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IMPROVING THE TRACEABILITY CHAIN IN GEODETIC LENGTH MEASUREMENTS BY THE NEW ROBUST INTERFEROMETER TeleYAG

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ABSTRACT
A novel primary standard for the calibration of geodetic baselines, the "TeleYAG" interferometer is being developed in the European Joint Project EMRP SIB60 "Metrology for long distance surveying". The optical distance measurement is realized as an absolute measuring heterodyne interferometer with a targeted measuring range of 1 km and an accuracy of 0.1 mm or better. To achieve such a measurement uncertainty outdoor, the index of refraction must be determined with an uncertainty of 0.1 ppm. Hence, the interferometer has to compensate for the influence of the index refraction in-situ by implementation of the dispersion-based two-color measurement method. In addition, particular focus was on the mechanical stability of the measurement head. The measurement principle, the device design, and first indoor verification results with this interferometer at the 50 m interference comparator of the PTB will be presented in this paper.
Keywords: traceability, refractive index compensation, multi-wavelength interferometry, surveying, geodesy

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1. INTRODUCTION
Comparability of measurement data, as well as the knowledge of their uncertainty, are mandatory requirements for the understanding of trends and risks in geodetic monitoring where often changes of a few millimeters per year or even less are of most critical importance, e.g. at future nuclear waste repositories or when monitoring tectonic movements. Traceability to the SI definition with low uncertainty is a prerequisite therefore, requiring traceable standards with lowest uncertainties. As part of the European joint research project (JRP) "Metrology for long distance surveying" an absolutely measuring heterodyne interferometer (TeleYAG) was developed for a measuring range of 1 kilometer in air with a target accuracy of 0.1 mm. This device is intended as primary standard for the calibration of geodetic baselines in order to improve the traceability chain in geodetic length metrology. The refractive index of air is one of the most dominant uncertainty contributions for the optical length measurement under these conditions. In the TeleYAG EDM, the refractive index is compensated *in-situ* by the two-color method which is based on the knowledge of dispersion. The basic technique was introduced by Earnshaw and Owens already in 1967, [1]. It had already been implemented in a geodetic instrument called Terrameter in the 1970s which was based on a time of flight measurement for two wavelengths in the microwave regime, [2]. In the TeleYAG EDM, optical interferometry is used, exploiting the long coherence length of modern frequency-doubled YAG lasers and making use

of modern high frequency electronics. In this paper, the measurement principle, in particular the complex light source and the interferometric head will be presented and briefly first results of indoor verification measurements presented.

2. LIGHT SOURCE FOR THE INTERFEROMETER

To achieve both long-distance measurement capability and high accuracy, several measurement scales (or "synthetic wavelengths"), ranging from millimeters to metres, must be generated. Following a scheme introduced by Azouigi et al., [3]. two frequency-doubled Nd:YAG lasers are used as common optical source. The whole light source is depicted in figure 1. Fundamental scales in the visible and the infrared are generated by phase-lock of the two lasers, fixing a frequency difference of 20 GHz in the infrared (1064 nm), or 40 GHz in the visible (532nm). This leads to synthetic wavelengths of 15 and 7.5 mm. By acousto-optic modulation, additional scales or ranges of non-ambiguity are constructed, ranging up to 1.553 and 1.557 m. To interpret the measurement result correctly, a pre-value of the distance to be measured with an uncertainty of approximately 75 cm must be available, which is no problem for geodetic baselines. The phase information of the various scales is demodulated using heterodyne signal processing. For this, additional acousto-optic beam preparation is implemented. By means of polarization maintaining single mode fibers the various synthetic wavelengths are combined, infrared and visible light, separately. The various measurement frequencies are depicted in figure 2, further details can be found in reference [4].

