

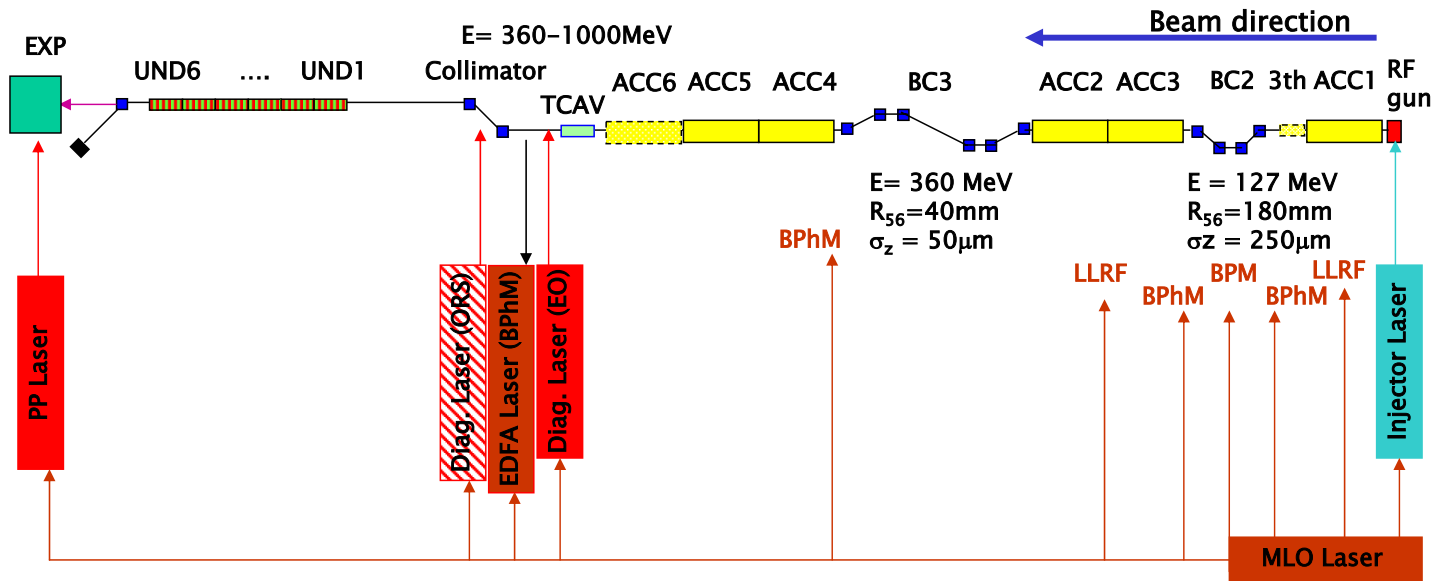
Status of the laser based synchronization system at FLASH

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J. Kim, F. X. Kaertner (MIT)**

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Overview of FLASH linac



- Laser based system is upgrade of existing RF synchronization
- Serves as prototype for XFEL

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Source of timing jitter

- Caused by RF acceleration prior BC-

Timing jitter Behind BC	Gradient	Phase	Incoming Timing jitter
↓	↓	↓	↓
$\Sigma_t^2 \approx \left(\frac{R_{56} \sigma_A}{c_0 A} \right)^2 + \left(\frac{C-1}{C} \right)^2 \left(\frac{\sigma_\phi}{c_0 k_{rf}} \right)^2 + \left(\frac{1}{C} \right)^2 \Sigma_{i,t}^2$			
	6.0 ps/%	2 ps/deg	0.05 ps/ps

C compression factor (20)

