Recent Developments and Layout of the Master Laser System for the VUV-FEL

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FLS Workshop

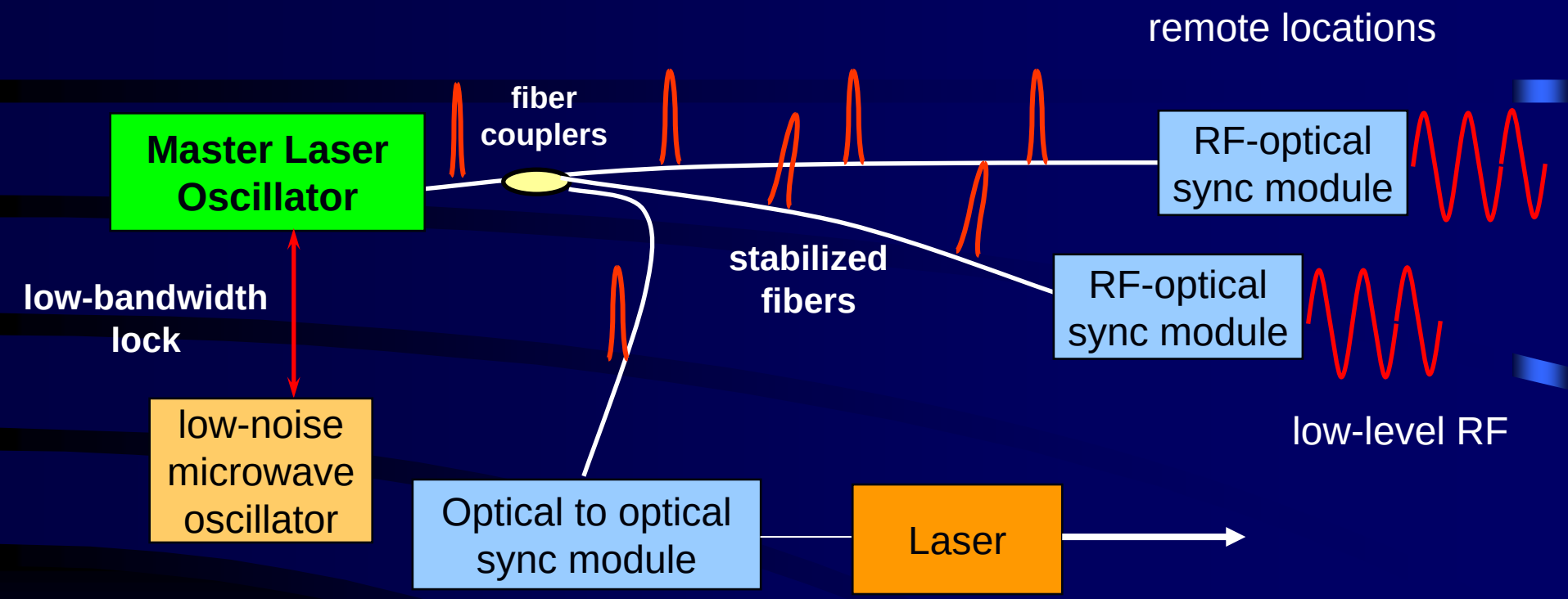
Overview

- Requirements for the Master Laser Oscillator (MLO) System
- Layout & Measurements
- Generation of non-integer multiples
- Locking external RF Oscillators to MLO
- Conclusion and Outlook

Requirements

- Generate optical pulse train to distribute in timing stabilized fiber links and use for synchronization, diagnostics and seeding of other laser systems
- Provide various frequencies with ultra-low phase noise, also at non-integer multiples of repetition rate
- Reliable system to guarantee required uptime

Synchronization System Layout



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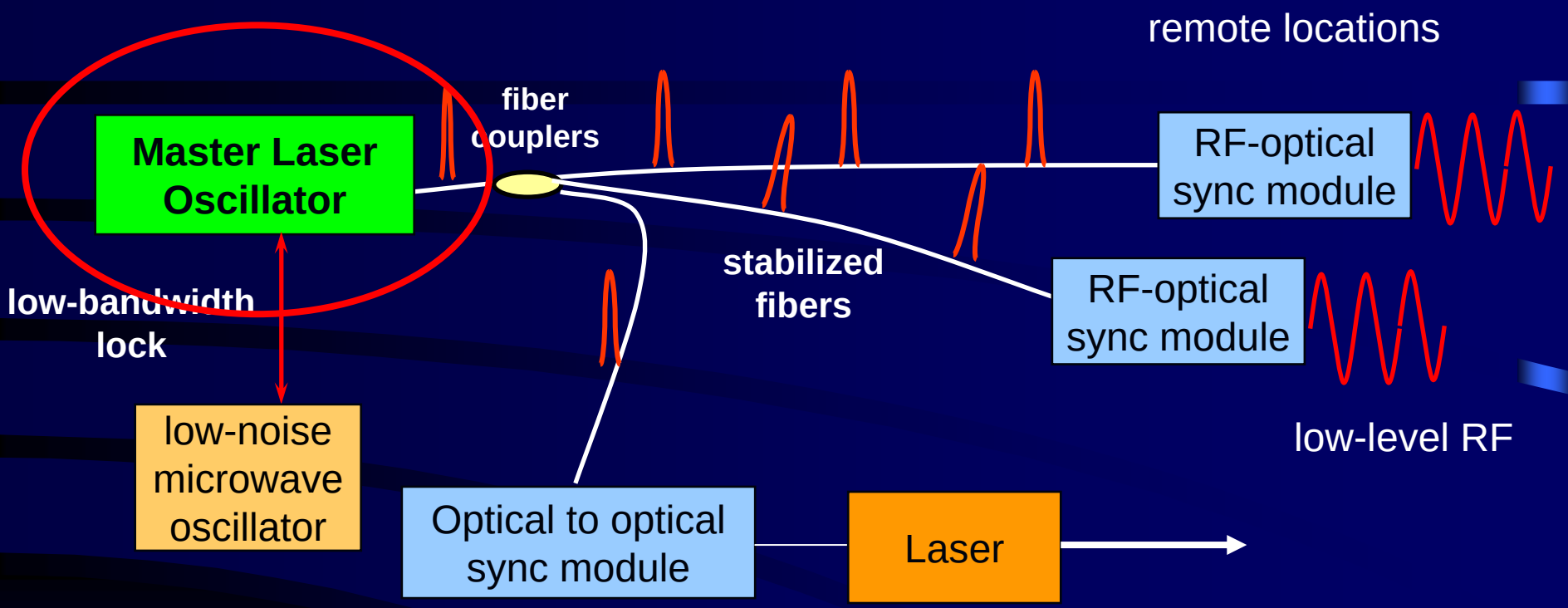
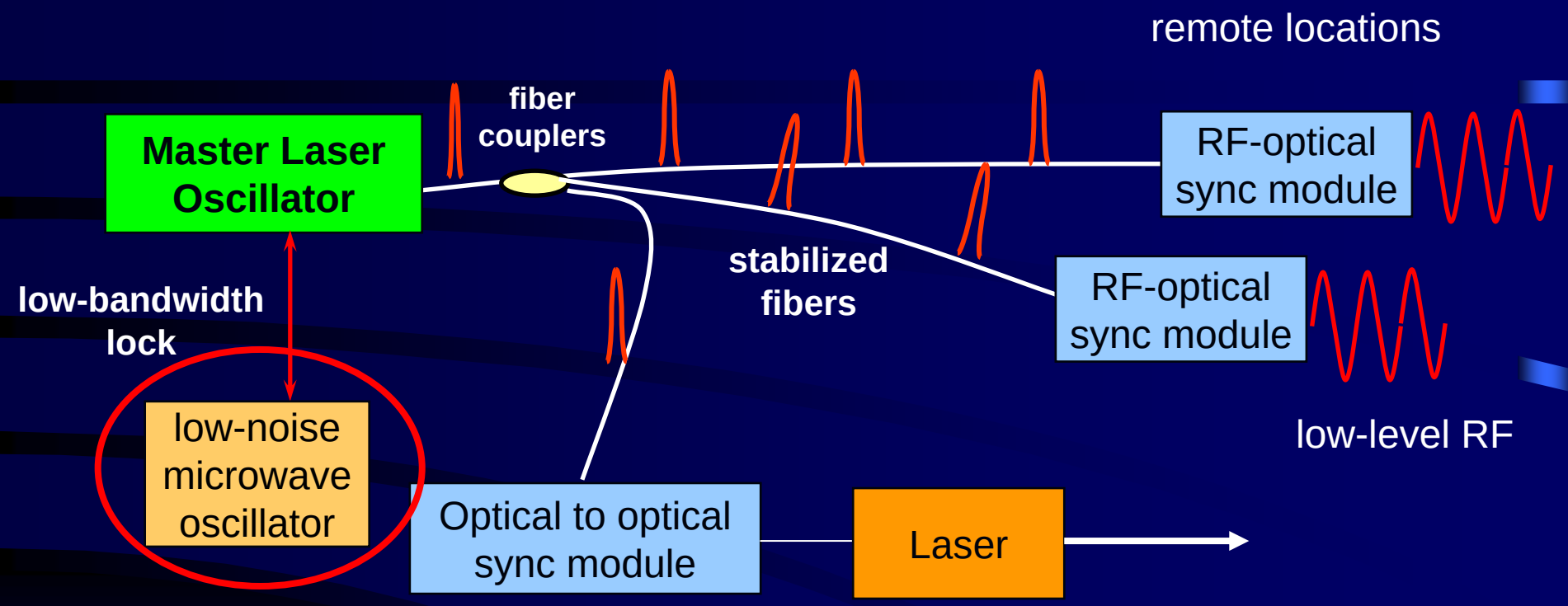


