XFEL MO and Phase Reference Distribution

Krzysztof Czuba

Warsaw University of Technology, ISE

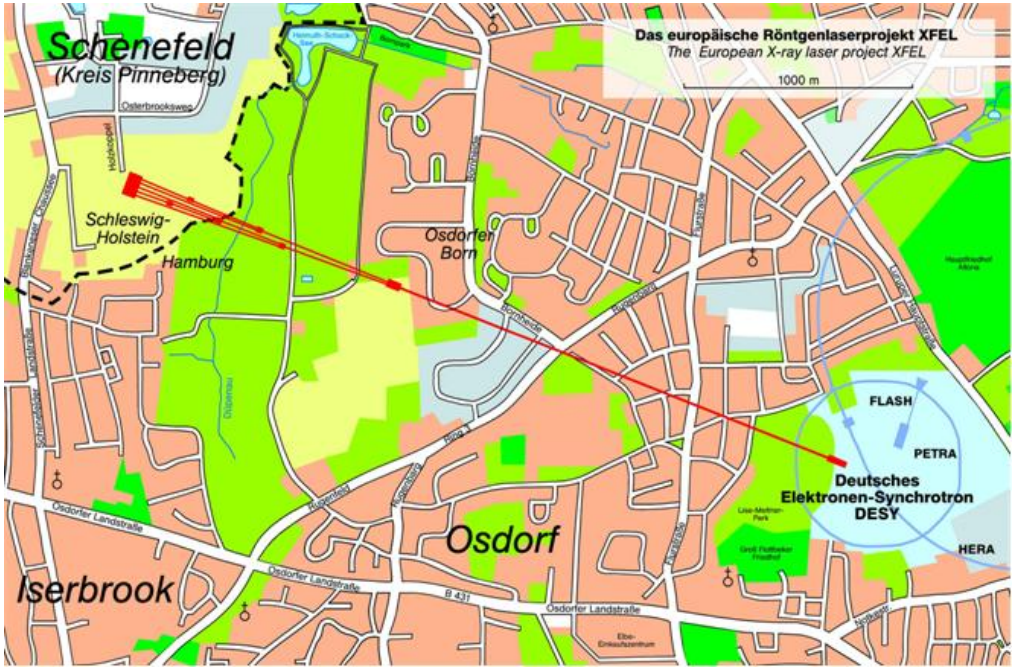
For the DESY LLRF Team

krzysztof.czuba@desy.de

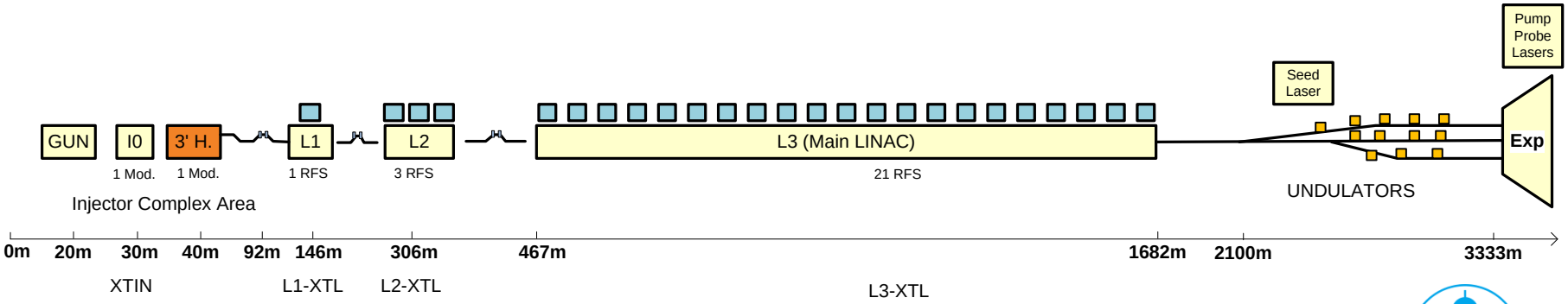
LLRF Workshop
Granlibakken, 4.10.2013

HELMHOLTZ
ASSOCIATION

Introduction – European XFEL



- 3.3km long machine
- Several thousands of digital, RF and optical devices to synchronize
- Most critical subsystems located in injector area
- Installations started in 2013
- Commissioning planned for 2015