R₅₆ ~ 180 mm

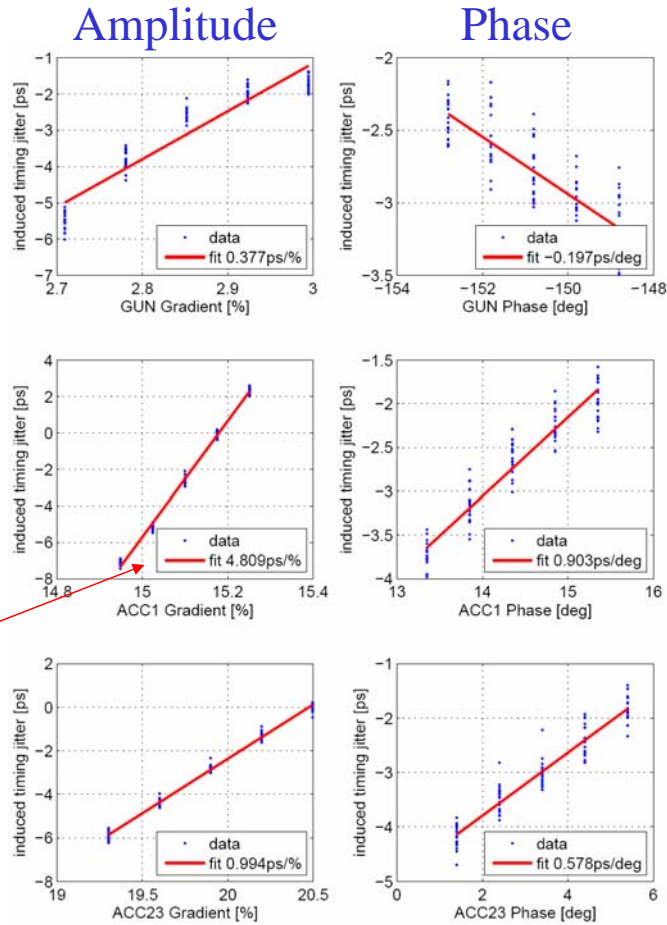
k_{rf}: wavenumber RF acceleration (27.2/m)

↑
Only if not
corrected

Vector sum regulation of 8 cavities => 1 deg == 1.8% (statistic 8 cav. helps)

