Q 4: Quantum Optics I

Time: Monday 14:30–16:15 Location: P 5

Group Report Q 4.1 Mon 14:30 P 5

A mixed bag of quantumness with a bit of tech — Kai Barnscheidt, Tom Ettrich, •Boris Hage, Semjon Köhnke, Melanie Mraz, Christian Reiher, Dieter Schick, and Oskar Schlettwein — Universität Rostock, Institut für Physik, AG Experimentelle Quantenoptik, Rostock, Germany

We report on the activities of the research group 'Experimental Quantumoptics' at the University of Rostock, which are divided into three areas:

1) The detection and verification including experimental errors of the quantumness/nonclassicality of the state of a laser beam using linear, nonlinear and single photon detectors. Additionally, the advance towards a measurement based quantification of nonclassicality.

2) The complete quantum state tomography (single mode) of a pulsed multi mode squeezed state of light emerging from a Kerr nonlinear optical fibre. Additionally, the advances towards a reliable simulation of the processes in the optical fibre including losses, dispersion (higher order), Kerr nonlinearity and Raman effect.

3) Progress towards the implementation of an optical spring with micro cantilevers used in atomic force microscopy with an optical excitation using photothermal and radiation pressure coupling.

Q 4.2 Mon 15:00 P 5

Phase-insensive test of phase-squeezed state nonclassicality — •Melanie Mraz[1], Benjamin Kühn[2], Semjon Köhnke[1], Werner Vogel[2], and Boris Hage[1] — [1]AG Experimentelle Quantenoptik, Institut für Physik, Universität Rostock — [2]AG Theoretische Quantenoptik, Institut für Physik, Universität Rostock

We experimentally realized the homodyne cross correlation detection (HCCD) proposed in [1]. This technique is based on an intensity noise correlation. Three different normally ordered moments of field amplitude and intensity are extracted from the recorded correlation in two dissimilar ways; by phase periodicity and by order of the local oscillator strength. We used a coherently displaced phase-squeezed state at 1064 nm with approx. -2.7dB squeezing generated in an optical parametric amplifier (OPA). To verify the presented method and to analyze the amount of squeezing, we used a standard balanced homodyne detector (BHD). The special features of our HCCD are an unbalanced splitting ratio of 14:86 and a matched local oscillator (LO) power to the order of magnitude of the signal power. This delivers us the needed information of three different normal ordered moments of field amplitude and intensity. A nonclassicality criterion is developed which is solely based on these moments. Remarkably, this test certifies quantum correlations for all phases, i.e., even in the antisqueezed region, of the generated squeezed state. Furthermore, the analysis of the data is free of quantum physical assumptions as present in the standard balanced homodyne detection.

[1] W. Vogel, Phys. Rev. A 51, 4160 (1995).

Q 4.3 Mon 15:15 P 5

Experimental Demonstration of Negative-Valued Polarization Quasi-Probability Distribution — •Kirill Spasibko[1,2], Maria Chekhova[2,3,1], and Farid Khalili[3] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — [2]Max-Planck-Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [3]Faculty of Physics, M. V. Lomonosov Moscow State University, 119991 Moscow, Russia

The polarization analog of the position-momentum Wigner distribution is the polarization quasi-probability distribution (PQPD) for the three non-commuting Stokes observables. This distribution fully describes the polarization properties of a quantum state and gives correct one-dimensional marginal probability distributions for all Stokes observables and their linear combinations (as the Wigner distribution for position and momentum does).

Usually the negativity of the Wigner distribution is considered as a proof of non-classicality for a quantum state. On the contrary, the PQPD demonstrates negativity for all quantum states. This feature comes from the discrete nature of the Stokes observables.

In this work [arXiv:1508.03510] we have demonstrated the experimental reconstruction of the PQPD for a linearly-polarized weak coherent state of light measured with single-photon detectors. The reconstructed distribution demonstrates well pronounced negative-valued areas. This intrinsic negativity was not observed in previous experiments, because they were performed with photon-number averaging detectors.