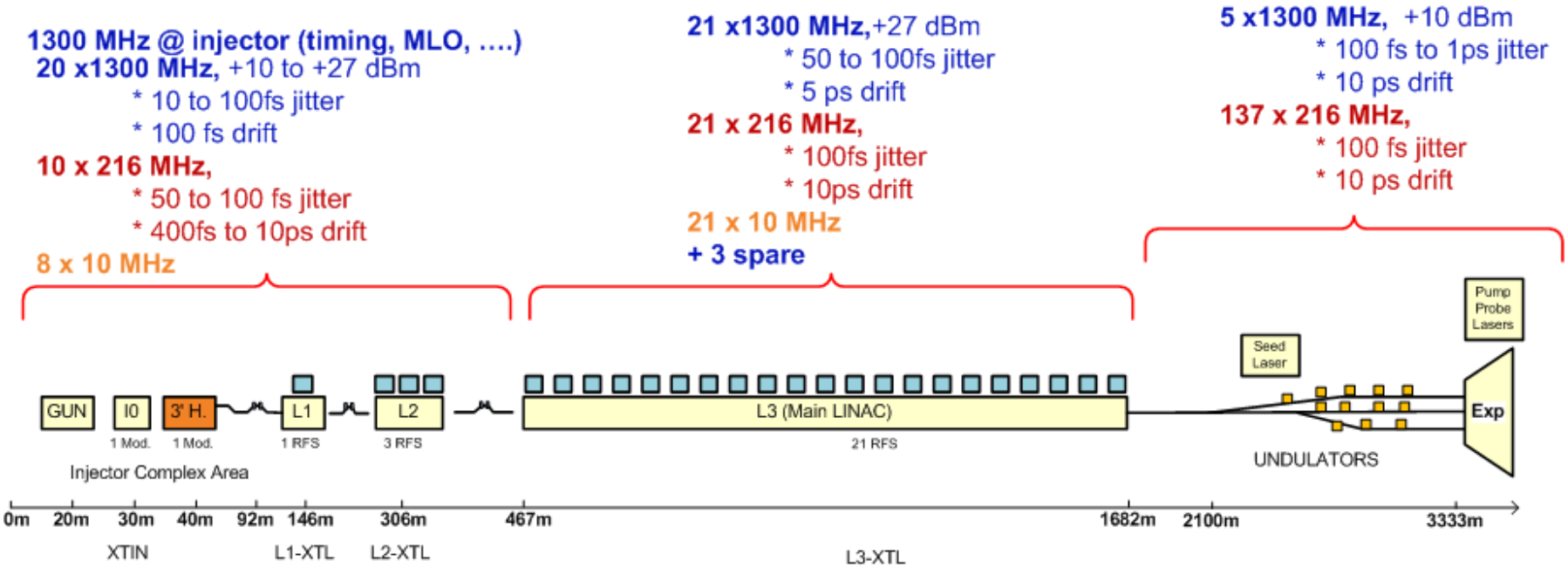
Field Stability Requirements for Accelerating Sections

Accelerator Section	RF Station	Amplitude Stability [%]	Phase Stability [deg]
I1 (GUN)	1300 MHz	0.01	**0.01**
I2 (Injector)	1300 MHz	0.003	**0.005**
I3 (3rd-Harmonic)	3900 MHz	0.005	**0.03**
L1 (Injector Linac)	1300 MHz	0.03	**0.03**
L2 (Booster)	3 x 1300 MHz	0.03	**0.03**
L3 (Main Linac)	20 x 1300 MHz	0.1	**0.1**

- Numbers in the last column indicate the required synchronization accuracy
  - Not straightforward! (contribution of control system components and feedback loops) but can give a good approximation
- 0.01 deg @ 1.3 GHz corresponds to roughly 20 fs of jitter

Short Summary of Requirements

LO, precise clocks and other locally generated and distributed signals not included here but also of concern for the RF distribution