- A master mode-locked laser producing a very stable pulse train

Synchronization System Layout



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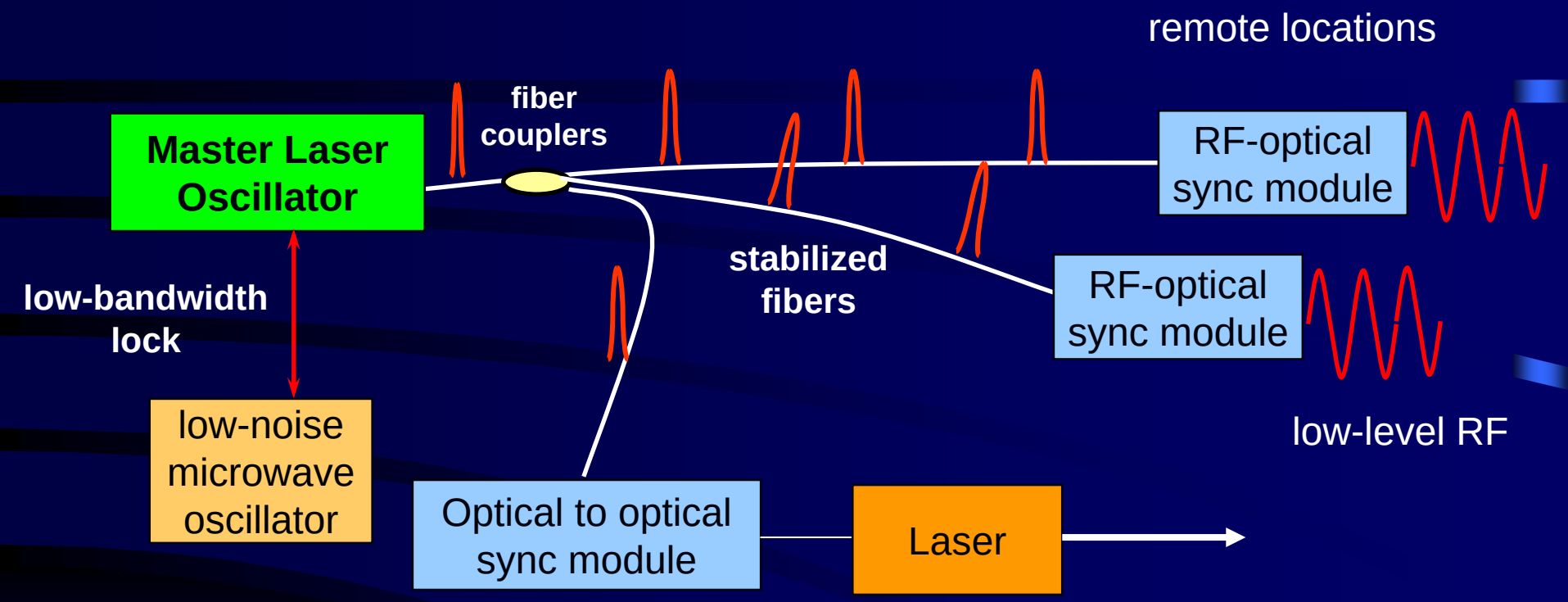
- The master laser is locked to a microwave oscillator for long-term stability

Synchronization System Layout



- A master mode-locked laser producing a very stable pulse train
- The master laser is locked to a microwave oscillator for long-term stability
- length stabilized fiber links transport the pulses to remote locations
- other lasers can be linked or RF can be generated locally

