Compact narrow-linewidth lasers for distributed fiber optic sensors

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Highly stable narrow-linewidth single frequency lasers are widely used both in scientific research and in multiple applications such as fiber-optic communications, distributed fiber optic sensing (including coherent reflectometry [1-3]), radio over fiber technology, optical interferometry etc. In addition to the low level of phase and amplitude noises of laser radiation, most of these applications also require compactness, portability, easy and low cost production combined with various methods of phase noise reduction: laser diode coupled with an external whispering gallery modes (WGM) optical cavity [4, 5] (e.g. OE Waves lasers), a laser diode with external planar Bragg grating (BR) [6] (e.g. RIO “Orion” laser) and a single-frequency DFB fiber laser (e.g. EFL-SF-1550 laser manufactured by Inversion Fiber, LLC).

Earlier [7] linewidths and frequency drifts were measured in a variety of lasers by using the method of optical heterodyning. In this work, the previous results are supplemented with measurements made using the self-heterodyning method employing a 100 km optical delay line [8, 9], which allows measurements of white and flicker frequency noise levels [10] without a reference laser.

The experimental results incorporating measurements of frequency Allan deviation have been also confirmed by numerical analysis of the interferometer output signal based on white and flicker noises model [11] as shown in Fig.1.

The processed experimental data are summarized in Table 1. Among the tested lasers, the OE Waves laser has demonstrated the lowest phase noise, however, the use of this type of lasers is difficult in presence of strong external vibrations that can violate the mode coupling of the laser to the WGM cavity. The laser manufactured Inversion Fiber, LLC has a very narrow line (less than 100 Hz), but at the same time its flicker noise level is an order of magnitude higher than that of the WGM lasers. The RIO Orion laser has at least an order of magnitude larger linewidth (~ 2 kHz), and approximately the same flicker noise level than those of the OE Waves and Inversion-Fiber lasers. The main advantage of the RIO Orion laser is its low sensitivity to external vibrations and temperature changes [5], which makes it possible to use it in optical sensors for actual field applications. Since the frequency flicker noise in lasers is usually associated with the technical factors, the development of methods for suppressing frequency flicker noise [12–14] is an important practical problem.

In summary, this paper presents self-heterodyning measurements of phase noise levels made with a number of different compact lasers specified by low levels of phase noise and suitable for a wide range of practically important applications.

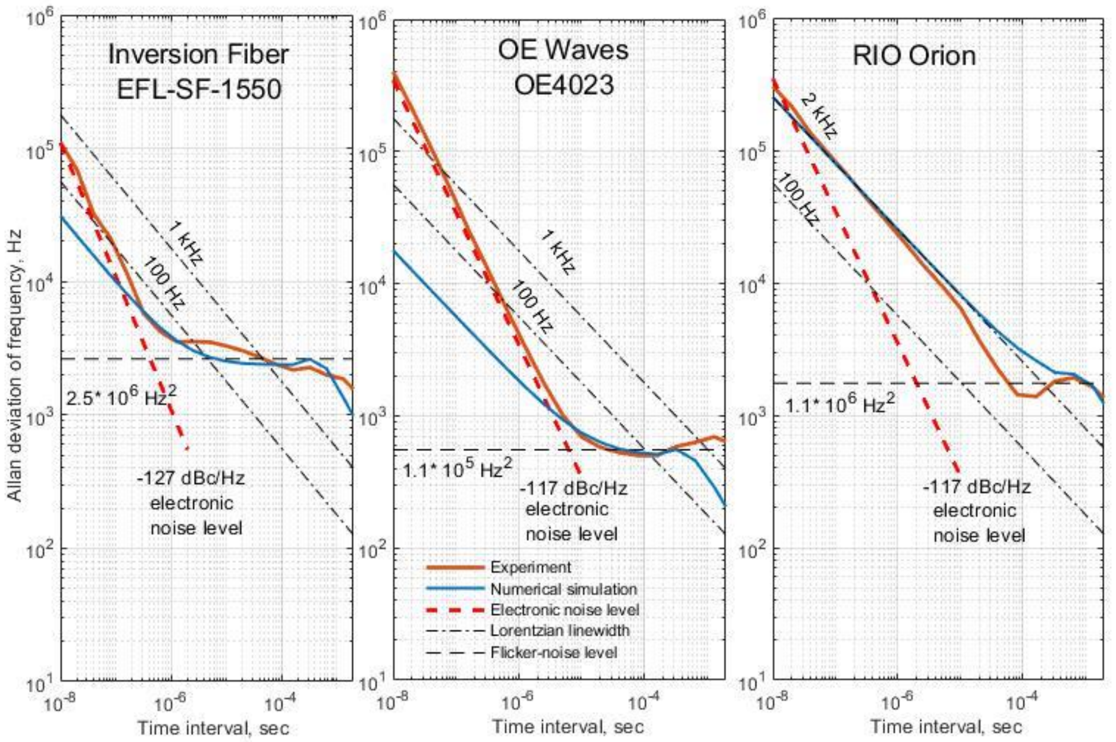

Fig.1 Experimentally measured and numerically simulated Allan deviation dependencies of the beat note frequency of tested lasers at the output of a path-mismatched Mach-Zehnder interferometer with a delay line of 100 km

Table 1. Lasers parameters measurement results

Laser	Linewidth narrowing method	Instant linewidth, kHz	Flicker-noise level, Hz^2	Frequency linear drift[7], MHz/s
OE Waves OE4023	WGM-resonator	< 0,1	$1,1\ 10^{5}$	< 1
RIO Orion	Planar BG	2	$1,1\ 10^{6}$	-
Inversion Fiber	Active fiber with inscribed BG	< 0,1	$2,5\ 10^{6}$	< 0,25

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