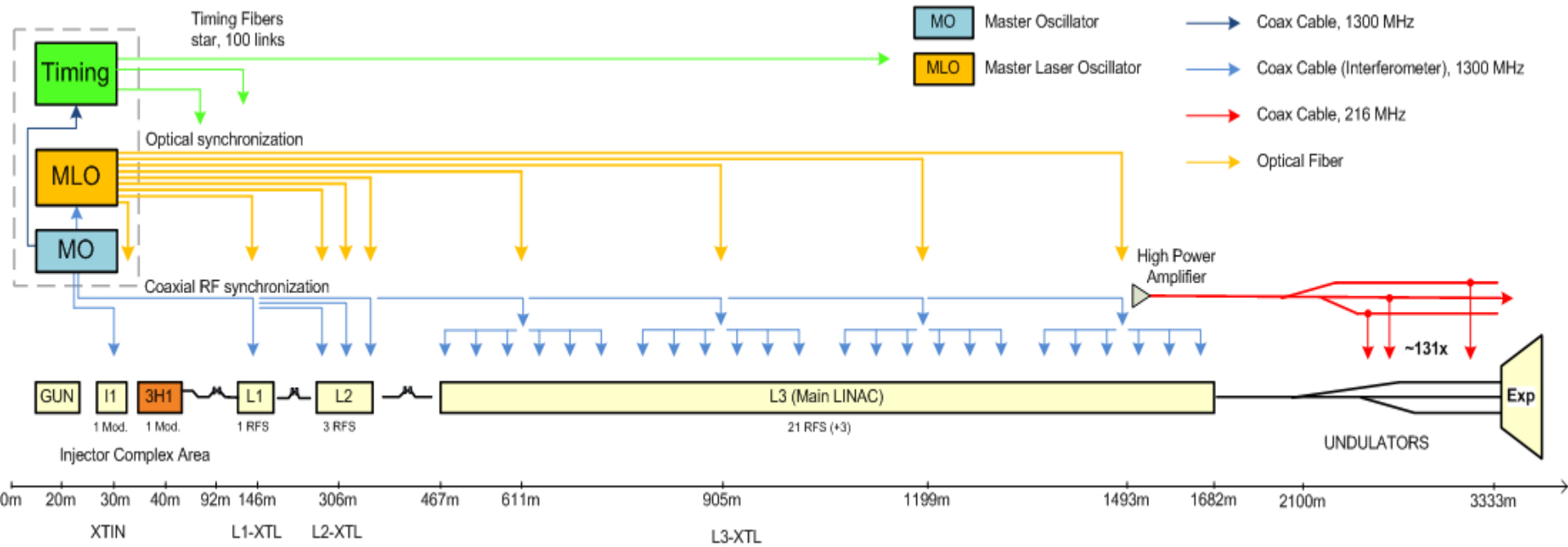


- Together more than 220 tap points
- Main reference signal frequency is 1300 MHz
- Required high availability (best would be no breaks in operation over XFEL life time)

Basic Assumptions

- Single frequency (1.3 GHz) MO
- Other frequencies generated locally
- Direct 1300 MHz distribution links from the Master Oscillator to injector devices
- 1300 MHz distribution along the LINAC
- 216 MHz distribution along undulators

