,soft}}(\beta) = \log_2(M) + \sum_{k=0}^{M} p(k|\beta) \log_2[p(k|\beta)]$$
$$I_{\mathrm{AB,soft}} = \int p(\beta) I_{\mathrm{AB}}(\beta) \mathrm{d}\beta$$

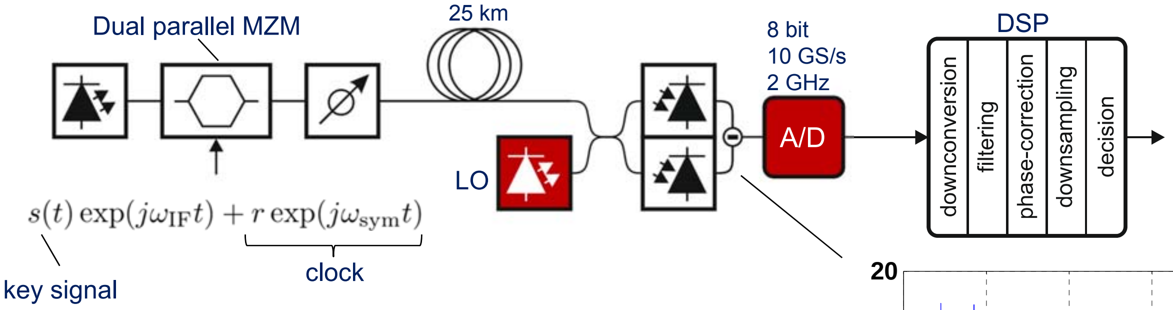


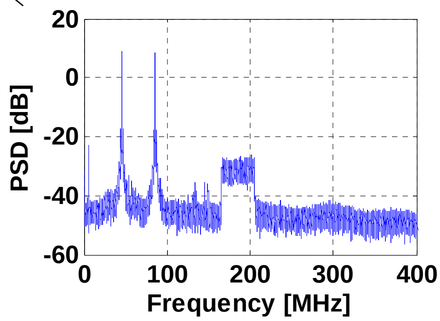
SASER ADVAntage-NET

M-PSK scheme system proposal and experiment

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

Rate: 40 MBaud





f_{IF}=140 MHz

Heterodyne detection

Free running LO and A/D at **SNR < 0 dB**

Combined linewidth ~200 kHz

Unsuppressed carrier

Transmission of clock

Experimental Results

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

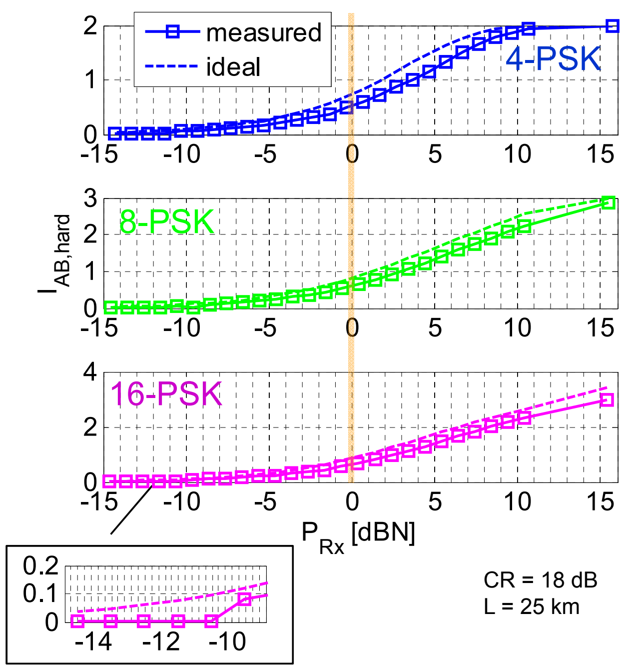
Direct evaluation of $I_{\mathrm{AB,hard}}$

~2 dB penalty

- quantum efficiency (~1 dB)
- thermal noise (~0.5 dB)

- lowest power

0,1 photons/symbol



CR = 18 dB
L = 25 km

Experimental raw key-rate

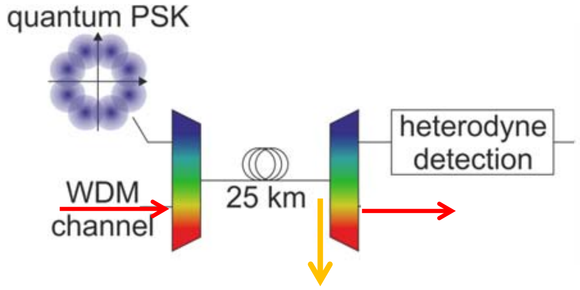
- feed back results to num. optimization

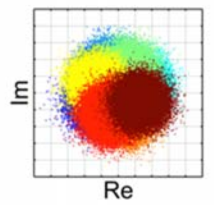
But: penalty can serve as worst-case estimator

N_{Rx}: number of photons per symbol

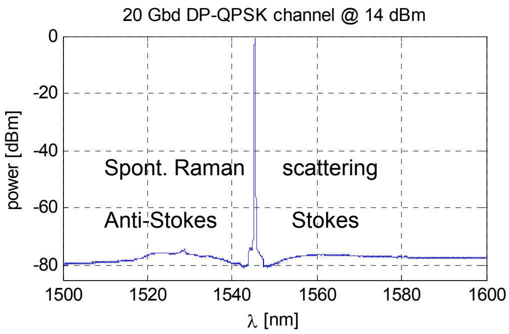
$\mathrm{dB}N \mathrel{\hat{=}} 10 \cdot \log_{10}(N_{\mathrm{Rx}})$

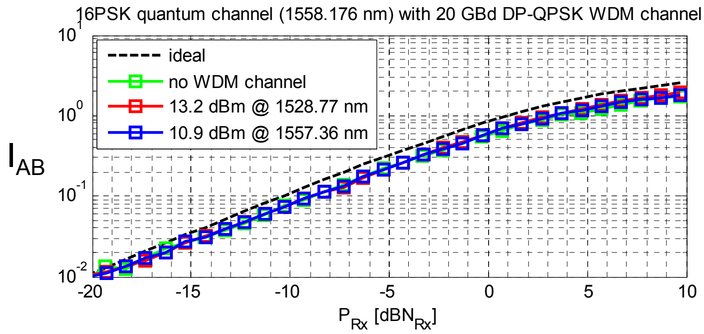
Co-existence of quantum channel and WDM channel(s)





Crosstalk by classical Interferers
- Raman scattering
- XPM





- No influence to be seen with one strong interferer

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

Bennett, C., "Quantum cryptography using any two nonorthoganol states.", Phys. Rev. Lett. 68, 1992, pp. 3121-3124.
http://prola.aps.org/pdf/PRL/v68/i21/p3121_1

Bennet, C. H., Brassard, G., and Mermin, N., D., "Quantum cryptography without Bell's theorem.", Phys. Rev. Lett. 68, 1992, pp. 557-559.
http://prola.aps.org/pdf/PRL/v68/i5/p557_1

“The BB84 Quantum Coding Scheme", June 2001.
http://www.cki.au.dk/experiment/qrypto/doc/QuCrypt/bb84coding.html

“The B92 Quantum Coding Scheme", June 2001.
http://www.cki.au.dk/experiment/qrypto/doc/QuCrypt/b92coding.html