But! Phase changes can be correlated due to local oscillator changes

Arrival time sensitivity measurements



Gun

Acc1

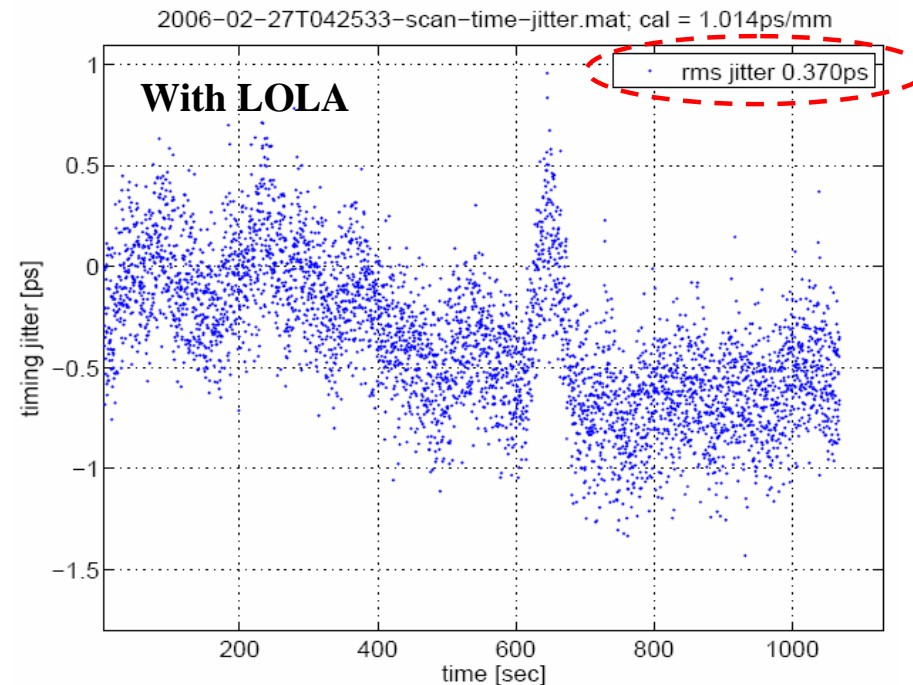
Acc23

Acc45 no effect

Most critical
at FLASH
4.8 ps/%

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Arrival time measurements



From BPM system easily sub 10fs resolution can be obtained

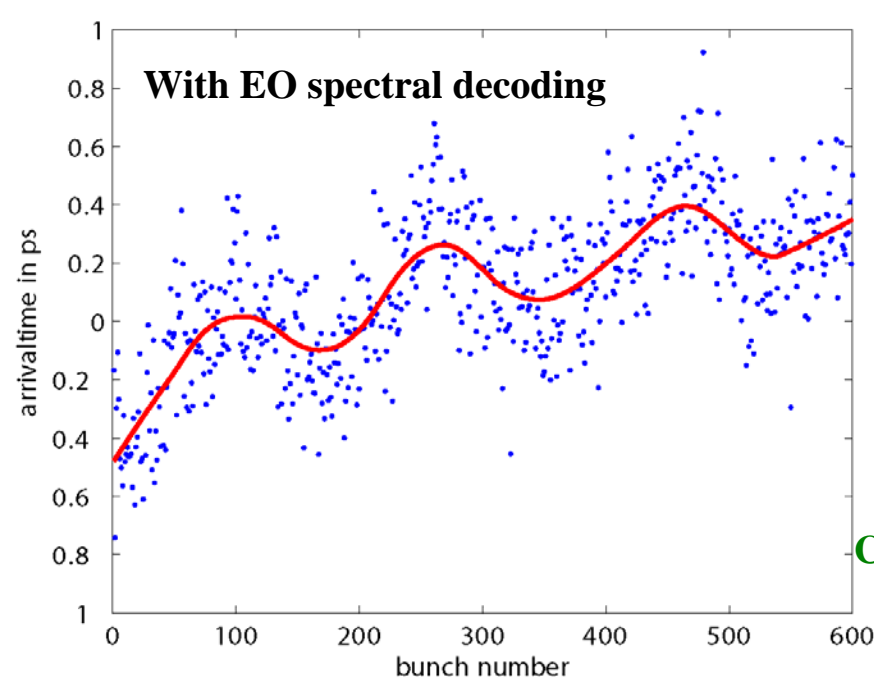
But! 1) RF cavity phase not known with sufficient precision

2) LO for phase measurement critical device!

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Arrival time measurements



Courtesy B. Steffen

TiSa laser system is much better synchronized to reference RF (<30fs)

Timing jitter 300 sec ~ 270 fs (rms)

If correlation removed ~ 200 fs (rms)

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Some conclusions:

- synchronization of the electron beam is **dominated** by **RF stability** of sections upstream of first bunch compressors (next generation LLRF controls + DCW)

⇒ **EUROFEL Project on Down-converter + connection to synchronization laser F. Ludwig**

- **beam based feedbacks** to stabilize arrival time & peak current requires to measure energy & incoming arrival time

⇒ **EUROFEL Project on compact beam phase monitor (F. Löhl & Triste)**

- fs stability requires **$\sim 10^{-6}$** amplitude and **0.0001°** phase stability

⇒ **this is hopeless !**

- lasers can be locked to reference with smaller timing jitter (< 10 fs feasible)
- remaining timing jitter need to be measured with high **accuracy** to timing reference system (e.g. for post-ordering, FB etc.)

How can we achieve better synchronization?

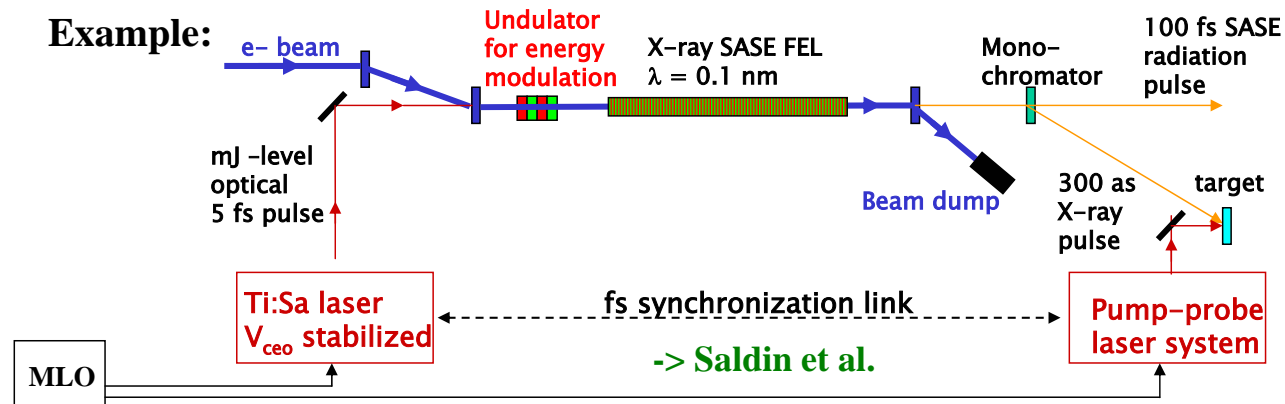
Attosecond synchronization!