Choice of Technology

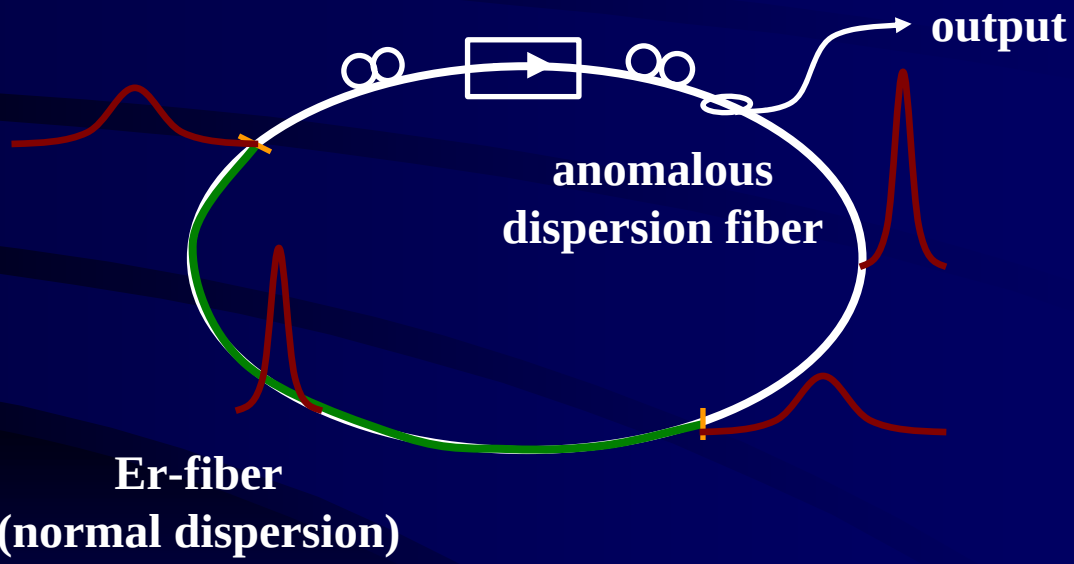
- Passively mode-locked lasers offer excellent high-frequency stability. For improved low-frequency stability, system is locked to a microwave RF Oscillator

- Er-fiber lasers:
  - sub-100 fs to ps pulse duration
  - 1550 nm (telecom) wavelength for fiber-optic component availability
  - repetition rate 30-100 MHz

- For VUV-FEL:
  - Fundamental Frequency is 1.3 GHz/144=9.02777 MHz
  - Choice of repetition rate of laser system: 9.0277 MHz*6=54.16 MHz

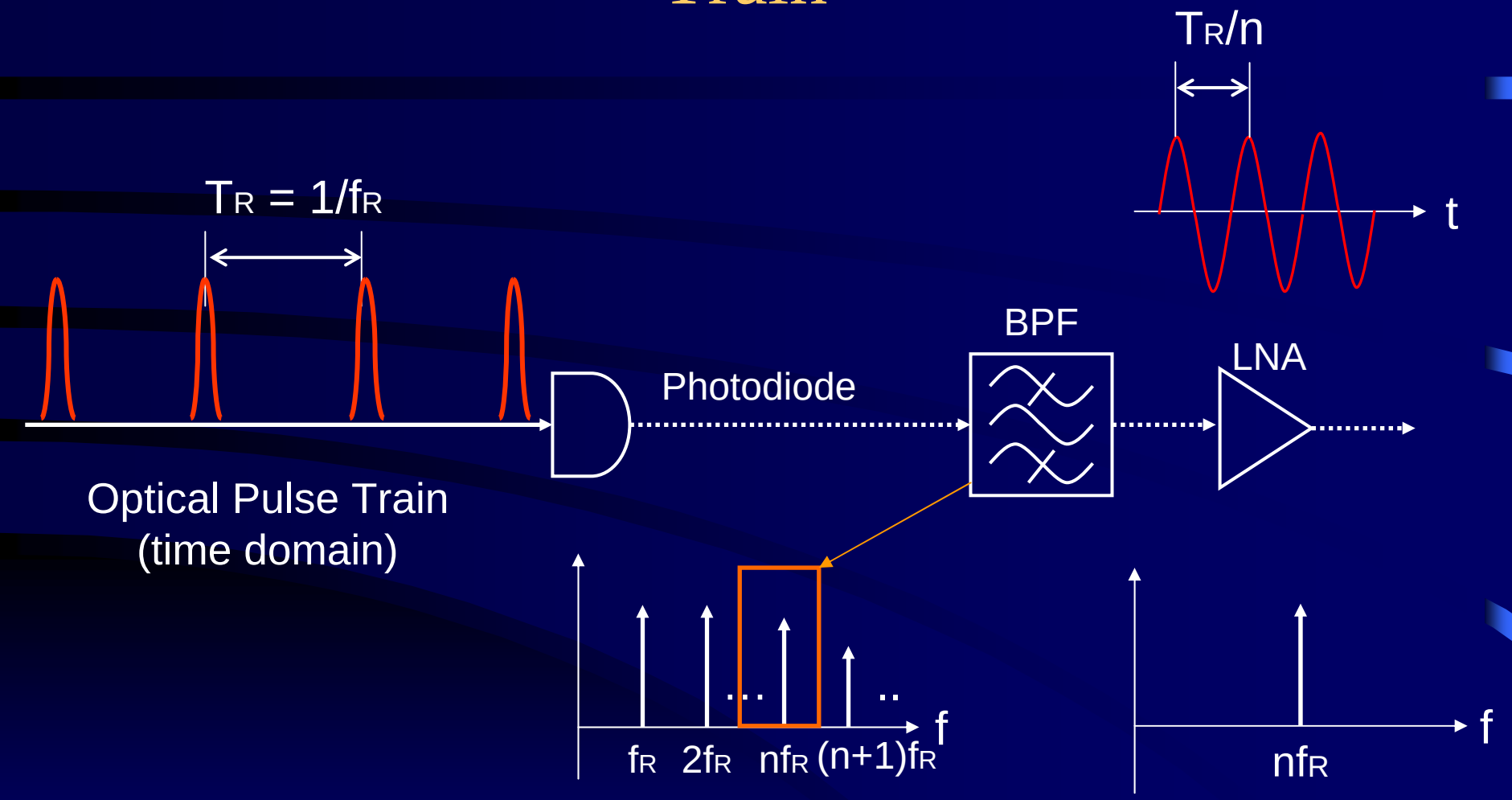
Passively Mode-locked Fiber Lasers

- Pulse builds up by itself from noise (ns-ps domain)
  - A saturable absorber ensures higher intensity <=> higher gain
  - Given constant intra-cavity energy, the stable solution is a localized solution (a single pulse).