Overall Synchronization System Concept

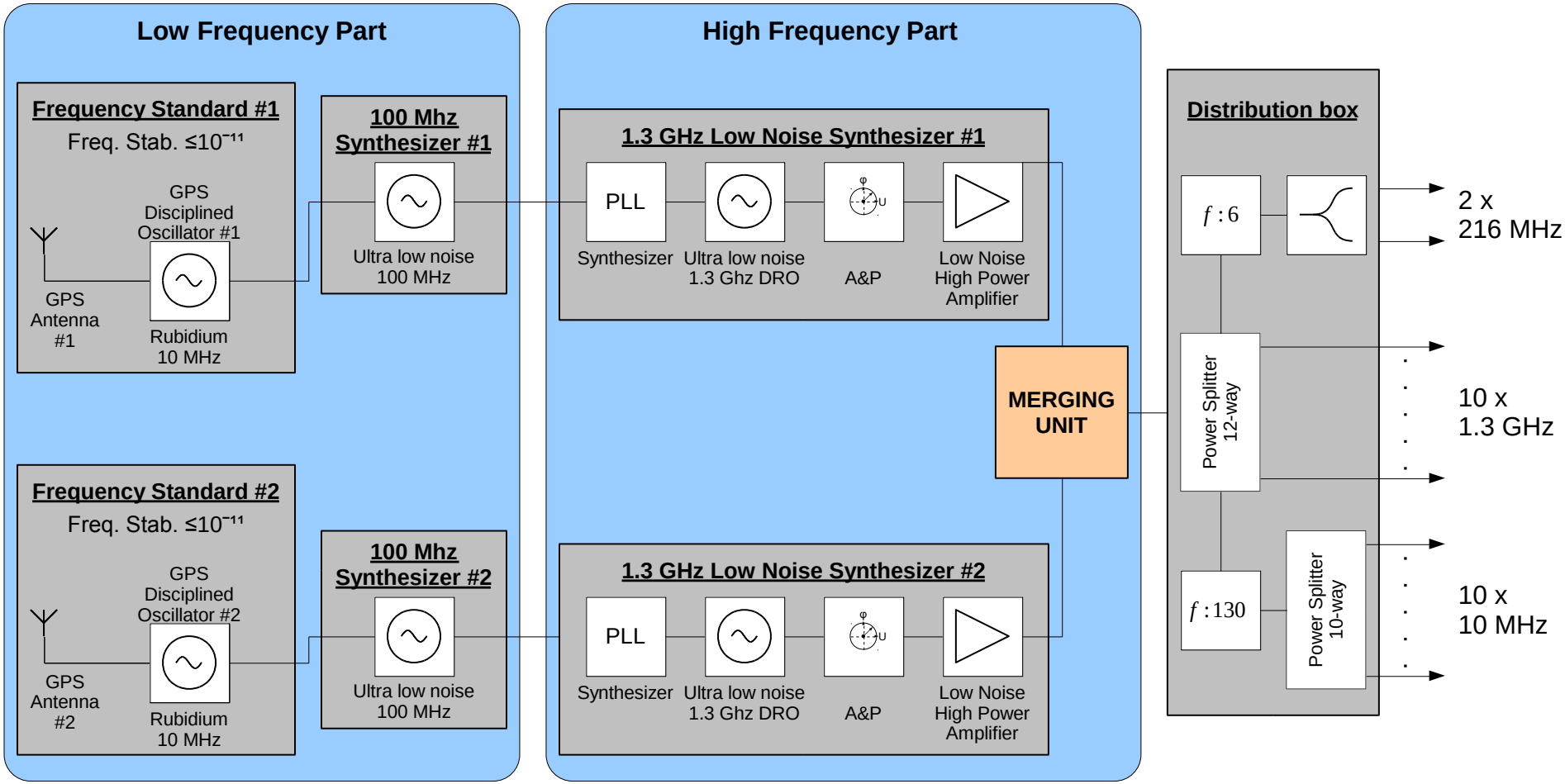


- Three complementary systems (compromise between performance and cost)
  - Optical synchronization: sub-10fs performance, 12 links
  - RF Coaxial distribution: sub-100fs performance, interferometers, local distribution
  - Timing system
- All systems phase synchronized do the RF Master Oscillator

Master Oscillator

- One frequency: 1.3 GHz
- GPS disciplined
- Redundant (auto recover capability)
- Battery backed up power supply
- On-line diagnostics for e.g.: power level, power supply status, PLL lock, temperature, humidity, phase noise
- Stable signal generation with sufficient short and long term stability is well known and relatively easy to achieve
- Main challenge – achieving high availability. Redundancy and phase-coherent switching is main driver for complexity and problems with MO concept

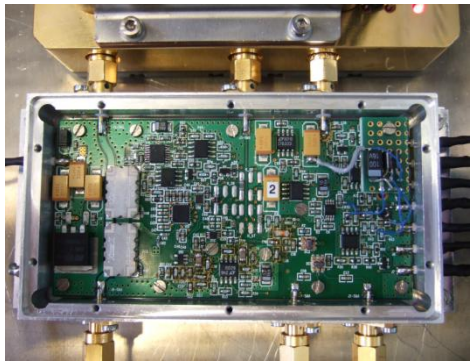
Master Oscillator System – Simplified Block Diagram