- outlook & upgrade -

- always based on electron beam manipulation by lasers

Requirements:

1. Electron beam is synchronized to laser $< \sigma_t \sim 30\text{-}60\text{ fs}$
2. Manipulation laser to exp. laser on femtosecond level

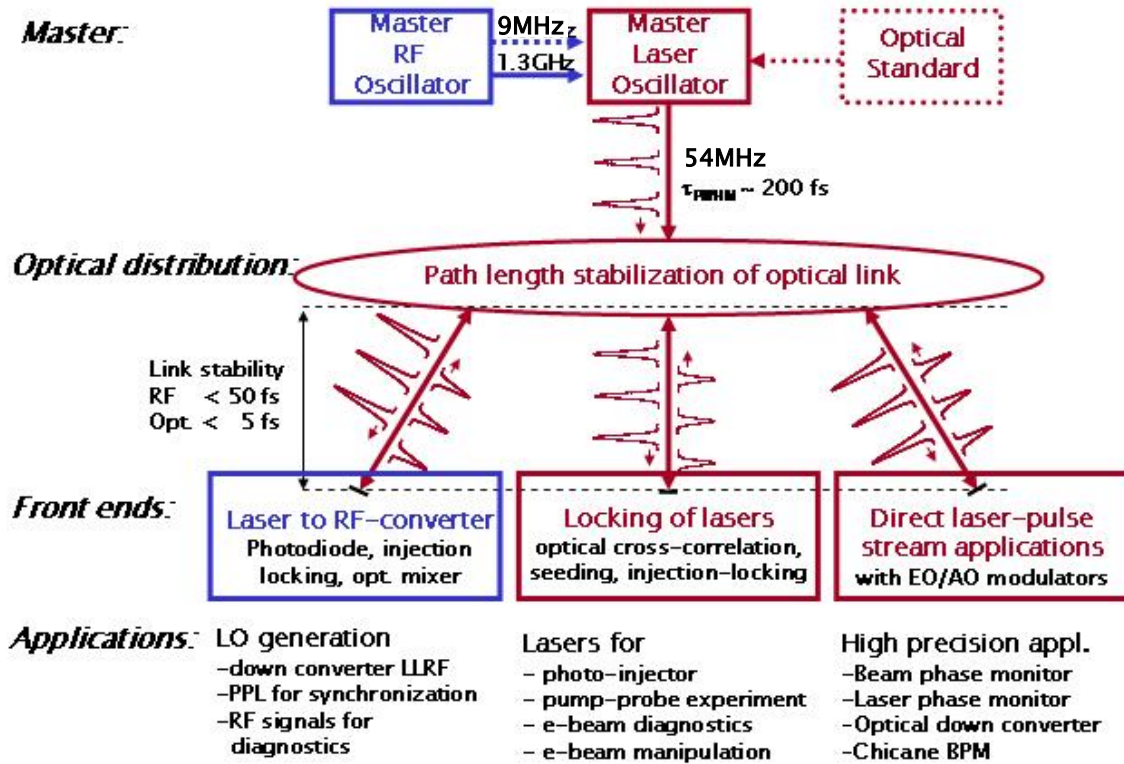


Optical clocks for lasers: synchronized to 100as level within macro pulse (1ms)
Avoids problems with **vibration and diffuse ground motion** ($< 1\text{kHz}$, $30\text{ns}=100\text{as}$)
Fiber link operates at small unity gain frequency (10Hz) for resynchronization

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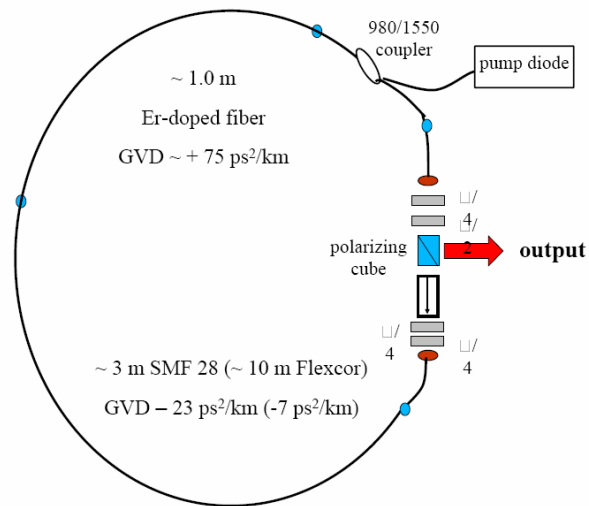
Layout of laser based synchronization