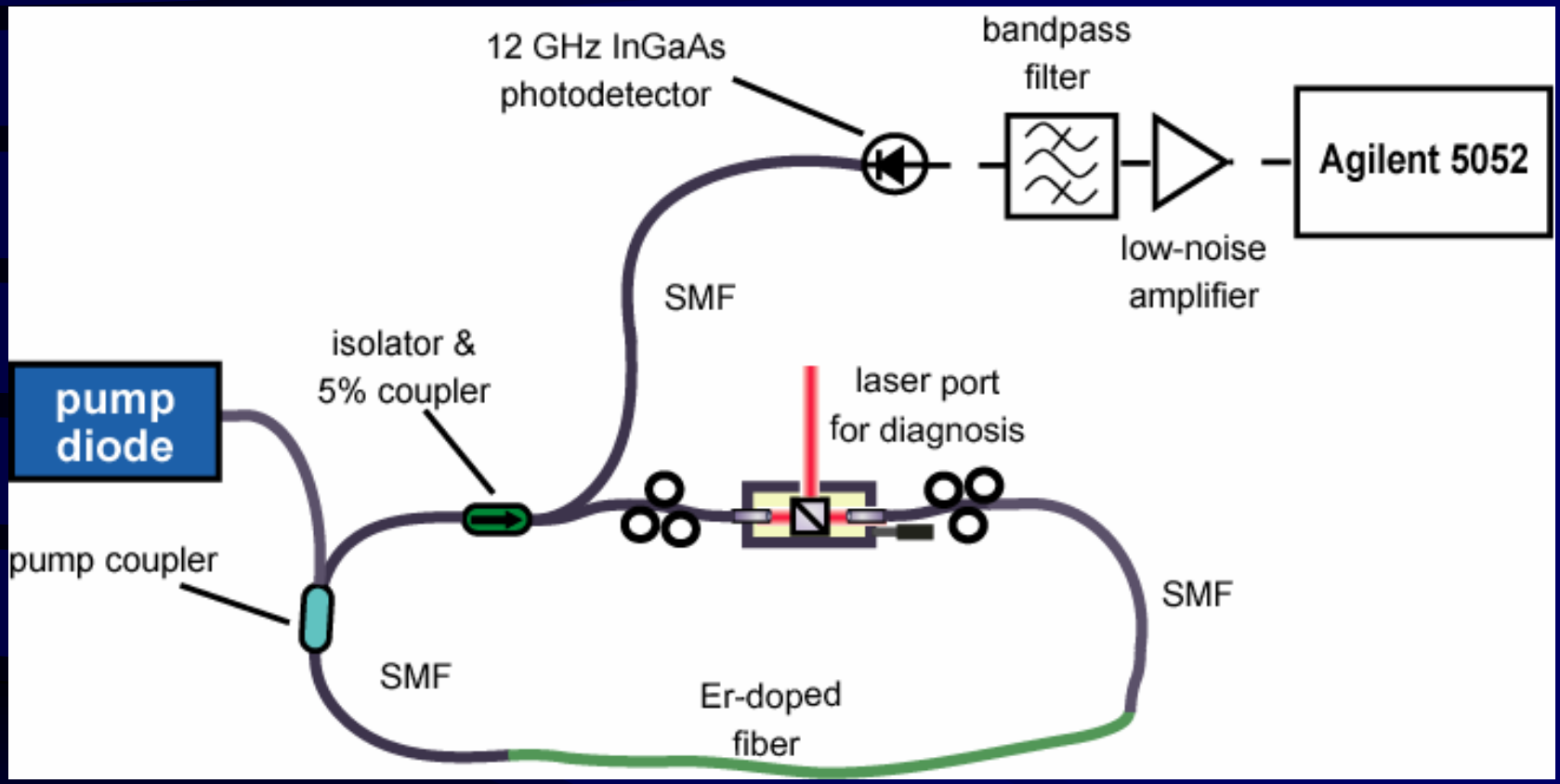


- Picture is different in the femtosecond domain:
  - Dispersion and Nonlinearity dominate pulse shaping.
  - Soliton-like pulses balance these effects => very short pulses

