PHYSICS

Viewpoint on optical frequency divider with 10^{-21} precision

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A frequency divider slaves the frequency (f_{out}) of an output at an arbitrary set ratio (R_x) with respect to the frequency (f_{in}) of an input wave: $f_{out} = f_{in}/R_x$, maintaining phase coherence, frequency stability and accuracy. Despite its wide appearance in modern electronics for radio waves and microwaves, frequency division in the optical domain, which requires two lasers (input + output), remains to be fully developed. In this issue of *National Science Review*, a team led by Profs Longsheng Ma and Yanyi Jiang from East China Normal University (ECNU) reports an optical frequency divider (OFD) with unprecedented 21 digits, or about 10^{-21} precision [1]. This milestone achievement sets the stage for applying OFD to several frontiers of science and technology: from transfer of light coherence across the span of electromagnetic bands to comparison of optical clocks based on different atomic species at different frequencies. It makes possible the frequency synthesis of coherent light given an ultra-stable input or an optical clock.

Limited optical frequency division is accomplished through multi-photon processes such as wave mixing (sparsely distributed R_x). The best frequency-stabilized sources approach 10^{-17} instability, and the best optical clocks of today approach 10^{-18} instability at 10 000 s [2,3]. The noise for the ECNU OFD is three orders of magnitude lower; it allows the frequency ratio to achieve higher precision than for the frequencies of the input and output lasers.

Optical frequency comb has been employed for precision frequency measurement or comparison before. These approaches [4–6] can often be described in terms of the schematics shown in Fig. 1, whereby the beat frequencies f_{b1} and f_{b2} of the input and output lasers with their nearby $N_1{}^{th}$ and $N_2{}^{th}$ comb teeth are synchronously counted, together with the comb's repetition frequency f_{rep} and the carrier-envelope off-set frequency f_{ceo}, against a common time base, shown here as derived from a hydrogen maser. The division ratio R_x is then computed from the counting results according to the formula shown in the bottom. Even with optical clock lasers at a hypothetical high performance of 10^{-17} fractional instability over 1 s, OFD operated this way typically gives a precision of around 10^{-16} at 1 s.

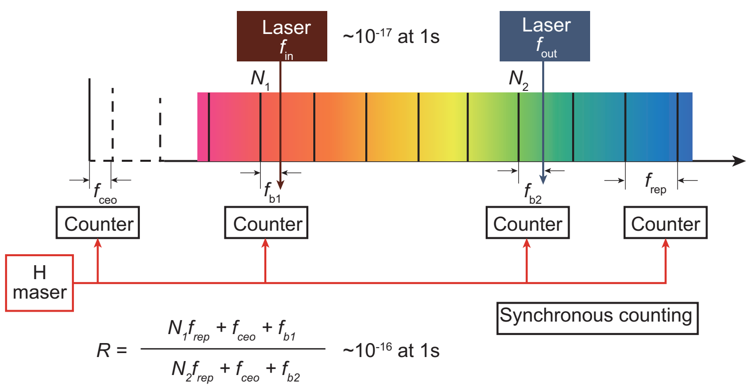

Figure 1. Optical frequency comparison making use of an optical frequency comb, whose N^{th} comb tooth is located at the frequency $N f_{rep} + f_{ceo}$.

The ECNU OFD [1] is greatly improved. Likewise it employs an optical frequency comb [4–6] to connect f_{out} and f_{in}. The stable microwave frequency standard is substituted by a RF signal synthesized in the time base of f_{in}, with which frequency division according to $f_{out} = f_{in}/R_x$ is guaranteed by a nested servo system, rather than from measurements of f_{out} and f_{in}. Any preset and arbitrary number R_x can be dialed in through three integer counters. Augmented by the use of the optically referenced comb and the careful elimination of the light-path fluctuations, record performance optical frequency division is demonstrated. The astonishing 10^{-21} precision raises encouraging prospects for adopting OFD to other precision measurement topics [4–6]. For instance, this precision limit is very suggestive, as it is of the same order of magnitude for the spatial strain of the recently detected gravitational wave [7]. Further elaboration along this direction and improvement to the ECNU OFD need to address the fundamental assumption used, that the division ratio for second harmonic generation is exactly 1/2. This same assumption has been taken for granted in the standard 1f–2f determination of f_{ceo} for a comb as well. Perhaps it is time to ask whether one can establish experimentally that harmonic generation is indeed equivalent to an OFD of $R_x = 1/2$ [8] to precisions much higher than 10^{-21}. In this special case, however, the output laser comes from the harmonic generation directly.

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