Synthetic wavelength interferometer for absolute distance measurements on Earth and in space

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Abstract—An absolute interferometer based on a pair of ECDL lasers generating a synthetic wave up to 40 GHz has been developed at the Italian Metrologic Research Institute (INRIM). The device has been designed to monitor reciprocal movements of large satellite parts, and has been validated in atmosphere up to 137 m distance with a resolution better than 7 nm/\sqrt{Hz} and an accuracy of tens of micrometers.

Keywords—Synthetic wavelength interferometry; geodesy; surveying; long distance metrology.

I. INTRODUCTION

Laser interferometers are the most accurate means to perform length measurements. Their use spans from standard industrial applications to the most demanding scientific experiments. Recently the use of laser interferometer has been considered for space borne applications (e.g. satellite-satellite gravimetric missions). For absolute distance measurements different techniques have been developed, such as time of flight measurement based on femtosecond laser sources or on pseudo random laser modulation, or interferometric techniques based on modulated laser sources. Here we propose a synthetic wavelength laser source made by superposing two high spectral purity diode lasers. The synthetic wavelength can be changed with continuity from zero to 40 GHz thus allowing absolute distance measurement. The system was developed for a space-borne application where the position of the antennas of a synthetic aperture radar (SAR) must be monitored to the micrometer level. In said application a maximum synthetic frequency of 20 GHz (corresponding to a synthetic wavelength of 15 mm) has been used with an accuracy limited by the electronics noise. The interest for absolute measurements on long distances is growing on Earth applications too, thus we tested our device in air to demonstrate its potentialities in ground surveying applications. In this environment the problems associated to the air turbulence (increasing phase noise) as well as the refractive index changes (affecting accuracy) must be addressed.

II. THE EXPERIMENTAL SET-UP

The Synthetic wavelength interferometer (SWI) we realized is presented in Fig 1. Two high purity external cavity diode lasers emitting at about 1542 nm are superposed in fiber generating a synthetic frequency $\nu_2 - \nu_1$ that could range from 0 to about 40 GHz. The narrow linewidth of some kilohertz allows long coherence length for long range distance measurement. The relative distance between the reference and the measurement arm is obtained by calculating in the phase difference between the two signals at the synthetic frequency. Since this synthetic frequency is too high to be conditioned and acquired by electronics, we implemented a superheterodyne detection scheme to down-convert the frequency to the kilohertz level maintaining the phase information [1]. In our case $f_2 - f_1$ is 120 kHz.

III. RESULTS

The technique was calibrated on a 26 m bench by comparing the distance measured by our SWI with the output of an incremental He-Ne laser interferometer. Later the system has been tested in a metrological 60 m long gallery in a controlled environment as well as in open air up to a 137 m distance. With synthetic wavelength of 15 mm the interferometer has a resolution of 7 nm/\sqrt{Hz} in the 300Hz-10KHz range and an Allan deviation of tens of micrometers at 10 s. An accuracy level of 20 $\mu$m in the absolute length measurement has been demonstrated over 26 m.

REFERENCES


This work was partially founded by the European Space Agency TRP Programme activity "Compact Optical Attitude Transfer System", Contract 4000105051/11/NL/CP