Optical Frequency Combs

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Kick-off meeting REFIMEVE+

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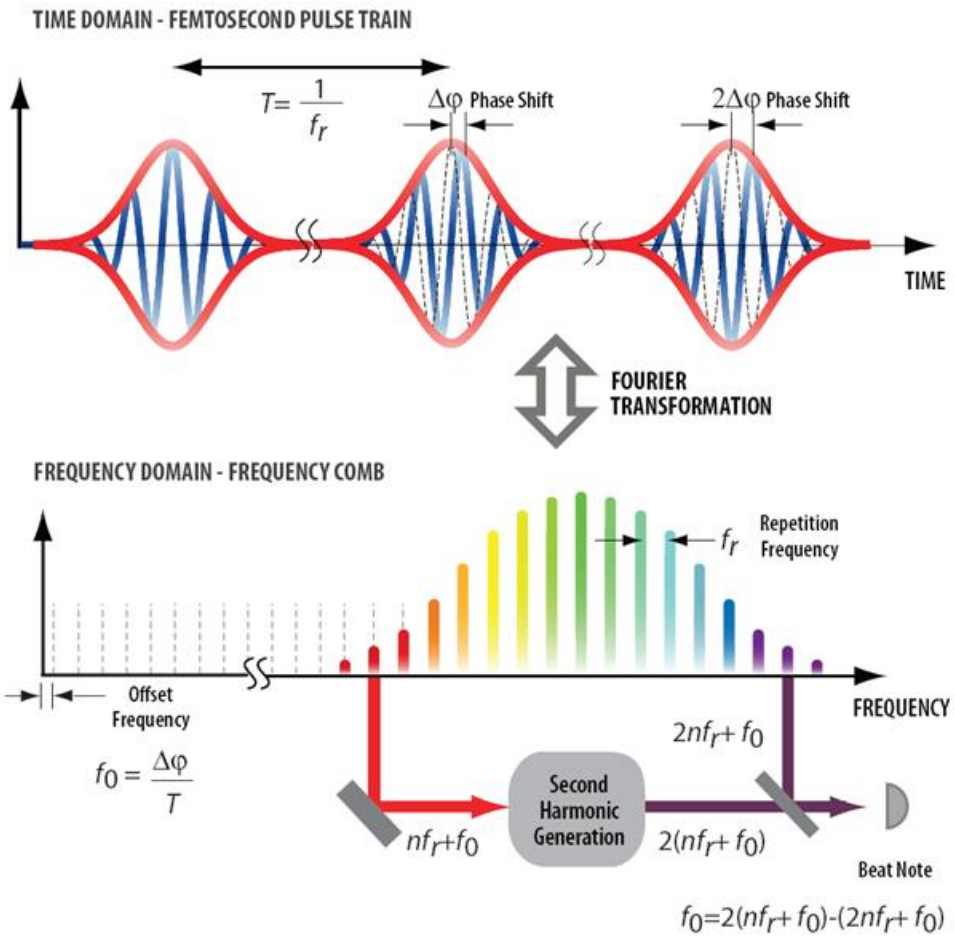
Comb Generator



Jones, et al. Science, vol. 288 (2000)

Udem et al. Nature, vol. 416 (2002)