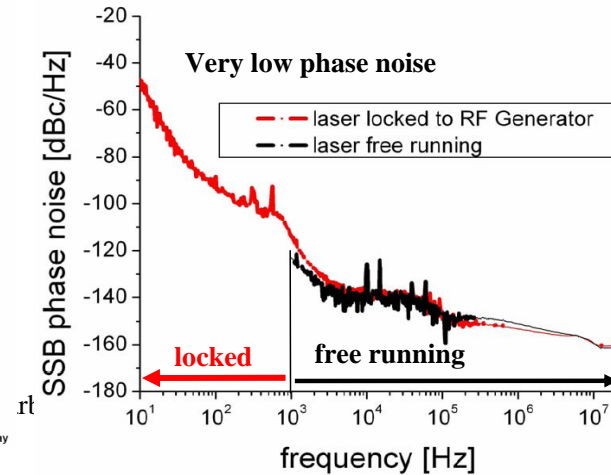
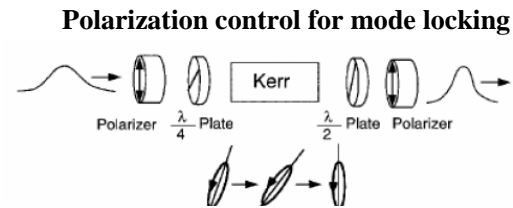
Synchronization laser

Dispersion managed soliton fiber-laser with artificial saturable absorber

- Fiber stretcher for passive mode locking to RF generator
- Gain medium Erbium, 1550 nm wavelength
- High output power up to ~ 1 nJ (50 mW average)
- Pulse duration ~ 100 fs FWHM
- Repetition rate ~ 54 MHz
- Mode lock based on artificial absorber

