New locking schemes for a carrier-envelope offset frequency

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An optical frequency comb connects optical and microwave frequencies with two parameters, the repetition rate (frep) and the carrier-envelope offset frequency (fceo).

$$\nu_n = n \times f_{rep} + f_{ceo} \qquad \cdots\cdots\cdots \quad (1)$$

To realize an optical frequency ruler, we need to control these two parameters. In this report we propose new and simple methods to lock the fceo referring to the frep. The beat note signal of the fceo is usually observed by means of the self-referencing method[1]. Detecting an output from the f-2f interferometer, we observe the fceo signal on an RF spectrum analyzer as shown in Fig.1. Usually we choose one beat signal (for example, "fceo" signal in the upper case of Fig. 1) using a band-pass filter. The skimmed signal is mixed with a fixed reference frequency signal from a synthesizer and is used for an electrical servo for locking of the fceo. In the new scheme proposed, we use a so-called "un-convenient case", where two signals are almost overlap in the center of the "free spectral range" (the region from 0 to frep, the lower case of the Fig. 1). We set our band-pass filter at the center and adjust to let two signals to be overlapped inside the pass-band of the filter. We split this signal into two parts by a simple power splitter and combine them again by a double balanced mixer. At the IF port of the mixer, we obtain the time averaged signal ($<\ldots>_t$) as follows:

$$< \text{mixer output} >_t = \cos\left\{2\pi\left(2 f_{ceo} - f_{rep}\right)t - \phi\right\} \qquad \cdots\cdots\cdots \quad (2)$$

We put a relative phase ϕ just to ensure generality. This signal can be used to servo control the fceo referring to the frep. Since the signal is always positive, we need to add a stable bias voltage to get a direction sensitive error signal. This locking scheme ensures the fceo to be half of the frep.

We apply the method on our home-made optical frequency comb[2] and we have achieved very good performance of the phase lock of the fceo referring to the frep. At the conference we will report the experimental results in details (an Allan deviation and a phase noise characteristics) and state the features of this method as well as another scheme which leads to locking the fceo to (1/3) of the frep.

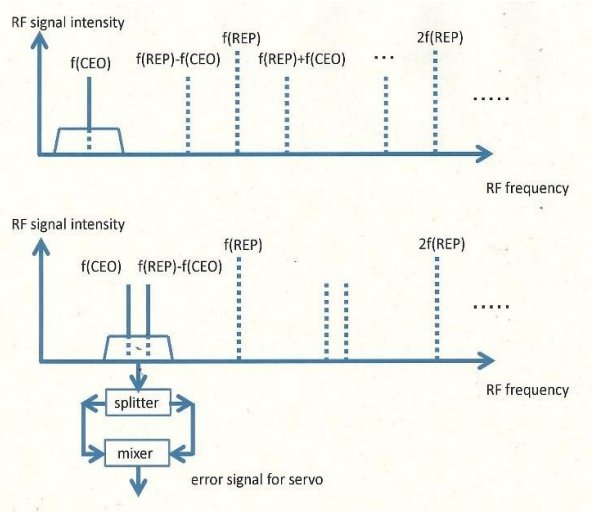

Fig. 1: Schematic explanation on the observed fceo beat signals on an RF spectrum analyzer.

[1] D. J. Jones et al., *Science* **288**, 635-639 (2000).

[2] K. Iwakuni et al., *Optics Express* **20**, 13769-13776 (2012).