Direct Detection to Extract RF from the Pulse Train

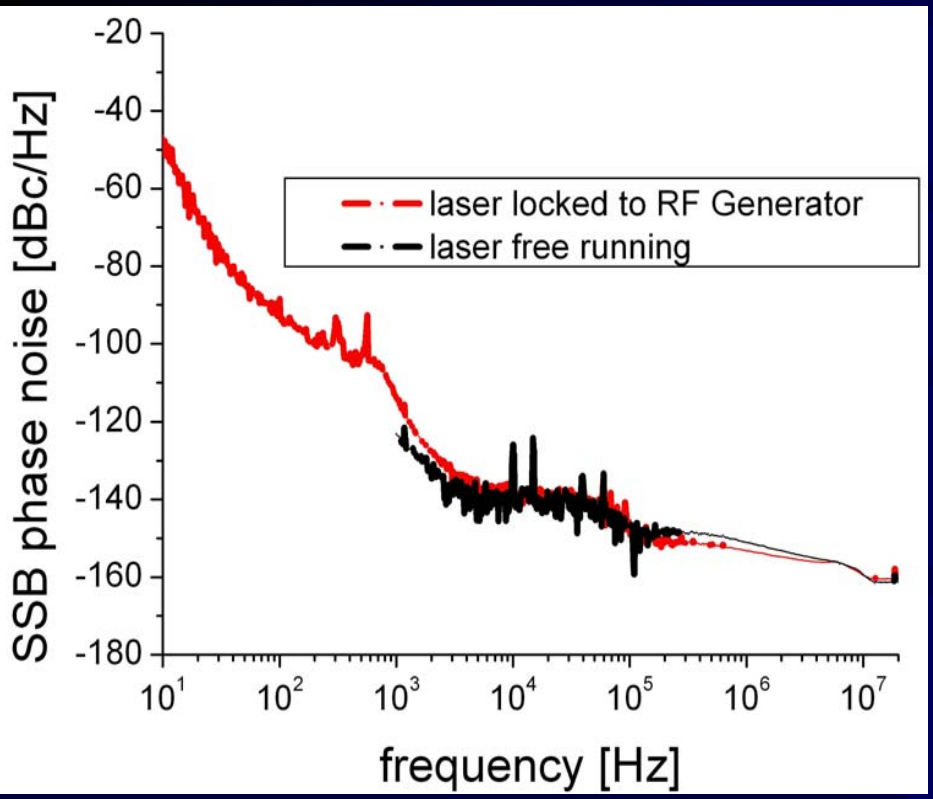


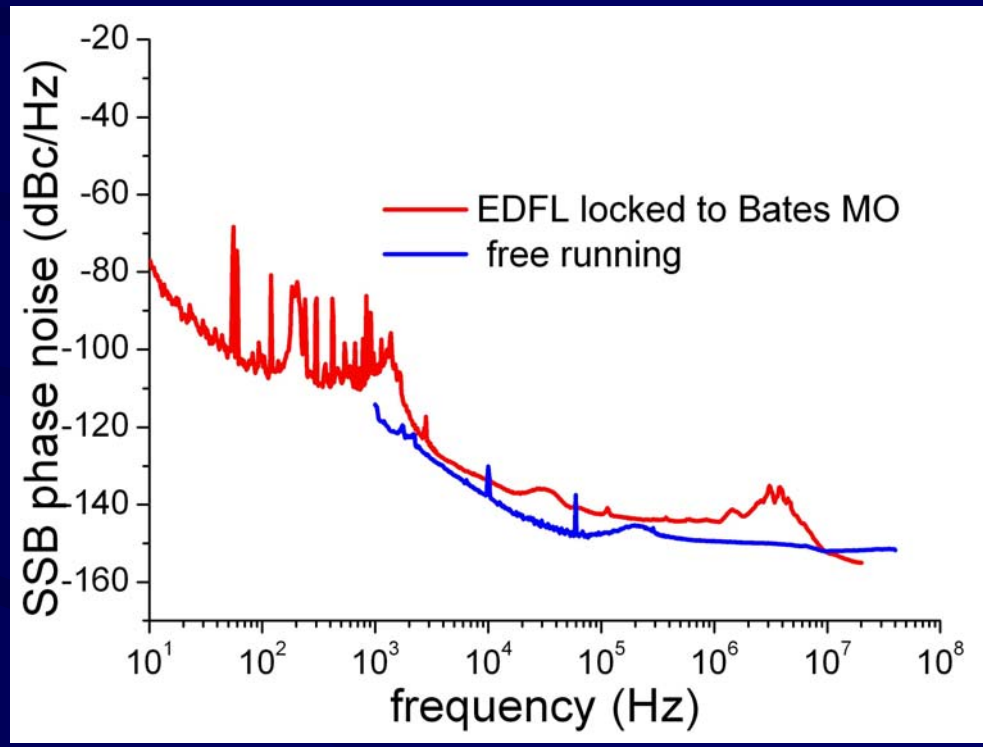
Timing jitter measurements



- signal converted to electronic domain by high-bandwidth photodector
- harmonic (1.3 GHz) of repetition rate filtered
- phase noise measured with Signal Source Analyzer

Timing Jitter of fiber lasers (after amplification by EDFA)

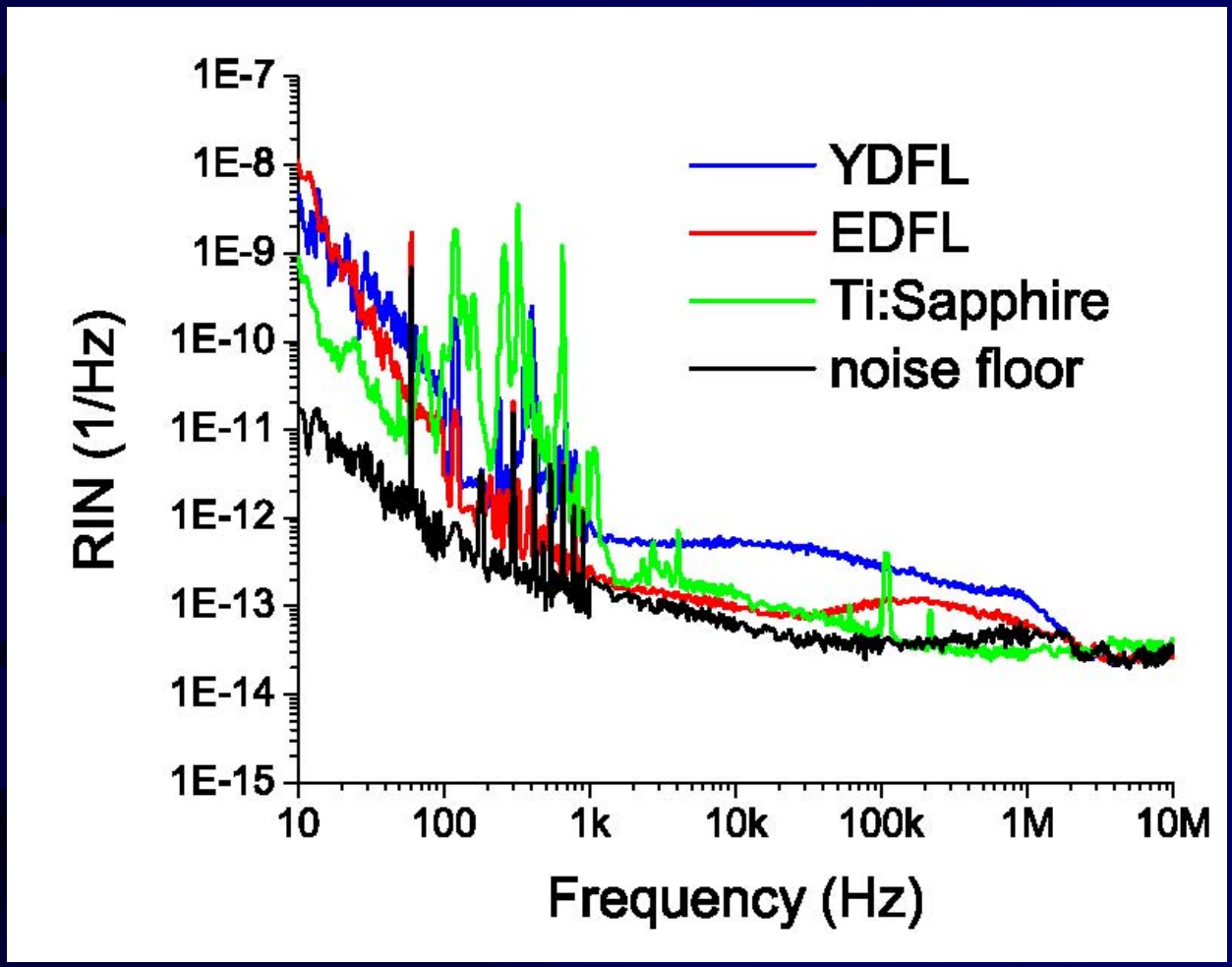




Data from FEL 2005

- All measurements at 1.3 GHz
- Unity gain of PLL ~1 kHz
- Noise ~10 fs (1 kHz..Nyquist); no significant noise added by locking
- Optical power sufficient to feed ~5 optical links