Q 4.4 Mon 15:30 P 5

Overcoming Vacuum Noise: The Unforeseen Benefits of Quantum Heterodyne Detection — •Christian R. Müller[1,2], Christian Peuntinger[1,2,3], Thomas Dirmeir[1,2], Imran Khan[1,2], Ulrich Vogl[1,2], Christoph Marquradt[1,2], Gerd Leuchs[1,2], Luis L. Sánchez-Soto[4,1], Yong S. Teo[5], Zdenek Hradil[5], and Jaroslav Rehacek[5] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany. — [3]Department of Physics, University of Otago, New Zealand. — [4]Departamento de Óptica, Facultad de Física, Universidad Complutense, Madrid, Spain. — [5]Department of Optics, Palacky University, Olomouc, Czech Republic.

The Wigner function and the Husimi Q-function are theoretically equivalent representations of a quantum state and are intimately linked to homodyne tomography and heterodyne detection, respectively. In state estimation via these measurement techniques one is confronted either with errors incurred during tomogram processing or with additional excess noise due to the simultaneous measurement of conjugate observables. We experimentally demonstrate that, contrary to a common believe, state estimation via heterodyne detection outperforms homodyne tomography for almost all Gaussian states.

[1] J. Řeháček et al., Sci. Rep., 5, 12289 (2015).
[2] C. R. Müller et al., Phys. Rev. Lett. 117, 070801 (2016)

Q 4.5 Mon 15:45 P 5

Quantum state tomography of Kerr squeezed femto second pulses in optical fibers — •Oskar Schlettwein, Kai Barnscheidt, and Boris Hage — Institut für Physik, Universität Rostock, Germany

The intensity dependence of the refractive index in standard optical fibers is usually very small ($n_2 \sim 10^{-20}\frac{m^2}{W}$). However it still can get a significant impact if short pulses with high peak power are launched into the small mode field diameter of the fiber. Using 250 fs (FWHM) pulses with peak power in the kW regime the impact of the appearing Kerr- and Raman-effect on the quantum properties of the light field are experimentally analyzed. For this purpose a new schema based on a ring cavity is set up to perform a full quantum state tomography of the light field.

Since the fiber output pulses are multimode quantum states the choice of the local oscillator (LO) plays a crucial role in the tomography. Our setup can be used to gain a LO which has the same temporal pulse shape as our signal without any further shaping technics needed. This allows us to also analyze the quantum properties of non-soliton pulses.

With the further addition of a pulse shaper in the LO path the multimode quantum structure of the Kerr squeezed pulses could be experimentally investigated. Our nummerical calculations predict separable squeezed modes in the pulse with a high amount of squeezing. The shape of this modes as well as the progress into their experimental investigation will be demonstrated.

Q 4.6 Mon 16:00 P 5

A Kalman Filter Approach to Quantum State Reconstruction — •Karsten Bölts, Stefan Scheel, and Boris Hage — Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23-24, 18059 Rostock, Deutschland

Kalman filtering, a technique which is mostly used for dynamical state estimation in the field of engineering, can also be applied to quantum state reconstruction [1]. This method yields not only the optimal Bayesian state estimate but also treats the measurement uncertainties properly and can in principle be adapted to any tomographic set-up. The reconstruction scheme is mainly based on linear vector equations and hence it is well suited for hardware implementation.

Here we show how to apply the Kalman filter method to balanced homodyne tomography [2]. We implemented a version of the algorithm on a field programmable gate array (FPGA) to enable hardware-assisted real-time state reconstruction and calculation of error bars.

[1] K. M. R. Audenaert and S. Scheel, *New J. Phys.* **11**, 023028 (2009)
[2] E. Agudelo, J. Sperling, W. Vogel, S. Köhnke, M. Mraz and B. Hage, *Phys. Rev. A* **92**, 033837 (2015)