Improving the performances of current optical interferometers & future designs
Proceedings of Haute Provence Observatory Colloquium (23-27 September 2013)
Edited by L. Arnold, H. Le Coroller & J. Surdej

Spectrally resolved frequency comb interferometry

Steven van den Berg

VSL, Thijsseweg 11, 2629 JA, Delft, The Netherlands

Abstract. In this contribution a novel method for interferometric distance measurement is presented, that is based on unraveling the spectrum of a femtosecond frequency comb. The light of a frequency comb is sent into a Michelson interferometer. The output of the interferometer is analyzed by a high-resolution spectrometer, resolving the individual comb modes. The path-length difference between the two arms is determined on the level of tens of nm, by utilizing the wealth of information present in the unraveled spectrum, showing homodyne interference for each individual frequency comb mode. The measurement method allows for high-accuracy measurements in combination with a large range of non-ambiguity.

The invention of the femtosecond frequency comb has been a step change in the field of optical-frequency metrology, with a wide outreach to other fields, like high-resolution spectroscopy, femtosecond-pulse shaping and absolute distance measurement. We have investigated the femtosecond frequency comb as a potential new source for accurate absolute long-distance measurements, exploiting the unique properties of the comb and utilizing the direct traceability to the SI second. In this contribution we focus on distance measurement with a mode-resolved frequency comb laser. The frequency comb light is sent into a Michelson interferometer, consisting of a measurement and a reference arm. Subsequently, the interferometer output is analyzed with a high resolution spectrometer based on a virtually imaged phase array (VIPA) and a grating. The VIPA spectrometer unravels the 1 GHz spaced comb frequencies to distinct modes. As a result, interferometry on the level of individual modes (wavelengths) can be observed (see Fig. 1). The distance is determined from both spectral interferometry and massively parallel homodyne interferometry of about 9000 frequency comb modes. We have delivered an experimental proof of principle of homodyne frequency comb interferometry by measuring a short displacement with an unraveled comb and a counting helium-neon laser simultaneously, showing an agreement of tens of nanometers. This new technique can be considered as a combination of multiwavelength interferometry with thousands of continuous wave (cw) lasers and spectral (dispersive) interferometry. It overcomes the limitations of the individual techniques, combining an interferometric scheme with a large range of non-ambiguity. This allows for non-incremental absolute measurement of an arbitrary distance with a single frequency comb laser. We have demonstrated the measurement principle on a short distance of about 15 cm and compared the measured distance to conventional incremental interferometry. An agreement within $\lambda/30$

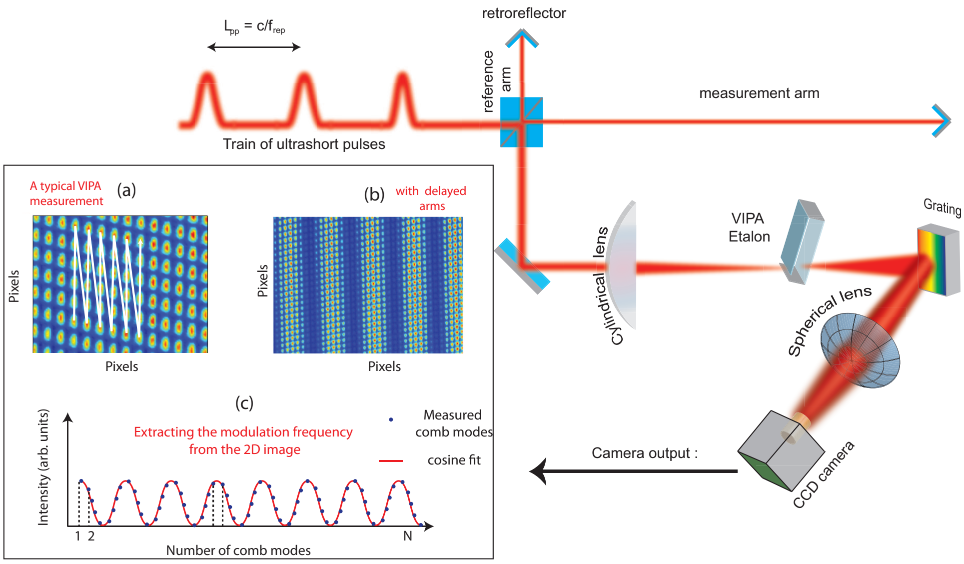

Figure 1.: *Schematic overview of the setup for unraveling the output of a Michelson interferometer into distinct modes. In the inset (a) a small fraction of a typical CCD image is shown, as obtained with the measurement path blocked. Inset (B) shows a part of the CCD image when interference between the two arms occurs. The mode-resolved signal is mapped on a frequency axis by stitching together vertical lines, as schematically indicated by the white arrows (in reality one vertical line consists of about 50 dots). The results is shown in (c).*

is found. It is anticipated that the measurement principle can be extended over much longer measurement ranges and that simplified detection schemes can be developed. A more extensive paper on this work can be found in van den Berg et al. (2012).

References

S.A. van den Berg, G.J.P. Kok, S.T. Persijn, M.G. Zeitouny and N. Bhattacharya 2012, Many-wavelength interferometry with thousands of lasers for absolute distance measurement, Phys. Rev. Lett., 108, 183901