Advanced Mach-Zender fiber pulse multiplier for ultra-low noise photonic microwave generation

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Optical frequency combs, in the past decade, have rapidly transformed from a laboratory tool in metrology and university laboratories to a commercial product that fills a growing demand from both industrial and military applications. A very prominent application of frequency combs is the generation of microwave radiation with unprecedented purity, by transferring the extremely low phase noise of optical frequency references to the microwave domain by optical frequency division. This produces signals with record low close-to-carrier phase noise unmatched by conventional microwave generation technology.

The principle of low-noise microwave generation (depicted in Figure 1) with optical frequency combs is that of a frequency divider, where the phase noise of a state of the art optical cw reference is down-converted to the microwave domain with the corresponding decrease in phase noise. From a 194THz cw laser to a 10 GHz microwave signal, the ~20,000 frequency division ration leads to a theoretical ~86dB phase noise reduction. A modern high quality Fabry-Perot stabilized laser exhibits flicker frequency noise limited frequency instability at or below 1 x 10^{-15}. The corresponding optical phase noise ($S_\phi(f)$ ~-(16 + 60×log(f)) dBc/Hz, where f is the Fourier frequency) may ultimately result in a 12GHz microwave signal whose phase noise can be as low as -(102 + 20×log(f)) dBc/Hz after division. Of course, the frequency obtained with an optical frequency comb is corrupted by various sources of noise, thereby limiting the quality of the extracted microwave signal.

In practice, the frequency division process can be realized by phase locking a self-referenced optical frequency comb to an ultra-stable optical reference. The repetition rate of the femtosecond laser is servo-looped so as to maintain a constant frequency offset between the cw optical reference frequency f_{cw} and the nearest comb line with optical frequency f_{ceo} + N×f_{rep} (with N a large integer). The microwave signal is typically extracted by direct photodetection of the femtosecond laser pulse-train with a fast photodiode followed by band pass filtering of the harmonic of interest.

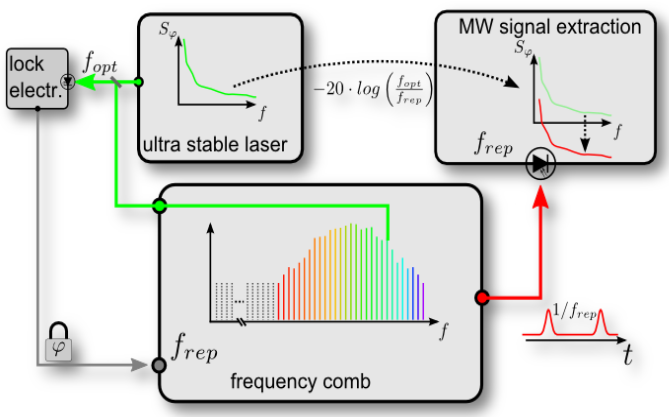

Figure 1: Operation Principle of a comb low phase noise microwave source