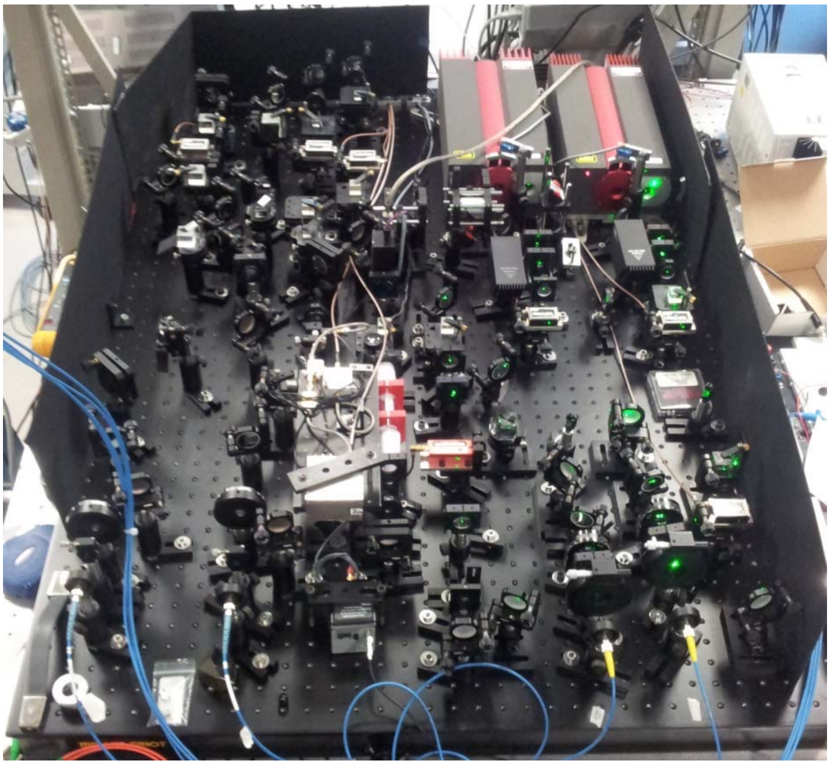

Figure 1. Light source for the interferometre

3. INTERFEROMETER

The interferometer concept for outdoor measurement was developed in the course of the SIB60 project. The main challenges regarding outdoor measurement were the development of an interferometer which is stable, compact (small dimensions) and portable at the same time. In order to achieve these requirements, Autodesk Inventor 3D CAD software was used. Finally, dimensions of 30 cm by 45 cm with a height of 12 cm were achieved allowing a relatively practical handling. A particular challenge for the miniaturization was the fact that standard optical elements designed for laboratory use were deployed. Invar steel was used as material for the base.

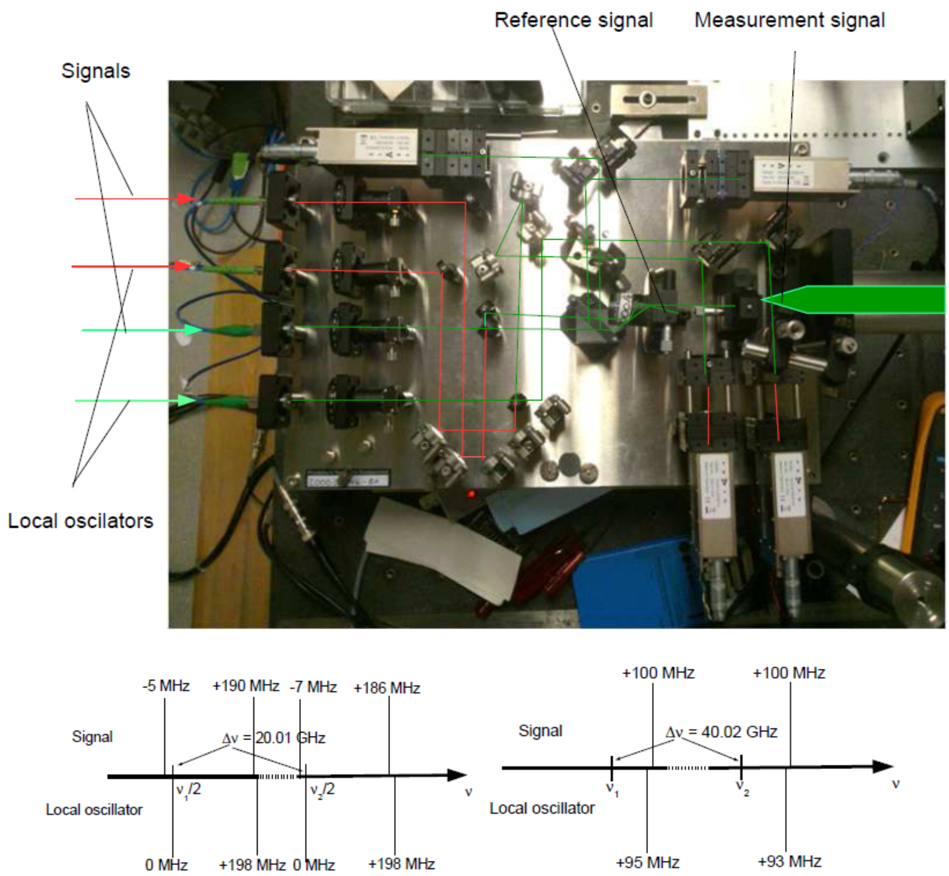

Figure 2. Interferometer with optical frequencies

For heterodyne signal processing, it is important that the polarization state of the measurement and local oscillator beams are very well defined, figure 2. In order to remove a possible elliptical component after the PM fibers, a half wave plate and polarizer at each fiber output is used. Measurement- and local oscillator beams are separated by a polarizing beam splitter. The measurement beam then passes through a Fresnel rhomb. A fraction is immediately reflected back to serve as reference signal to account for phase drifts in the device, introduced e.g. by the AOMs, or fibers, etc. The second part of the beam is expanded by a pair of achromatic lenses and traverses the measurement path. In order to reduce influences from thermal expansions resulting from the mounting base, the set-up is kept geometrically as symmetrically as possible.The returning signals pass again through the Fresnel rhomb, changing the polarization state. These signals are then coupled out by the polarization beam splitter and directed to the non-polarization beam splitter cube where they interfere with the local oscillator signals.