Amplitude noise of various fiber laser



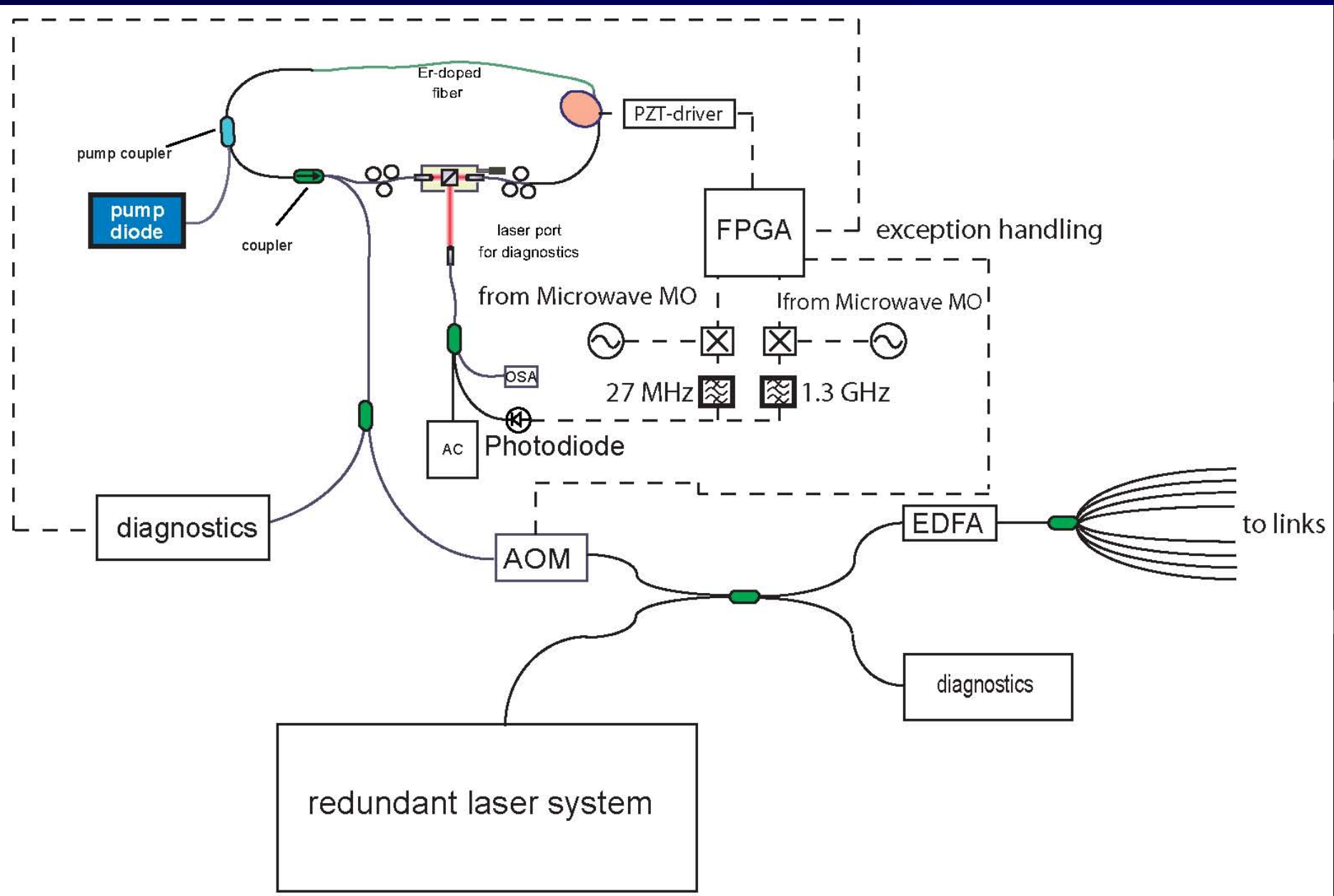
0.03% rms for Er-doped fiber laser (EDFL)
0.04% rms for Yb-doped fiber laser (YDFL)
0.1% rms for Ti:Sapphire

Some of the quietest lasers around (3x better than typical TiSa)