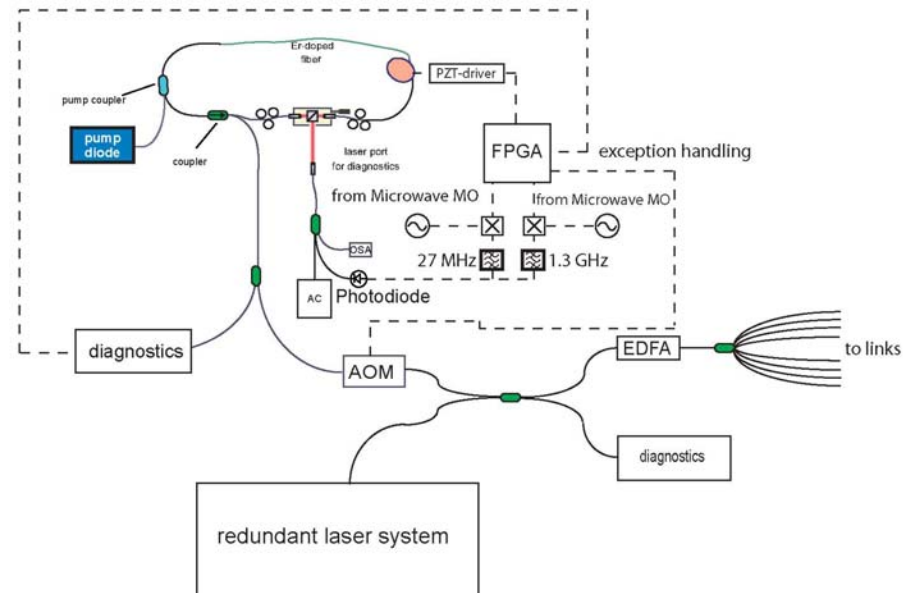


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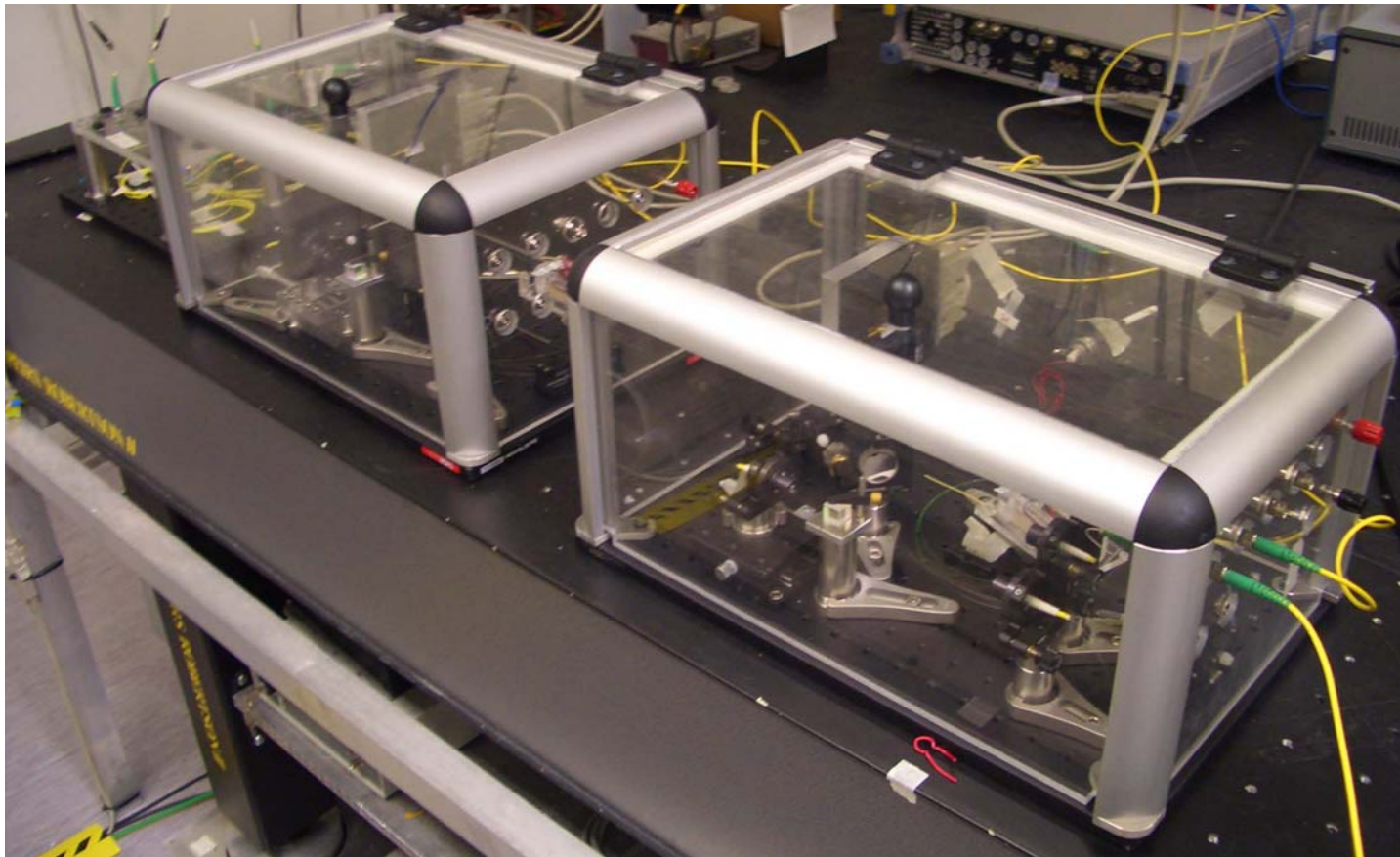
Status of Master Laser

- three fiber lasers build so-far
Experience: mode-lock usually no problem, but RF lock not stable enough
can be cured by improved piezo driver module
temperature stabilization
- concept of redundant systems (compatible outputs ????)
- PPL for phase lock test with digital controller (9/1300MHz)



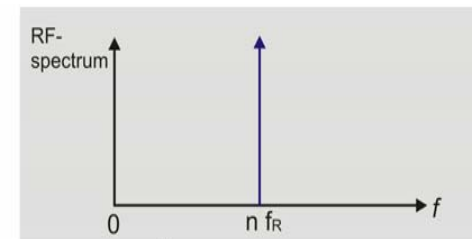
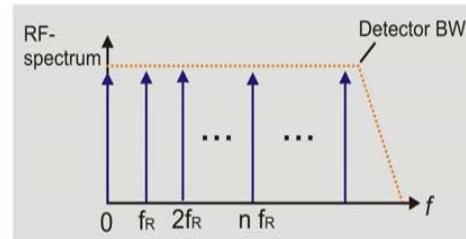
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Status of Master Laser