J. Hall & T. Hänsch Nobel Prize 2005

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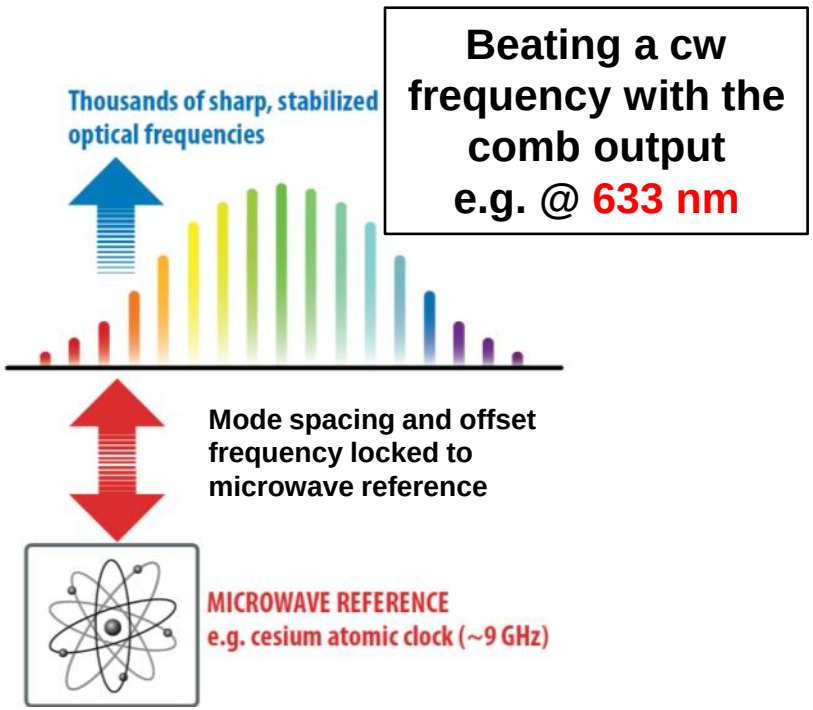
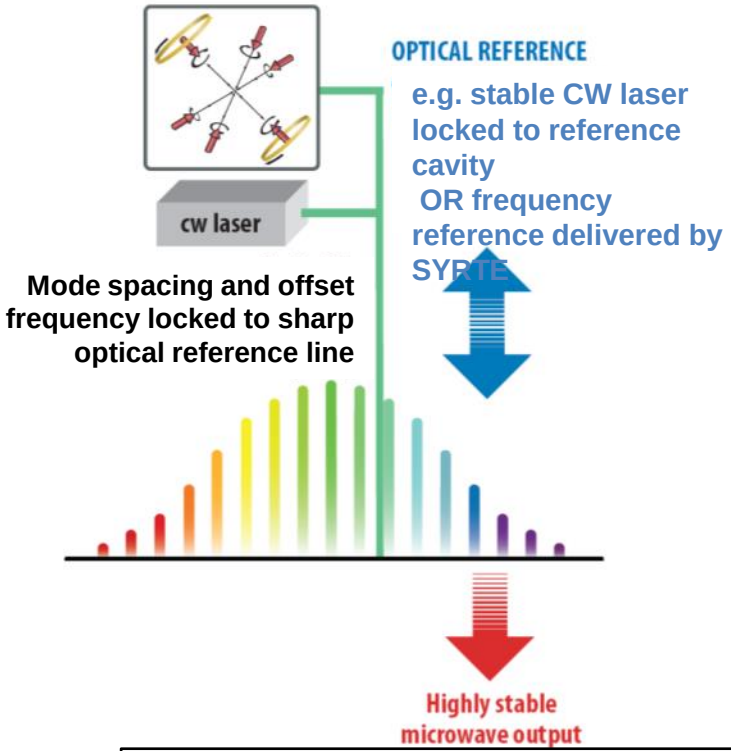
Two Modes of Operation

- Direct link between the microwave and the optical frequency domain
- Link can be used in both directions



Beating a cw frequency with the comb output e.g. @ 633 nm



Fast photodiode: e.g. 40th harmonics of 250 MHz @ 10 GHz

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FC1500-250-WG Optical Frequency Synthesizer

Stabilized comb spectrum: 25 nm bandwidth at 1560 nm
250 MHz mode spacing
Accuracy: 10^{-14}
Stability: $5 \cdot 10^{-13}$ in 1 sec.

Fully fiber-coupled optics for
offset beat generation /detection

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BDU-FF Fully-fiber-coupled Beat Detection Unit

- Efficient and robust
- Fixed wavelength
- Interface between comb and optical reference signal at 1542 nm

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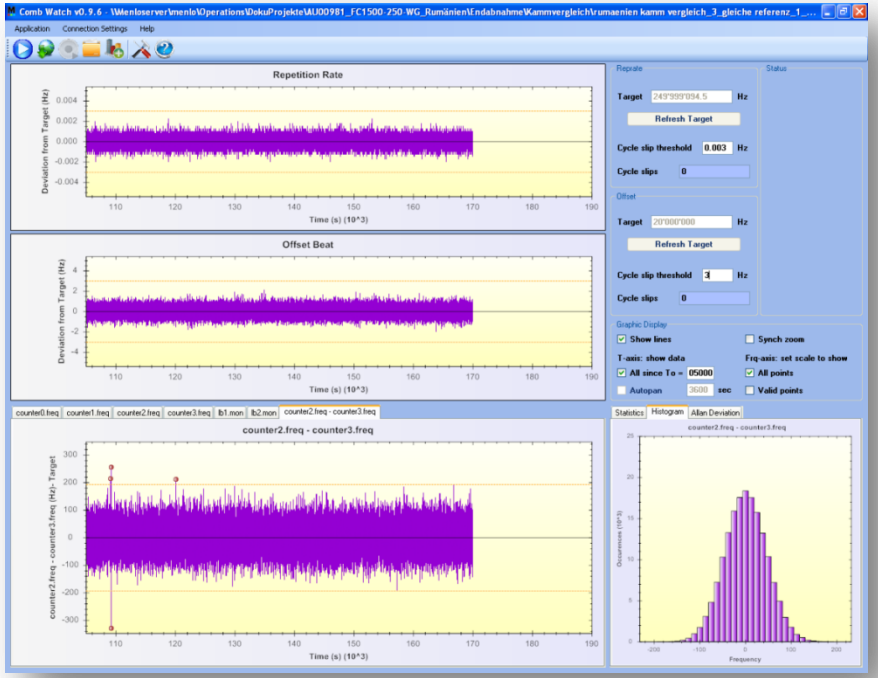
Full Automation and Metrology Software

