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Generation of ultra-low-noise microwave with a laser frequency comb for precision metrology

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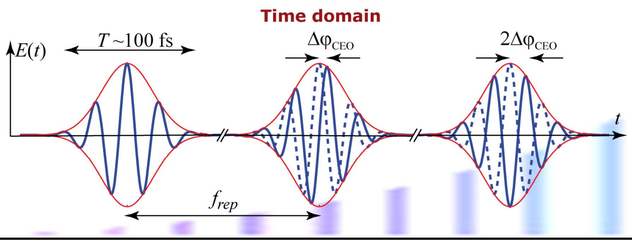
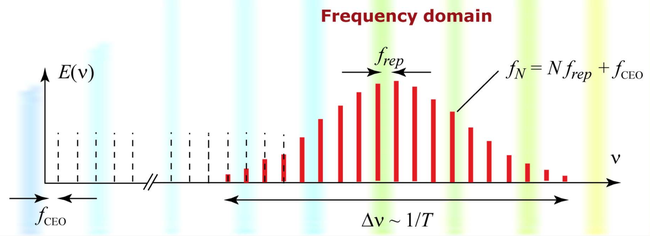
Optical frequency combs constitute a revolutionary tool in time and frequency metrology, enabling a phase-coherent link between optical and microwave frequencies to be established. Such a frequency comb based on a diode-pumped solid-state femto-second laser (called ERGO) developed in ETH Zürich is evaluated in UNINE for the generation of ultra-low noise microwave.

The Optical Frequency Comb: a revolution in time & frequency metrology

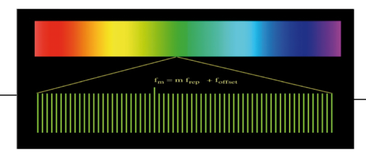
An optical frequency comb is a frequency ruler made of several hundred of thousands of equidistant optical frequencies. It enables to directly and accurately link an optical frequency (some 100 THz) to a microwave frequency (GHz).

A frequency comb is generated from an ultra-fast pulsed laser with fs-pulse duration at a highly stable repetition rate.

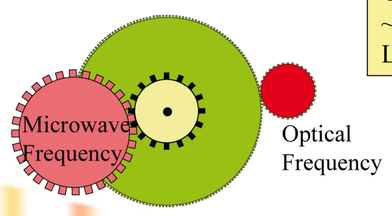




Microwave frequency
~10^{10} Hz
Microwave oscillator

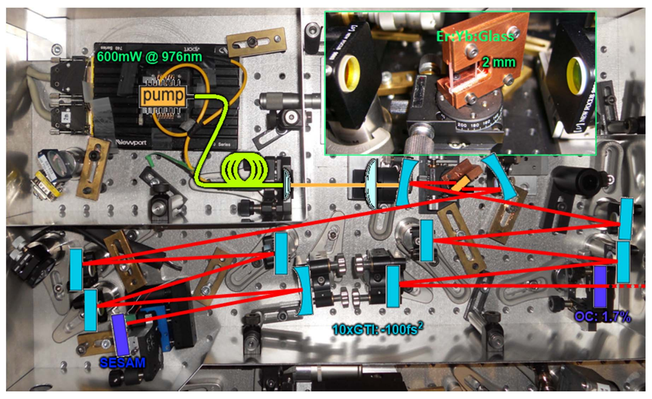


Optical frequency
~10^{15} Hz
Laser



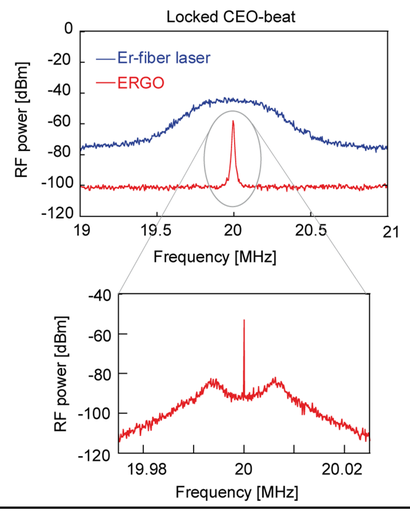
>100'000 simultaneous reference optical frequencies

Low-noise Er:Yb:glass frequency comb for frequency metrology



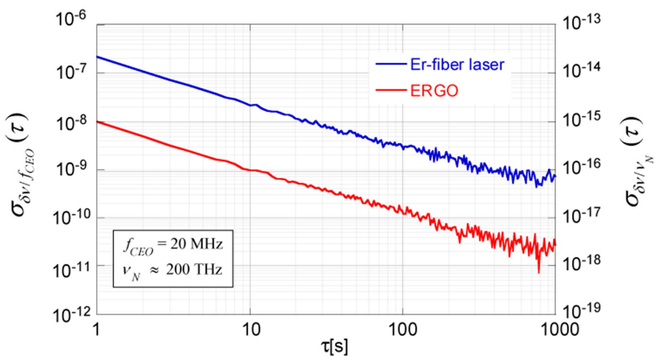
An Er:Yb:glass (ERGO) optical frequency comb developed in ETH Zurich is used in LTF in Neuchâtel for frequency metrology. The ERGO comb has shown better noise properties compared to a commercial Er-fiber comb, in particular at the carrier-envelop-offset (CEO) beat, which makes it very attractive for frequency metrology applications.