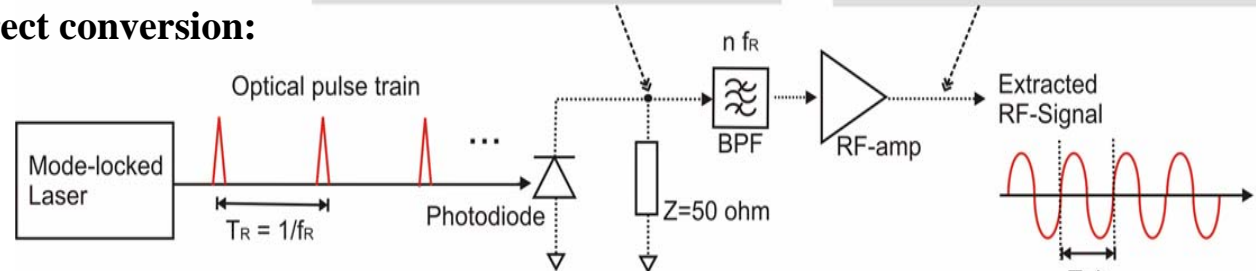


Laser to RF conversion

Mode locked laser pulse train in frequency domain

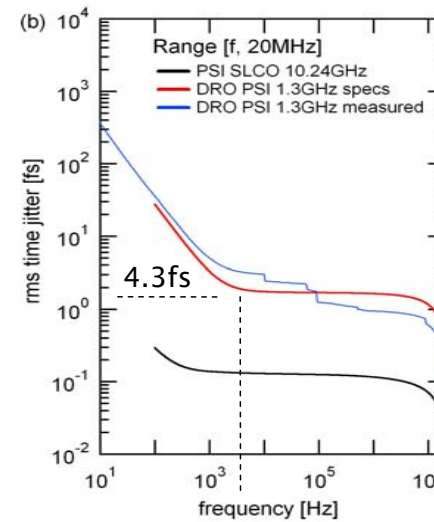
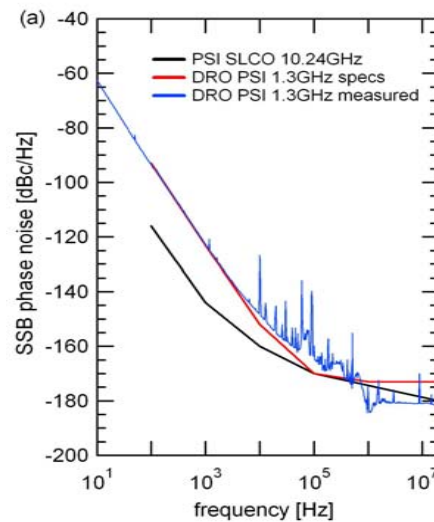
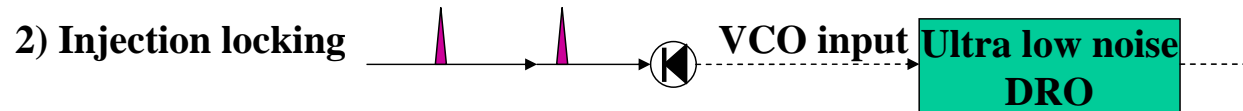


1) Direct conversion:



- **AM to PM conversion requires accurate stabilization of laser power (photo-detector 1 ps/mW @ 10mW -> dP/P < 10⁻³ for 1 fs)**
- **Drifts may critical to control since PD and Amplifier are out of loop**
- **Thermal noise limitation of PD due to limited output power (~10fs)**

Laser to RF conversion



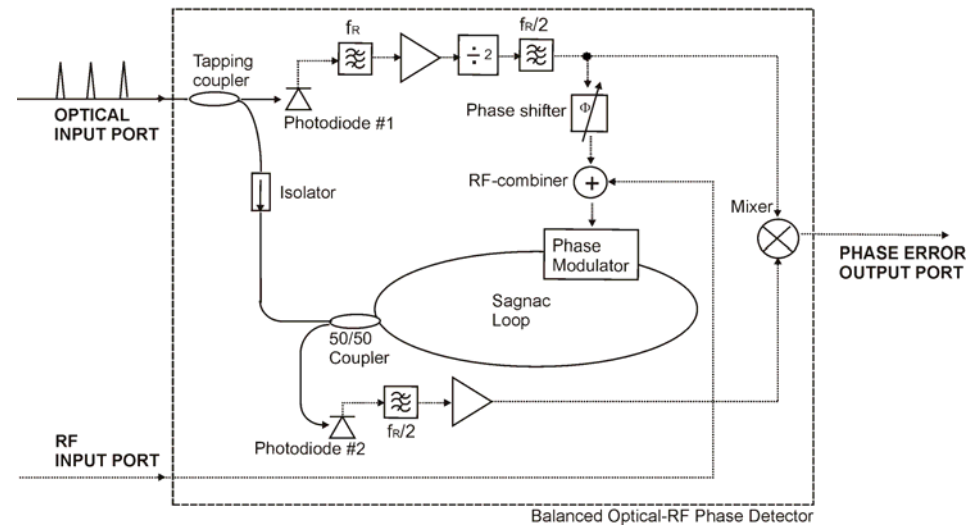
- Still rely on phase detection by photodiode (drift?, ampl. Stab. required)
- + Full PD output used
- + Thermal noise limitation at high offset frequencies given by DRO