- comb control and remote monitoring
- continuously calculating relevant statistical parameters, data histograms, and Allan deviation plots
- graphical analysis
- data export in ASCII



Special metrology features

offset beat control :

- motorized wedges (slow)
- pump currents (fast)

repetition rate control:

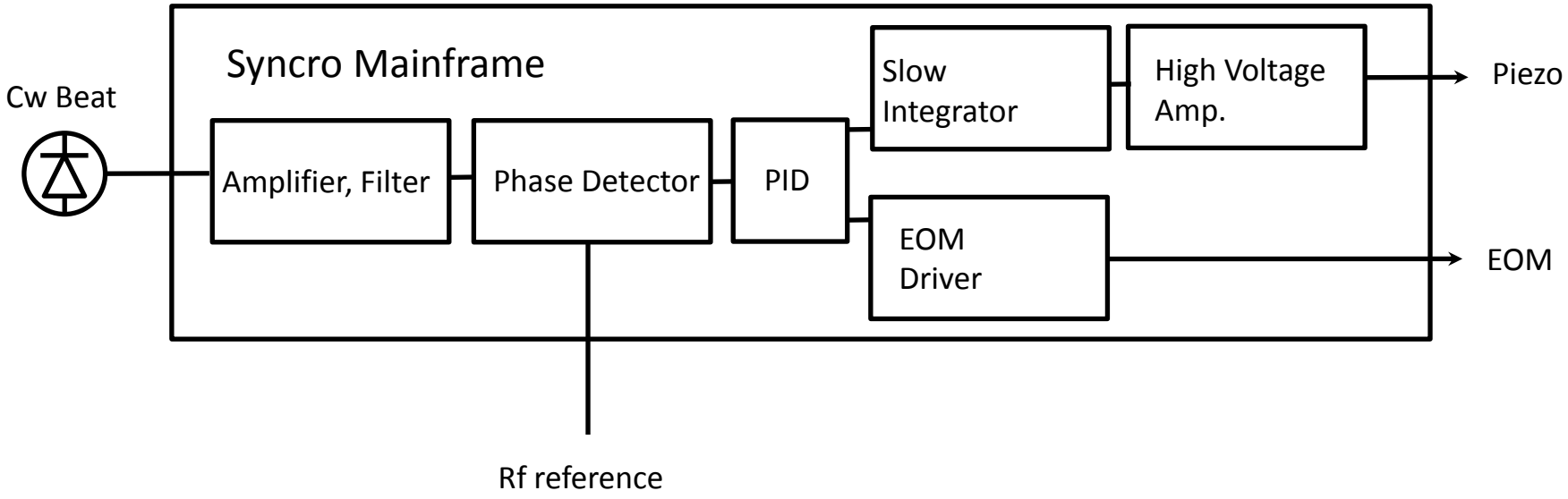
- motorized translation stage (slow)
- piezo actuator (fast for RF referencing ~10 kHz)
- EOM for high bandwidth modulation (fast for optical referencing >200 kHz)

