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Simulating and Optimizing Laser Interferometers

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Abstract. This paper introduces the IFOCAD software which is designed to simulate laser interferometers using different beam models, including non-astigmatic as well as simple and general astigmatic Gaussian beams in the fundamental mode. With IFOCAD it is also possible to compute heterodyne signals such as pathlength signal, differential wavefront sensing signal, differential power sensing signal and contrast. Another important feature of IFOCAD are optimization algorithms that are useful for designing laser interferometers and adjusting them to fulfill specific requirements.

1. Introduction

Designing complicated optical systems often requires simulations to create the most efficient setups. To make sure that the simulation gives representative results we need a special software that is able to trace different types of Gaussian beams through an arbitrary misaligned 3D optical setup and compute the same signals as are used in the experiment. Such a tool, called IFOCAD, has been developed in our group. Apart from the features listed above it includes various algorithms to help with optimization and design of interferometers. IFOCAD is a library of functions that is available in two different versions: in C and C++ programming languages. The C library works only with circular (i.e. non-astigmatic) beams and will not be developed further. The C++ library works with simple and general astigmatic Gaussian beams in the fundamental mode. The generalization to higher order modes is under development. The C code is available at the url given in the references, and the C++ code will soon be there as well.

2. IFOCAD features

When designing optical experiments with picometer sensitivities even tiny misalignments of components and small tilts of beams should be taken into account. Therefore, while developing IFOCAD, one of our key concerns was the accuracy of the laser beam representation, which in turn affects the accuracy of the heterodyne signal prediction.

In the C library the circular (i.e. non-astigmatic) Gaussian beam model is used. Beyond geometrical parameters (origin and direction of propagation) it is characterized by a so-called q-parameter (ref. H. Kogelnik (1966)) that carries information about phase and intensity of the beam. Beam transformations (reflection and transmission) are simulated using ABCD-matrices. This method doesn't take into account the angle between the beam and the surface normal vector (incidence angle) which leads to an inaccuracy in the prediction of the beam tilt effects.

In the C++ library simple and general astigmatic Gaussian beam models are used instead. The simple astigmatic (or elliptical) Gaussian beam model (SAGB) gives accurate results for non-zero incidence angles. In this model two q-parameters for the two axes of the beam ellipse are introduced. They can be transformed separately as shown in ref. G. A. Massey (1969). Nevertheless, the SAGB model is also limited. It fails when none of the principal axes of the elliptical beam lies in the plane of incidence, and therefore none of the q-parameters can be considered as tangential. The most general case of the first order Gaussian beams is a general astigmatic Gaussian beam (GAGB). For such beams the constant intensity ellipse and constant phase ellipse (or hyperbola) can be oriented at an oblique angle with respect to each other. In this case the orientation of both ellipses changes along the path of propagation (ref. J. A. Arnaud (1969)). GAGB can be described by two q-parameters and a complex angle or by a so-called complex curvature tensor (ref. J. Alda (1991)). Beam transformations can be represented by formulas from A. Rohani (2004) that are applicable for an arbitrary 3D case. A detailed paper about GAGB model will follow.

IFOCAD also includes a unique feature whereby heterodyne signals can be computed in the same way as they are produced by phasemeters in the lab. Detailed information about heterodyne signals and their software implementation can be found in Wanner (2010) and Wanner et al. (2012).

To design and optimize interferometers IFOCAD includes a nonlinear equation solver (ref. S. Bellavia (2004)), minimizers and the shift-out algorithm (ref. Heinzel (2012)). The latter is designed to automatically position a component such that it doesn't intersect with other components or beams in a setup.

3. Conclusion

The new IFOCAD software was presented in the paper. Its key features were discussed. Although IFOCAD is still under development (for example, the work on higher order modes is ongoing), at the moment it is a ready-to-use tool for designing, optimizing, simulating and analyzing laser interferometers.

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