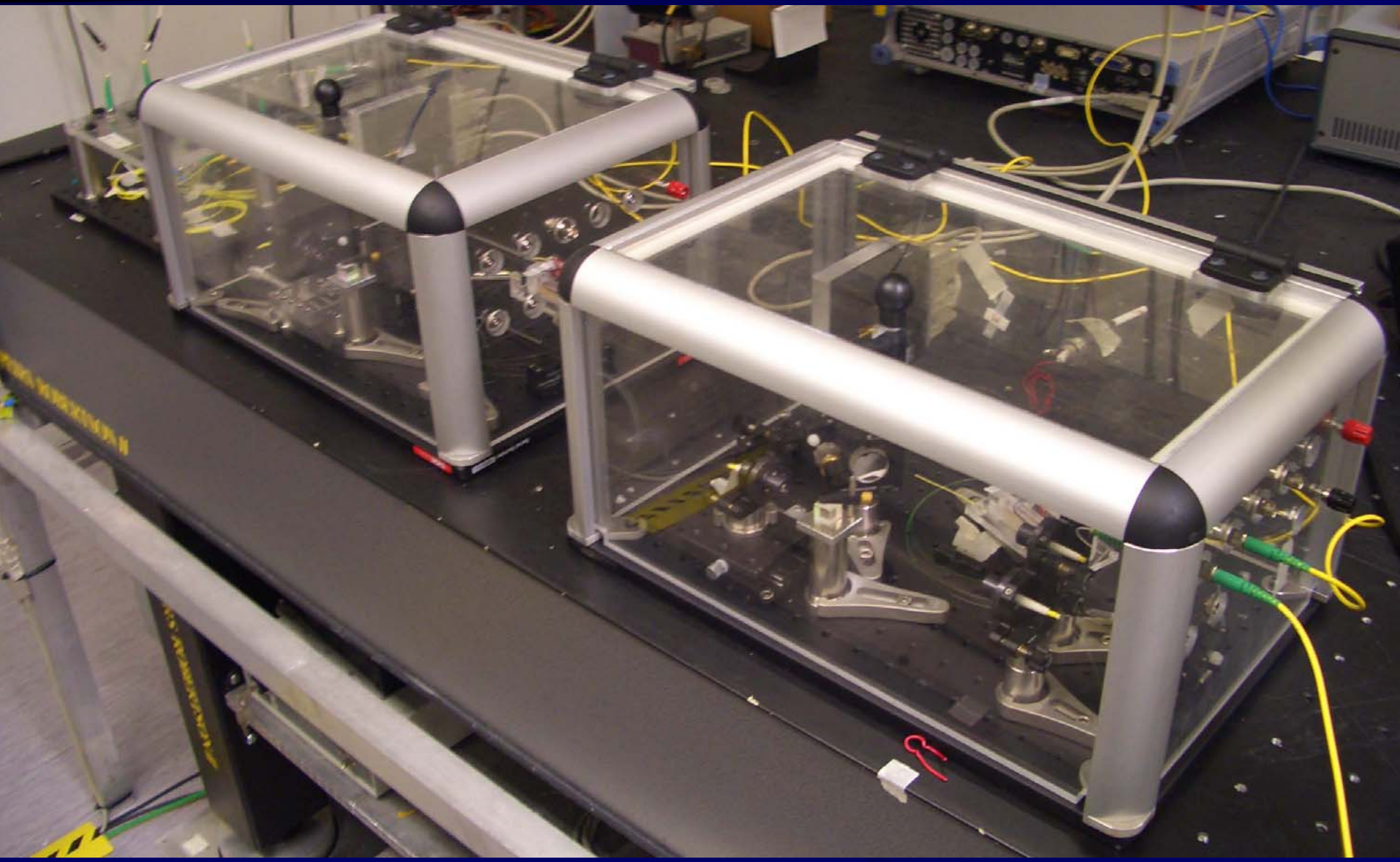
Design Considerations for MLO System

- Maximize uptime:
  - Redundant lasers
  - Switching from one system to another without machine interruption
    - Exception handling and switching must be fast to minimize interference to machine operation in case of failure
    - Phase of outputs of different lasers must be the same even after restart
    - Second feedback at ½ of repetition rate needed
  - Suitable diagnostics to determine operation according to spec
    - Optical spectrum
    - Average and peak power
    - Phase noise