PM output from oscillator

Optical Lock of Comb Repetition Rate

Lock of Comb Teeth to narrow CW laser

Slow integrator: to piezo
High bandwidth: to EOM



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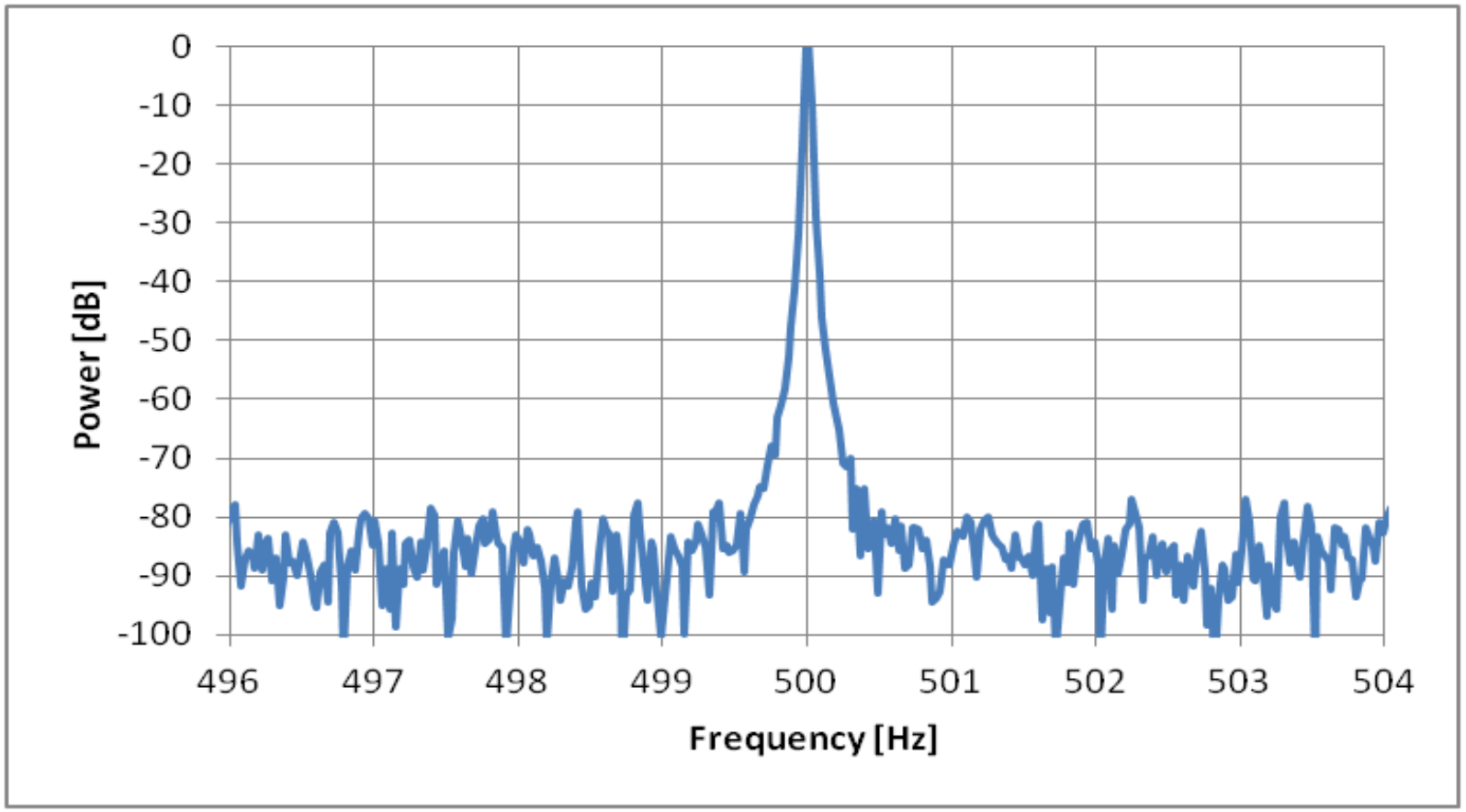
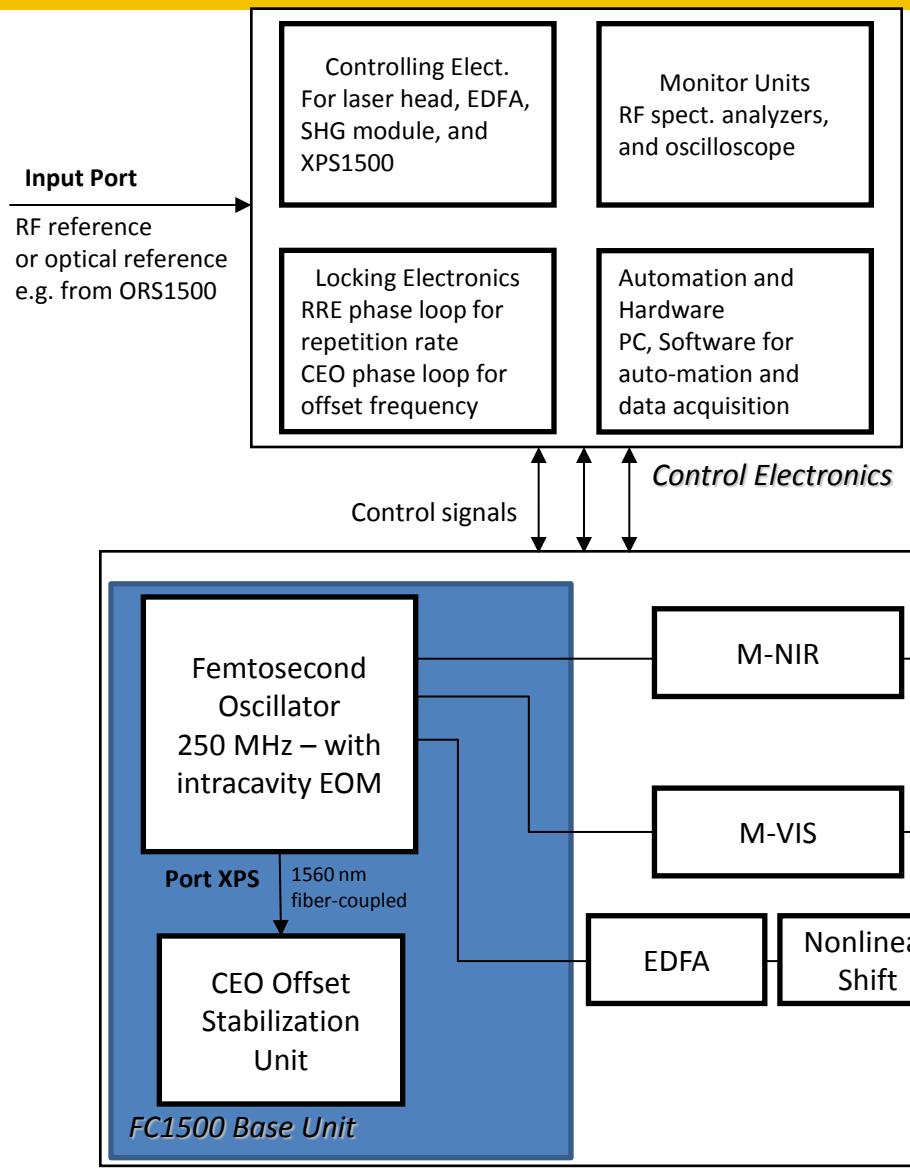
Locked Beat Note: High Resolution Analysis