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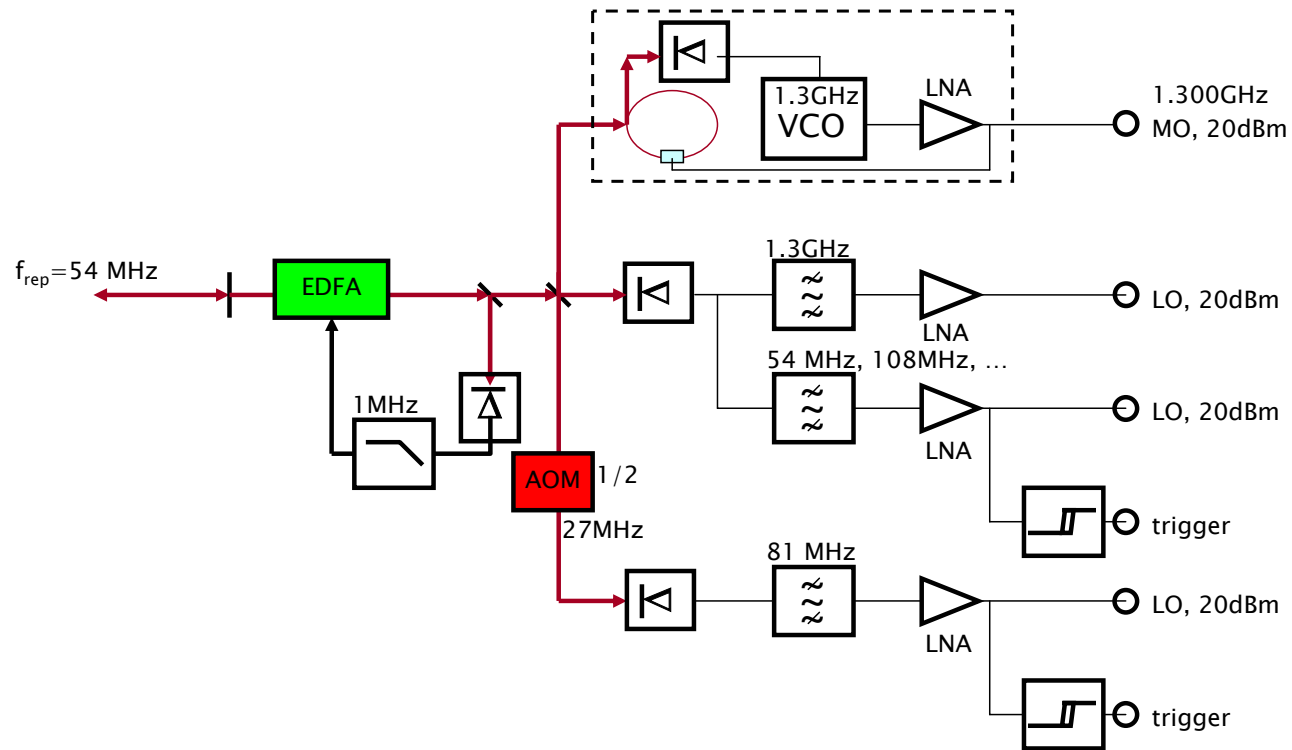
Laser to RF conversion

3) Balanced optical-RF phase detector



- + Does not rely on phase detection by photodetectors (EOM are used)
- + to first order gain and offset drifts are compensated
- More complex setup

Scheme of L2RF converters



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Front end system & near term projects

- **beam phase monitor**: proof-of-principle very successful
first problems found ... F. Löhler
- Start of **laser seeding** CPA2001 (Clark) for optical replica
- Laser link stabilization is focus for near future
 - limitation of RF detections scheme (thermal drift of PDs)
 - dispersion compensated links
 - two photo detection optical cross-correlator
 - versus bulk SHG system
 - PMD???
- EDFA + SHG for electro-optical sampling
- Optical-cross correlation based lock of laser system

End

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