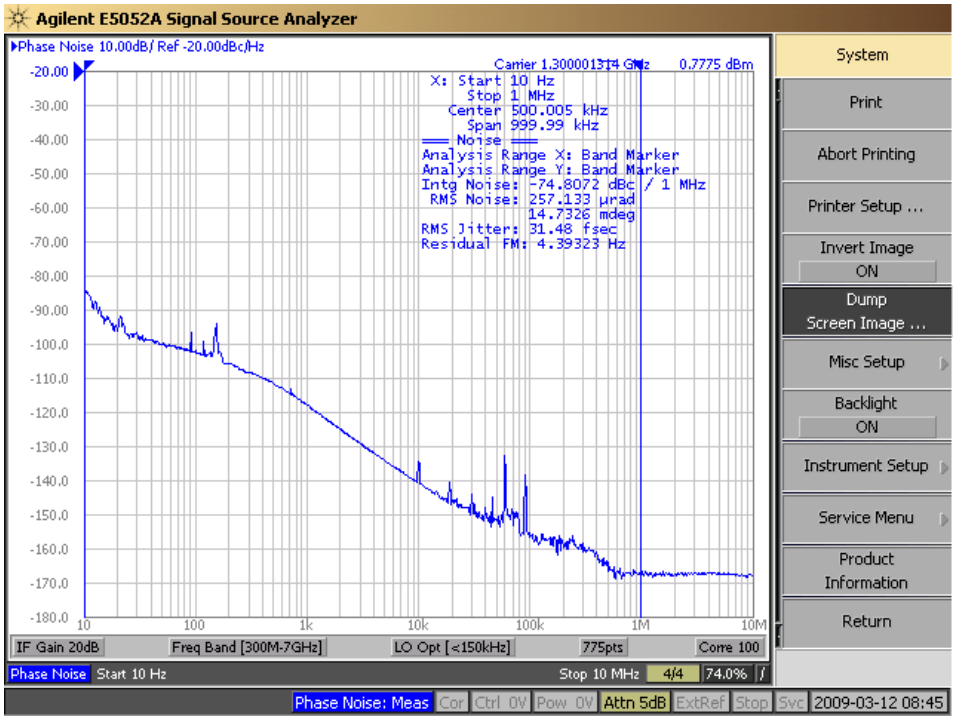
MO – Current Status

- Experience gained during design of the FLASH MO (with. H. Weddig)
- Demonstrated 31fs jitter (@ 1.3GHz, 10Hz – 1MHz BW)