High resolution measurement via FFT analysis (RBW 25 mHz), logarithmic power scale

System Layout



Sub-systems:

FC1500-250-WG Optical Frequency Synthesizer / base unit
Complete metrology system with EOM-Phase option in the oscillator

Extension units:
P250 PM PULSE-EDFA amplifier seeding HMP1060 high power measurement port

Optical output at 1560 nm and 1060 nm.

fiber-coupled output ports
LC/APC connector
1560 nm +/-20 nm, >25 nm
Not dispersion compensated
Prepared to seed additional EDFA

Allow for additional extension units

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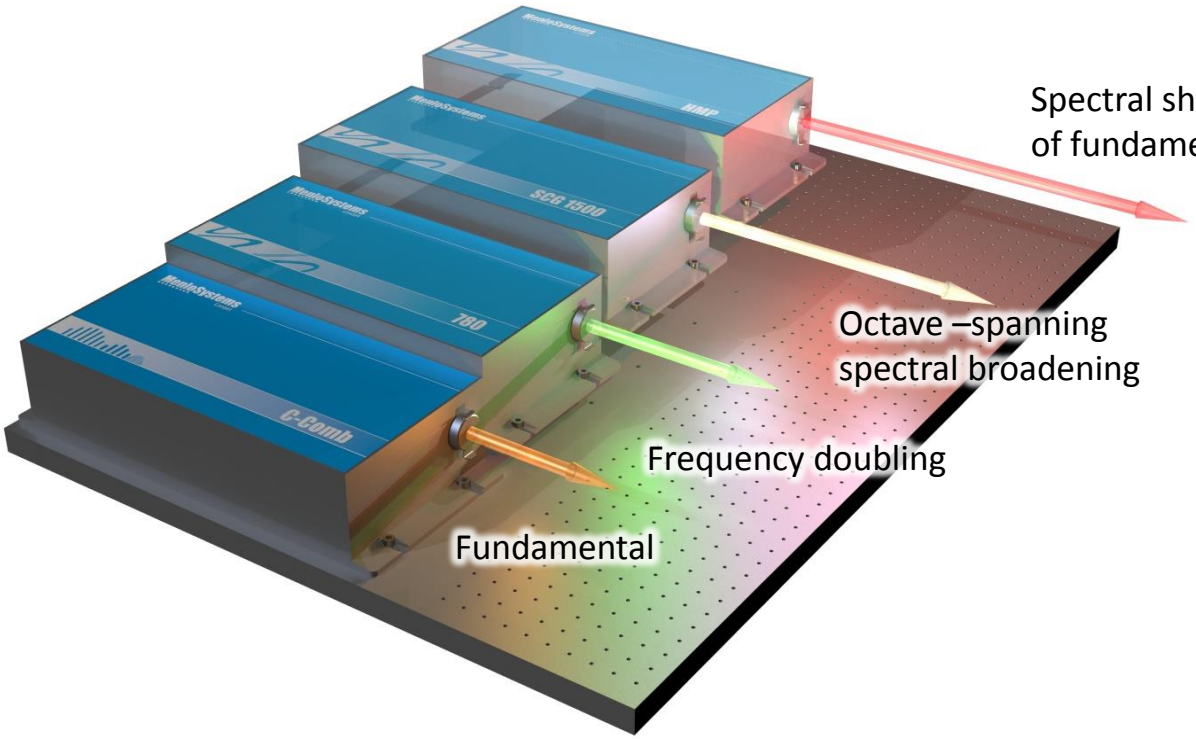
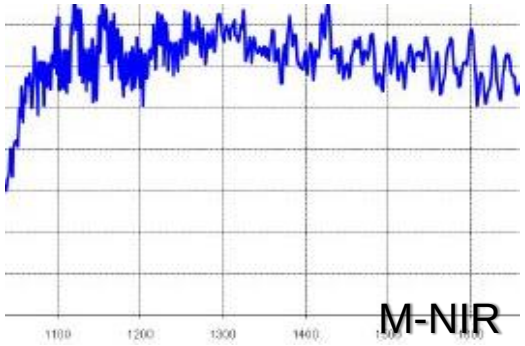
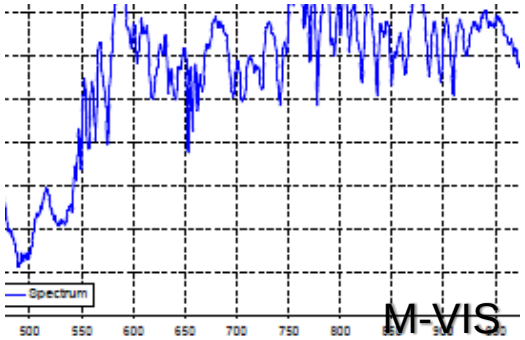
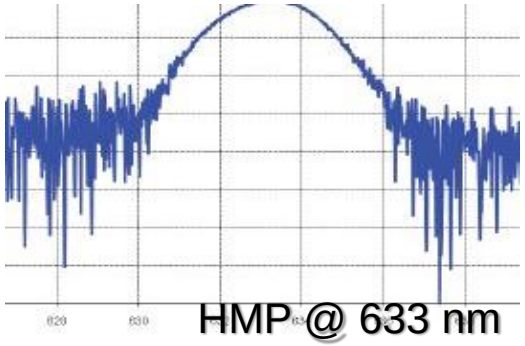
Extension Units – Spectral Extensions 1.

Generate stabilized comb light from fundamental at 1560 nm









Extension Units – Spectral Extensions 2.