The interfering signals are focused on the photo detectors, interference filters separating the correct wavelength. This is necessary since the heterodyne interference signals (1064 nm and 532 nm) use the same frequencies. In the final version of the interferometer head, raw photo diodes with external amplifiers will be used to avoid local heat sources in the interferometer head. The photo detectors with integrated amplifiers depicted in Figure 2 were used for the first measurement since suitable transimpedance amplifiers were not available at this time. The optical elements are fixed to the base without alignment screws. The alignment can solely be performed by the half inch mirror holders which are fixed in specific slot holes in the base, providing some translational degree of freedom.

The phase information of the six synthetic wavelengths at the two working wavelengths of the Nd:YAG, 1064 nm and 532 nm, are used to realize both, an absolute distance measurement by multi–wavelength interferometry, and the compensation of the refractive index of air by using the dispersion between two wavelengths, [5].

4. EXPERIMENTAL RESULTS

First results of a comparison with the HeNe reference interferometer at the 50 m comparator of the PTB (geodetic base) are shown in Figure 3 [5].

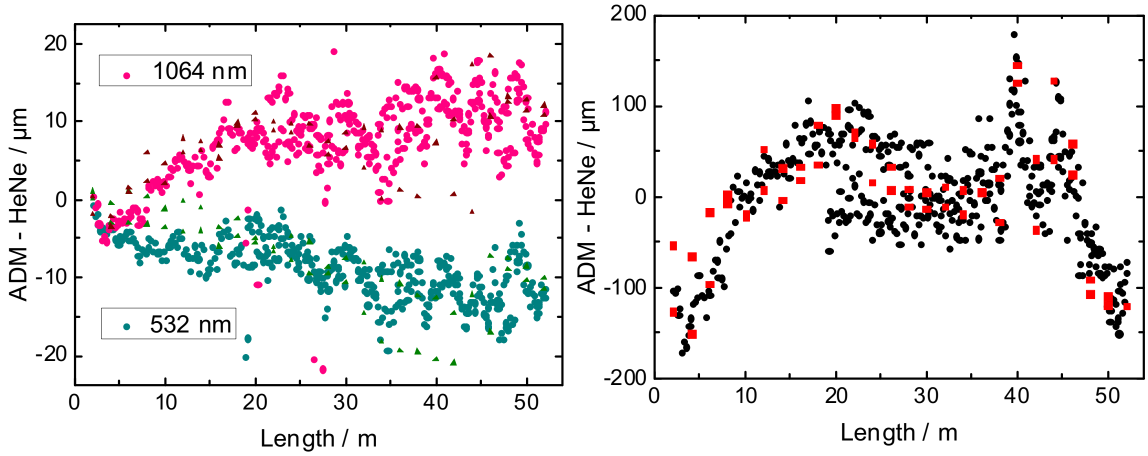

Figure 3. Comparison with HeNe reference interferometer:calculated with Edlen equation (left) and refractive index compensated result (right)

The left graph of Figure 3 shows two measurements with the results calculated using the Edlen equation. A reproducible almost linear deviation of 10 µm at 50 m could be achieved with the commercial collimators used in the set-up. It can be attributed to an imperfect collimation of the beam. The slope was hence used to calibrate the interferometer for calculating the refractive index compensated result, shown in the right part of Figure 3. The scaling of uncertainties by a factor of approx. 21 for the compensation leads to deviations up to 150 µm. In the final version of the interferometric head, an additional degree of freedom will allow an improved collimation.

5. CONCLUSION

A refractivity-compensated distance meter is being developed in an effort to improve the traceability chain in surveying [5]. It supposed to be capable of measuring distances up to 1 kilometer in air with a relative uncertainty of 10^{-7}. To achieve this, an absolute distance interferometer based on six synthetic wavelengths with in-situ dispersion-based refractivity compensation was developed. Specific emphasis was put on stability in the mechanical design. First measurements on the 50 m comparator of the PTB reveal a remaining missing degree freedom for the alignment of the independent collimation of the two colours which is currently being implemented.

6. REFERENCES

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