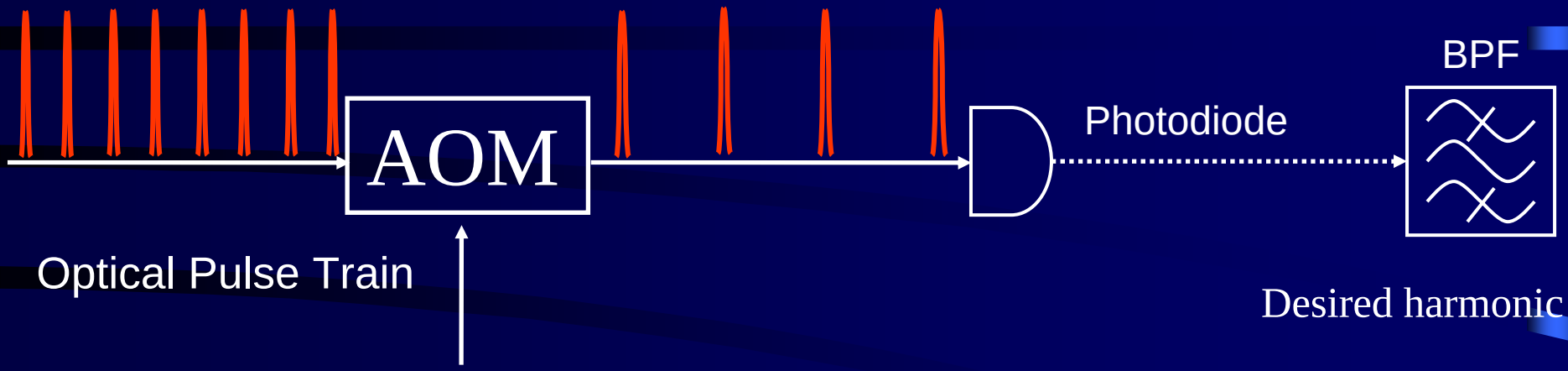
Layout of MLO System



Experimental setup

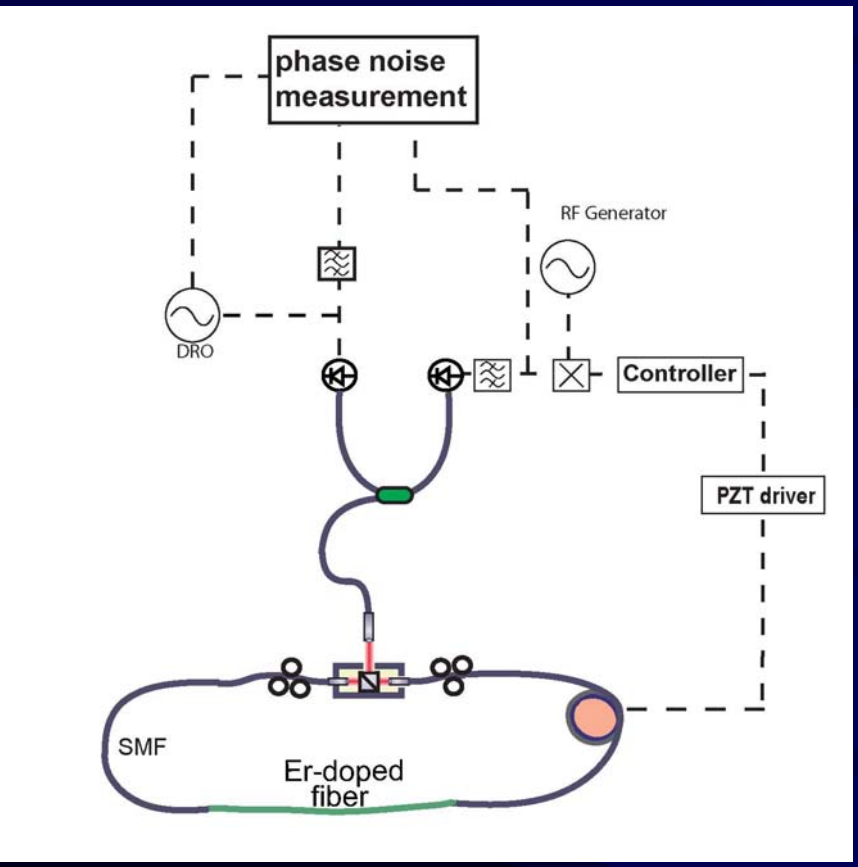


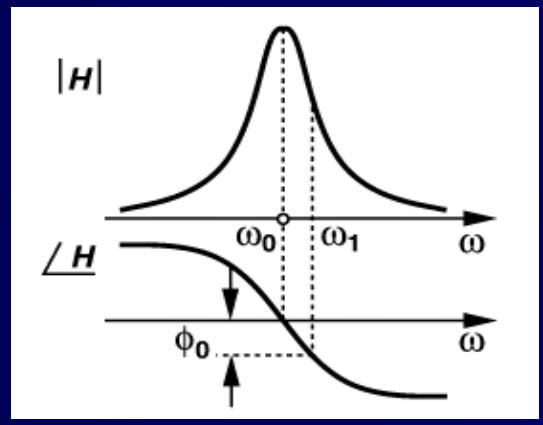
Generation of subharmonics

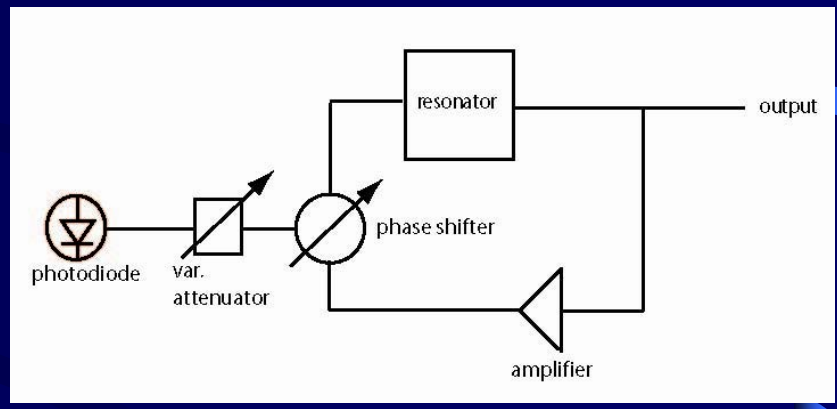


- Divide repetition rate using suitable RF pulse (~15ns pulsewidth)
- RF pulse can easily be created synchronous to laser, jitter is no issue
- Application: e.g. diagnostics with 1 MHz repetition rate
- Pick up harmonic of divided repetition rate with photodetector

Injection locking of DRO



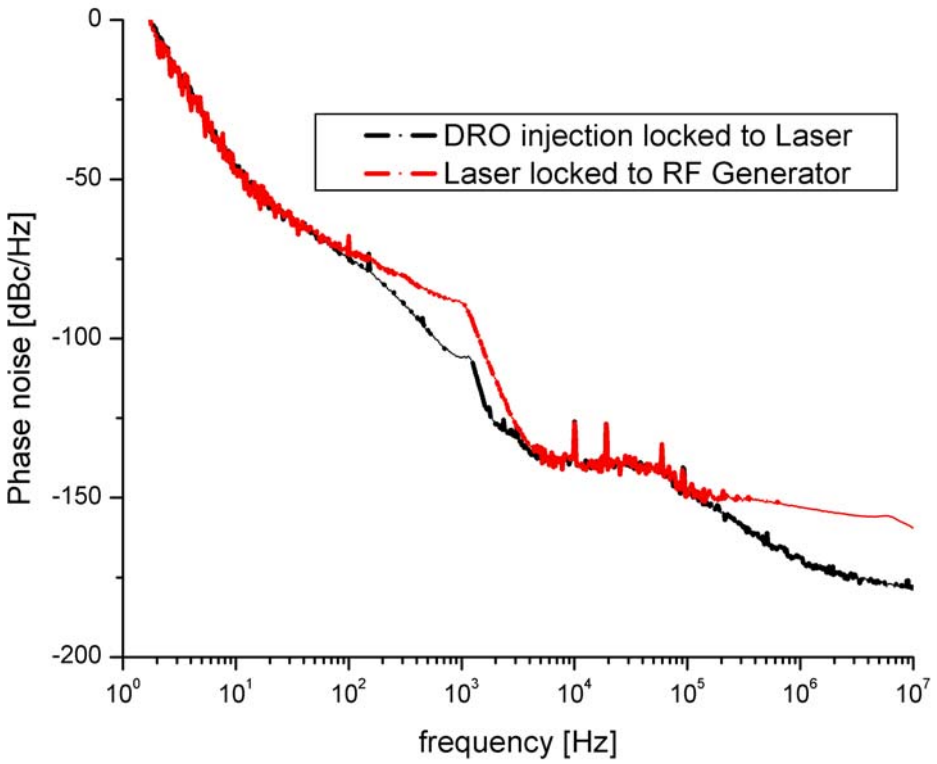


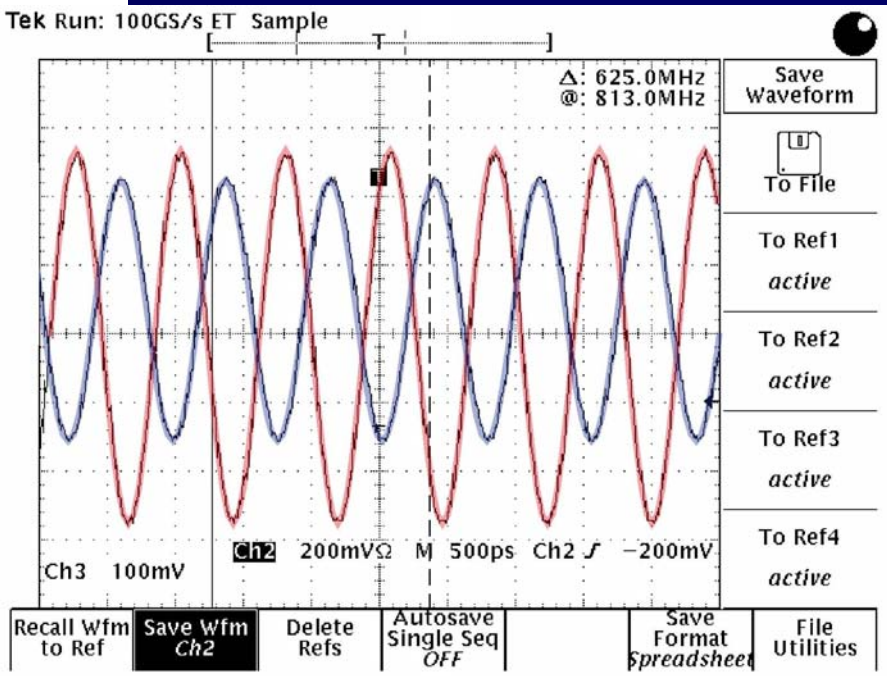


- Pulse train is directly fed to VCO input of DRO
- Unity gain is determined by amplitude of pulse train

- Resonant circuit: phase=n*360 deg
- DRO reacts to phase shift by changing center frequency
- If locked: pulses will be at zero-crossing of 1.3 GHz wave
- High bandwidth of photodiode can be fully used

Injection Locking of DRO





- DRO follows laser phase noise for lower offset frequencies and is free running for higher frequencies.
- Extremely simple yet effective way to combine ultra-low far-from-carrier noise of DRO with optical timing system based on optical pulses
- Photodetector drifts are under investigation.

Conclusion and Outlook

- Present state:
  - Engineering and design effort on first generation master laser oscillator system for the VUV-FEL
- Things accomplished:
  - Lock of Laser to RF source
  - Switching concept to combine redundant MLO's
  - First tests with FPGA-based regulation
  - First tests with injection locking external DRO to MLO
- Things to be done:
  - Evaluate performance of FPGA-based regulation and include second feedback and exception handling
  - Implement suitable set of diagnostics for MLO's to assure reliable operation of system
  - Long-term tests of system
  - Evaluation of injection locking performance

Thank you for your attention !!