- M-NIR to the near infrared 1050-20100 nm
- M-VIS to the visible 530-900 nm

- Enough power to measure
- Offers high flexibility

- HMP high-power measurement port for user-defined wavelength

- Can measure low light levels <1 mW
- Highly stable

Extension Units – Add-ons

- BDU beat detection units

- LLE-SYNCRO locking electronics

- Interface bw. Menlo Comb & cw laser from user
- Free space or fiber-coupled

- Locks cw laser to Menlo Combs

Extension Units – Reference Sources

- GPS-10 RF Reference

- GPS disciplined stable quartz oscillator

- ORS1500 Optical Reference System

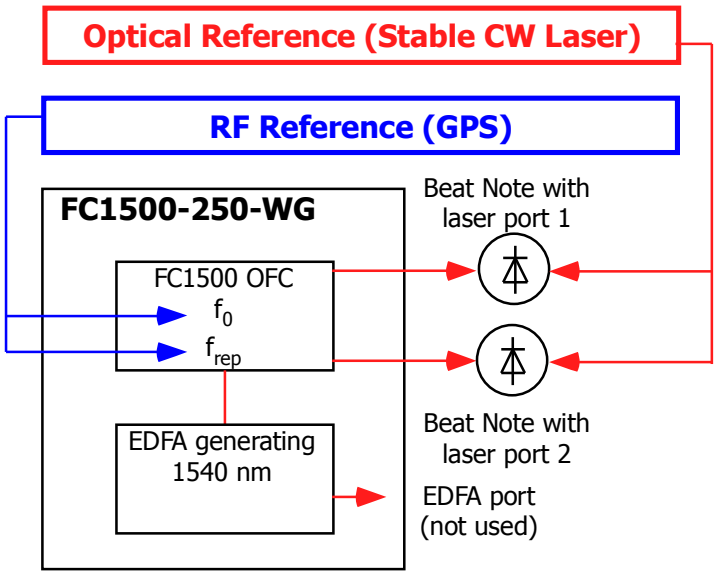
- cw laser locked to a stable high-finesse cavity

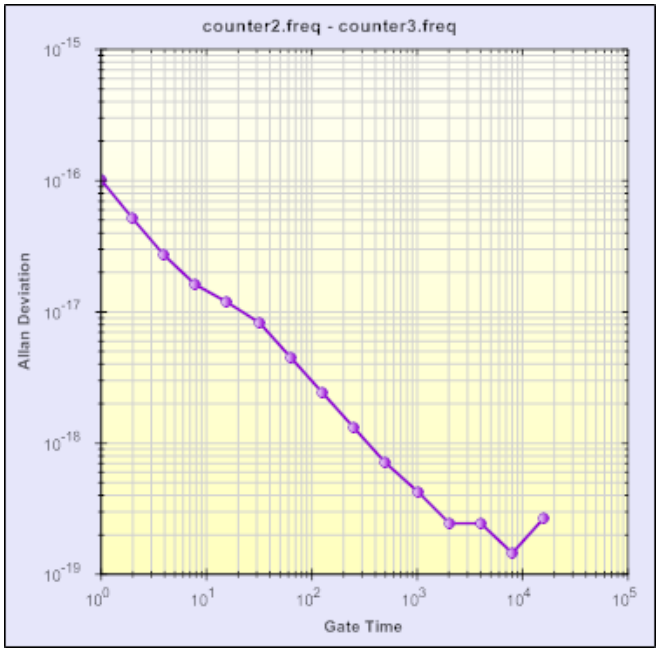
high vacuum, temperature stabilization, vibration and acoustic isolation integrated into a 19” system

Comb Accuracy

Noise floor of measurement setup:
- lock frequency comb laser in the RF domain
- beat frequency comb laser outputs against a stable cw laser
- Compare the two resulting beat notes

Result: stability better 2E-19 @ 10 000 s (measurement time: 40 000 s)

