Electro-optical frequency division and stable microwave synthesis

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Abstract: Optical frequency division and stable microwave generation is demonstrated using an electro-optical-based frequency comb created through phase modulation of two stable optical signals. The technique is simple, tunable and scalable to higher division ratios.

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Optical frequency division (OFD) using a frequency comb to divide a stable optical reference frequency down to microwave or radio frequency rates may revolutionize applications requiring high-stability microwaves [1]. All frequency dividers reduce the phase noise spectral density by the square of the division ratio. The new optical frequency dividers perform division by a factor of 50,000 (the ratio of optical to microwave frequencies), so that phase-noise reduction is greater than 10^9.

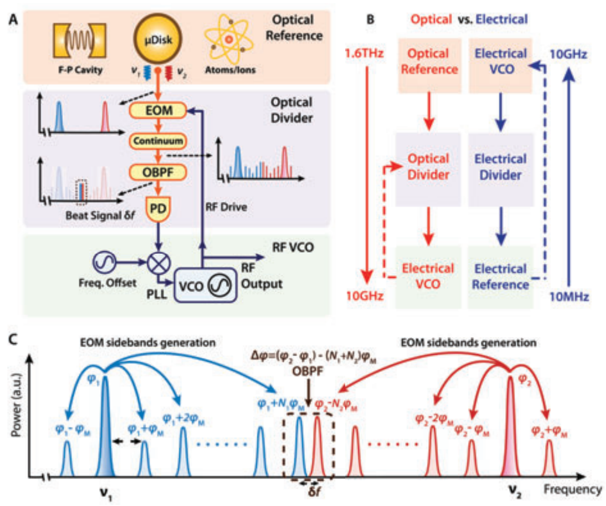

Fig. 1. Conceptual schematics of stable microwave synthesis using an electro-optical frequency comb. (A) Two optical reference laser lines are phase modulated to produce sidebands and the drive frequency is provided by the electrical VCO that is to be stabilized. Detection of the nearly overlapping sidebands gives a beatnote that is used to phase lock the VCO. (B) Comparison of conventional, electrical, phase-locked-loop control of a VCO with the present method is shown, where frequency reference and oscillator are transposed in eOFD.(C) Analysis of the relative phase of the inner sidebands in the optical spectrum.

Here, we present a novel form of OFD that directly stabilizes an electrical voltage-controlled oscillator (VCO) by transferring the relative frequency stability of two, widely separated laser signals to microwave rates using dual electro-optical frequency combs. The method called electro-optical frequency division (eOFD) sets up a feedback loop in which the VCO generates the comb line spacing and is, itself, controlled by detection of a comb-derived signal [2]. These stable laser lines are produced by Brillouin oscillation within a single, high-Q microcavity. The laser lines enter the frequency divider portion of the signal generator and are phase modulated by a pair of modulators at a frequency set by the VCO (Fig. 1A). The spectrum is further broadened by pulse forming and self phase modulation in an optical

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fiber. The comb of lines extending from each laser line results in a pair of sidebands near the mid point of the frequency span that are optically filtered and detected. The detected beat note signal contains the phase noise of the VCO, but magnified by the optical division factor. It therefore serves as a suitable error signal for phase-lock loop control of the VCO. Compared with a conventional microwave synthesizer, this approach transposes the frequency reference and oscillator (Fig. 1B). As a result, the VCO in eOFD experiences greatly improved phase noise performance. Also, in comparison to conventional OFD, the present method greatly relaxes the linearity requirements of the detection step [1].

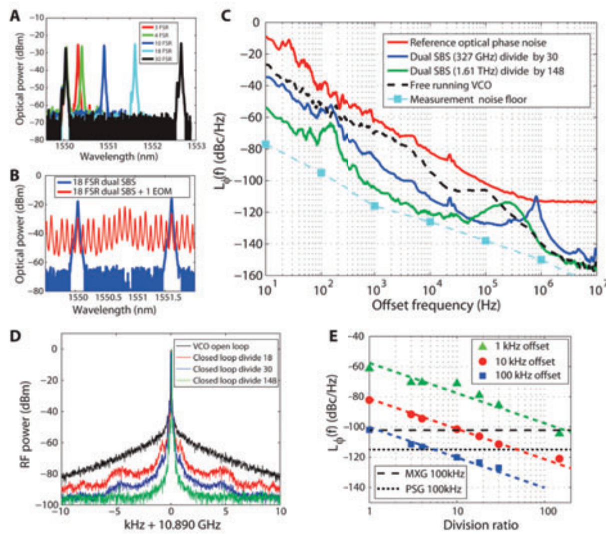

Fig. 2. Summary of experiment results. (A) Optical spectrum of dual-Brillouin lasers at several pump wavelengths. (B) Optical spectrum of Brillouin laser lines with (red) and without (blue) phase modulation. (C) and (D) show the phase noise and electrical spectrum of the VCO at several division ratios. (E) Summary of measured phase noise versus optical division ratio at several offset frequencies.

To test the optical divider, the microwave carrier frequency is held at 10.89 GHz and the frequency separation of the Brillouin laser lines (tuned by adjusting the pump lasers - Fig. 2A) is set to produce a desired division ratio. VCO phase noise spectra (20kHz span and 30Hz resolution bandwidth) and corresponding electrical spectra are presented in fig. 2C and 2D. For division by 148x, the achieved phase noise level is 104 dBc/Hz at 1 kHz and 121 dBc/Hz at 10 kHz. Figure 2E summarizes the results by giving the measured phase noise at 1 kHz, 10 kHz and 100 kHz offset frequencies plotted versus division ratios of 1, 3, 4, 10, 18, 30 and 148. The phase noise levels versus division ratio agree with the dashed $1/N^2$ trend lines. For comparison, the phase noise of an Agilent MXG microwave synthesizer [carrier 11 GHz, offset 100 kHz, Agilent online data sheet, Literature number 5989-7572EN] and a high performance Agilent PSG microwave synthesizer [carrier 11 GHz, offset 100 kHz, Agilent online data Sheet, Literature number 5989-0698EN, option UNX] are shown as black, dashed and dotted lines. As an additional feature, the output frequency can be tuned by changing the division ratio, which can be adjusted by the VCO frequency.

The optical division factor can be scaled to higher values for additional phase noise improvement. Spectrally-broadened EOM combs with more than 500 nm bandwidth have previously been demonstrated [3]. This number does not necessarily represent a fundamental limit, but nonetheless would feature a division factor of approximately 7000.

References

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