Frequency Comb on a Sounding Rocket
Technology demonstration and prototype LPI test

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Frequency Combs

Frequency comb generation is based on the principle of frequency doubling or tripling of a laser frequency. The output frequency is given by:

$$\omega_{\text{opt}} = N \omega_{\text{rep}} + \omega_0$$

This paradigm shift, demonstrated by Ted Hänsch from 1978 to 1998, opened new avenues in precision spectroscopy and optical frequency metrology.
The Nobel Prize in Physics 2005

John L. Hall and Theodor W. Hänsch

„for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique“

Frequency Comb Technology gets scientific crown
Menlo Systems

- No outside financing (some BMBF money and customer prepayment)
- Privately owned
- As of today: 70 employees (1/3 with PhD)
- >150 combs installed
- Located at a Innovation Centre (IZB) in the Munich area

→ Bootstrap
What are Combs good for?

- **Time domain: Attosecond Physics**
- **Stable microwaves**
- **Direct comb Spectroscopy UV to THz**
- **Distance measurement**
- **Precision spectroscopy**
- **Optical Frequency Synthesizer**
- **Spectrograph calibration**
- **Optical Reference**
- **Clockwork for optical clocks**
- **Dissemination of time and frequency**
Combs in Space: Areas of Interest

Earth Observation:
LIDAR, Gravimetry

Navigation
clocks, time and frequency dissemination

Science Missions
Tests of Relativity, Fundamental Constants, Astronomy
The Rocky Road from Lab to Space

For
- space optical clocks
- distance measurements
- etc.

Drop tower Bremen (2011)
Zero g for 5 sec

Sounding rocket (2013)
5 min

Satellite (20XX)
years

Funded by and in cooperation with

DLR
FOKUS Project

„Faseroptischer Kamm unter Schwerelosigkeit“

Goal: Development of a frequency comb for the use in microgravity (μ-g) on a sounding rocket.

Work packages:

- Specially designed
- Mechanics
- Optics
- Electronics
- Software
- Interface

Partners:
MPQ, Menlo Systems, DLR RY

Funded by
FOKUS Laser

- NOLM (nonlinear optical loop mirror) mode locking
- All PM fiber
- Only standard telecom components
- Extremely robust and easy to handle
- Design choice: 100 MHz repetition rate

NOLM:
Phase shift depended on optical power
FOKUS Comb

Key data:
- Repetition rate: 100MHz
- Output power: 3mW
- Spectral bandwidth: 39nm
- Startup time: <10s
Radiation Induced Absorption in Rare Earth Doped Optical Fibers


Abstract—We have investigated the radiation induced absorption (RIA) of optical fibers with high active ion concentration. Comparing our results to the literature leads us to the conclusion that RIA appears to be only weakly dependent on the rare earth dopant concentration. Instead, co-dopants like Al, Ge, or P and manufacturing processes seem to play the major role for the radiation sensitivity. It is also observed that different types of irradiation cause very similar RIA at the same dose applied, with the exception at very high dose rates. It has been studied how RIA can be efficiently reduced via moderate heating. Recovery of up to 70% of the original transmission has been reached after annealing at 450 K. We conclude that radiation induced color centers have weak binding energies between 20 and 40 meV. This suggests that annealing could become a key strategy for an improved survival of rare earth doped fibers in radiative environments, opening up new possibilities for long-term missions in space.
Local Position Invariance

LPI implies that the frequencies of two atomic clocks of different internal structure should suffer identical redshifts as they move together through a changing gravitational potential.
LPI Test Experiment

- RF atomic clock (Rb hyperfine transition)
- Frequency comb
- DFB-Laser
- Optical atomic clock (Rb $5^2S$-$5^2P$ transition)

Clock comparison (LPI test)
LASUS Project

• At FBH/HUB/UHH a DFB laser + rubidium spectroscopy cell has been developed.

• Robust mechanical design based on ceramics (DFB) / zerodur (Rb)
• Integrated photodiodes for Doppler-free and Doppler-broadened signal.
• Fibercoupled output
• power: ~7mW, linewidth: ~1MHz

Funded by
LASUS

A. Kohfeldt, A. Wicht, A. Peters  FBH
V. Schkolnik, M. Krutzik  HU
H. Duncker, O. Hellmig,
P. Windpassinger, K. Sengstock  UHH
The FOKUS System

- Pressurized dome
- Electronics
- On-board PC
- Rb Spectroscopy
- Comb Optics
- Pump module
- DC/DC converter
- TEXUS Electronics / Battery

- Weight: 23kg
- Size: 30 cm (height) x 30 cm (diameter)
- Volume: 28 l
Measurement limit

![Image of measurement setup and Allan deviation graph]

The graph shows the Allan deviation $\sigma_y(\tau)$ plotted against the averaging time $\tau$ in seconds. Two reference standards are compared: SA.45s CSAC (Symmetricom) and FOKUS Rb Reference. The graph indicates the measurement limit for both standards as a function of the averaging time.
FOKUS in real life
TEXUS: DLR program since 1970’s, 50 successful flights 400kg payload, zero g for 6 min. TEXUS 50 was launched on April 12, 2013,
Scheduled on TEXUS 51

- TEXUS 51 launch in April 2013 was cancelled the day before launch (April 19th, 2013).
- Miss aligned guiding rails
- Relaunch scheduled for November 2013
The extended FOKUS team

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FOKUS before Integration into Texus 51
Rocket Engine VSB 30
TEXUS 50 inside the launcher
Launch of TExUS 50
Future Space Combs

ca. 190 x 140 x 75 mm

Follow-up project: FOKAL
• 2 dark fibers (ITU-T G.652)
  • $n \approx 1.4681$ at 1550 nm
  • $A \approx 0.23$ dB/km
  • $CD \approx 18$ ps/(nm⋅km)
  • 920 km total length
Now: 1840 km