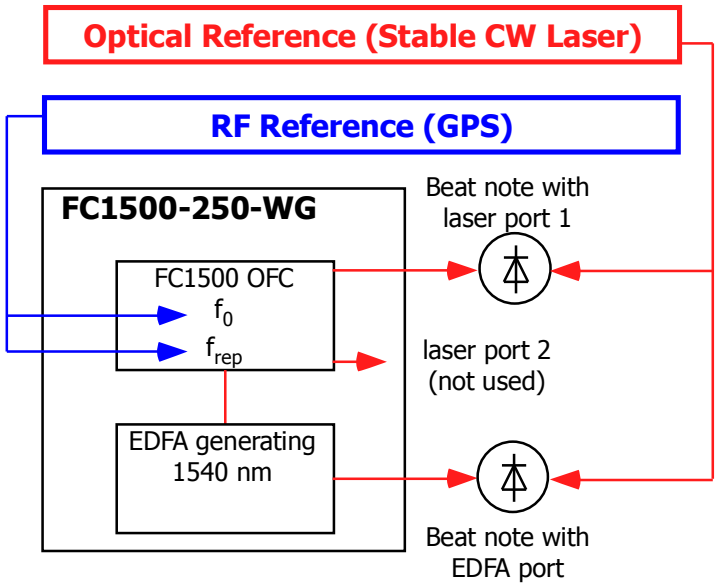


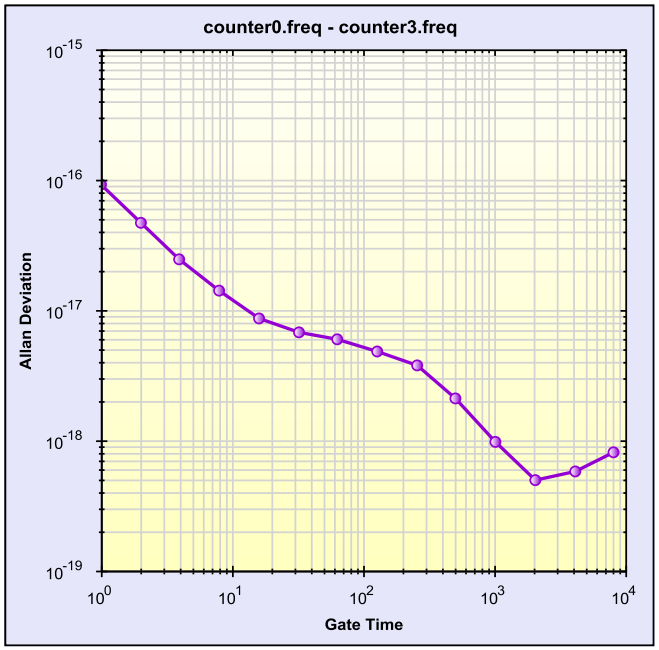


Multi Branch Comb System

Stability of different comb branches:
- lock frequency comb laser in the RF domain
- beat laser output and EDFA output against a stable cw laser
- Compare the two resulting beat notes

Result: stability <1E-18 (measurement time: >1000 s),
Excellent short-term stability: relative ADEV < 1E-16 @ 1 s.





Comparing Optically Locked Combs

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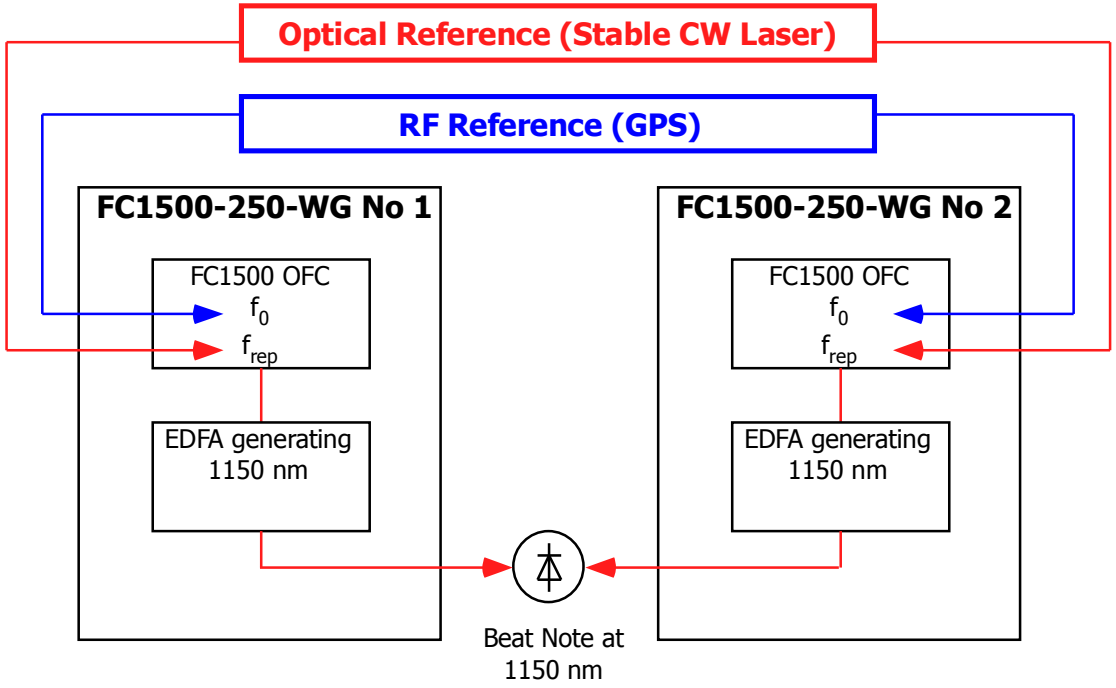
Stability and accuracy of independent combs:

- lock reprates to stable optical reference @ 1542 nm via EOM
- lock CEO frequencies in the RF domain
- beat the two independent combs, e.g. @ 1150 nm



Comparing Optically Locked Combs

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Result: Stability @ 1150 nm, divided by SQRT(2):

ADEV @ 1s: 1E-15

ADEV @ 1000s: 3E-18

Accuracy: Mean value of 1000 s subset: 3.0E-3 Hz, Std.Dev. 2.8E-1 Hz which equals a relative accuracy of

8.2E-18