Pulse repetition rate:	75 MHz
Average output power:	110 mW
Pulse duration:	170 fs
FWHM spectral width:	14.7 nm
Center wavelength:	1560 nm



- Smallest CEO phase noise for a 1.5-μm comb
- High stability achieved for small feedback bandwidth (~5 kHz)
- < 10^{-15} contribution of the CEO to the optical carrier relative frequency instability (@ 1 s)
- **20-fold improved stability** compared **to a fiber comb** with similar feedback bandwidth

CEO fractional frequency stability

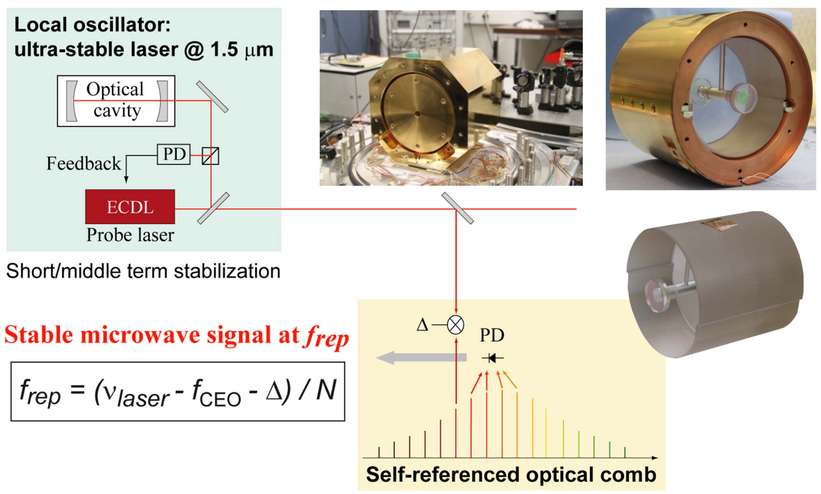


All-optical microwave generation

Low noise microwave signals are of prime importance for radar applications, timing distribution, synchronization and very-long baseline interferometry. Ultra-low noise microwave is generated for the first time from a diode-pumped solid state laser at 1.5 μm using the ERGO comb. One line of the comb is stabilized to an ultra-stable laser and a high harmonic of the comb repetition rate (around 10 GHz) is detected. The generated microwave is evaluated by comparison to the transportable cryogenic sapphire oscillator ULISS developed by Femto-ST. A strong improvement in terms of phase noise is obtained compared to a commercial Er:fiber comb.

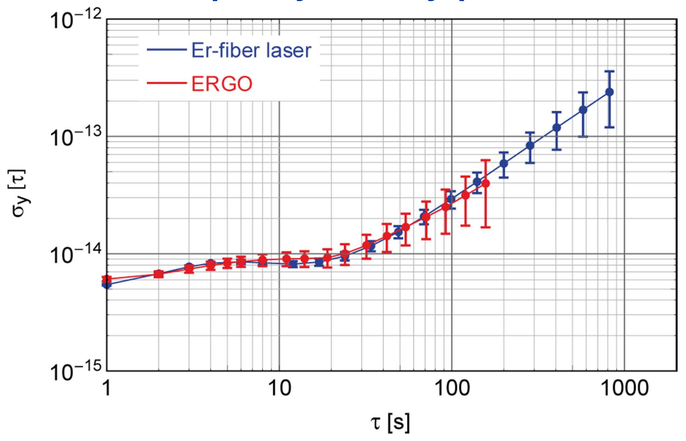
Uliss®

Scheme of ultra-stable generation from the ERGO comb



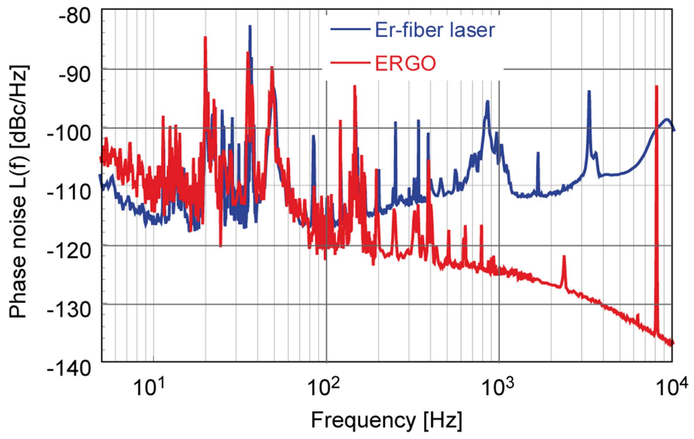
The comb acts as a **frequency divider** by *N*

Relative frequency stability (Allan deviation)



- **Relative frequency stability of 5x10^{-15} @ 1 s**
- Comparable to a commercial Er:fiber comb

Phase noise



- **Strong improvement in terms of phase noise** compared to a commercial Er:fiber comb

Other comb applications with high societal impact

- IR spectroscopy: chemical sensing, LIDAR, Earth observation (pollution and climate monitoring)
- Medicine: non-invasive diagnostics (optical coherence tomography, breath analysis)
- Telecommunications: advanced sources for high-capacity DWDM networks

Future prospects

Miniaturized combs currently under study, such as MIXSELs, are a key technology for frequency combs implementation in applications with a high societal impact.