FLASH MO

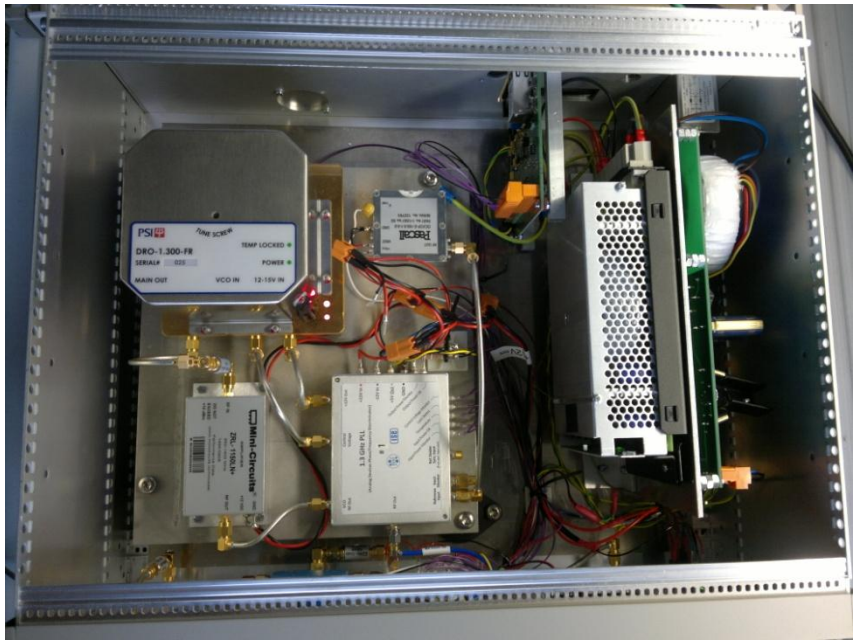


Low noise and low drift PLL by L. Zembala and H. Weddig



MO Prototype and Installation Tests

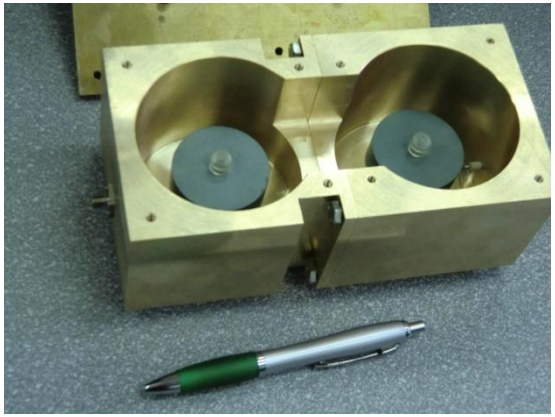
Developed MO prototype with vibration reduction.
Very good results – measured no vibration driven lines in phase noise spectrum



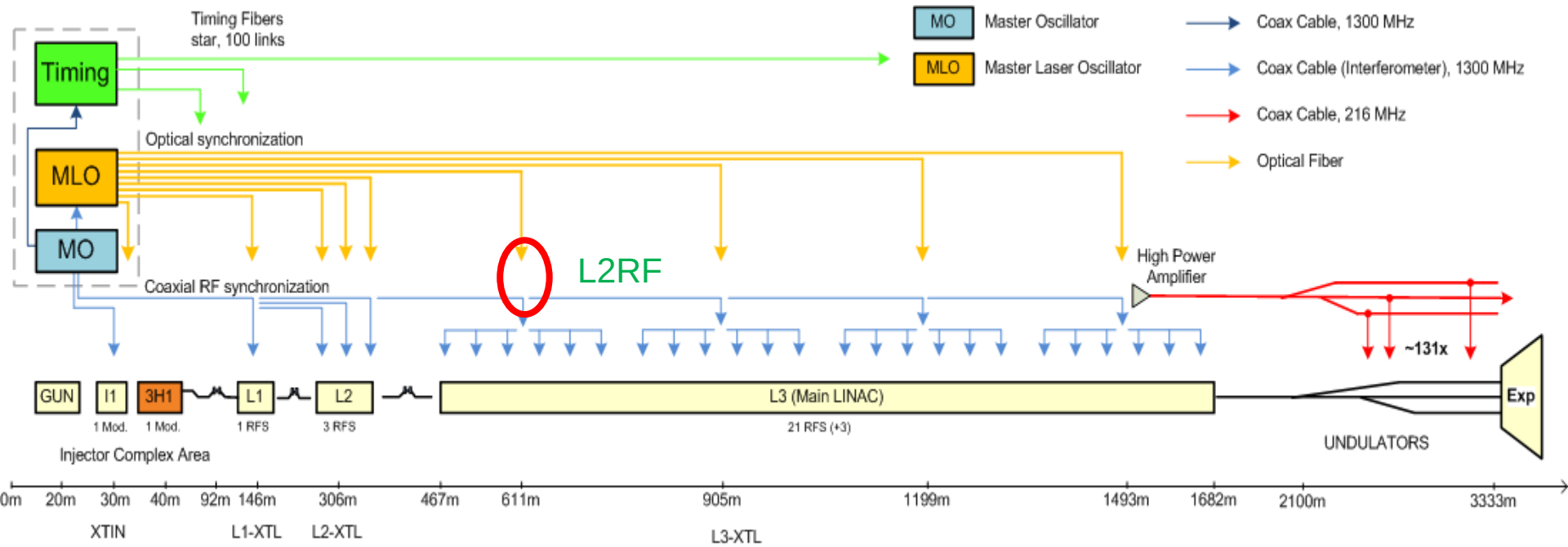
Air conditioned rack with special rubber dumpers to reduce vibrations under test at DESY

MO – Current Activities

- Work on concept for redundancy switching
- In general it seems to be not possible to switch between main and spare system without phase/amplitude changes (<10% in amplitude, <5deg of phase in time much shorter than 1 us)
- Problem is in diagnostics
- Idea of using a narrowband filter after a switch
- Design to be finalized by end of 2013



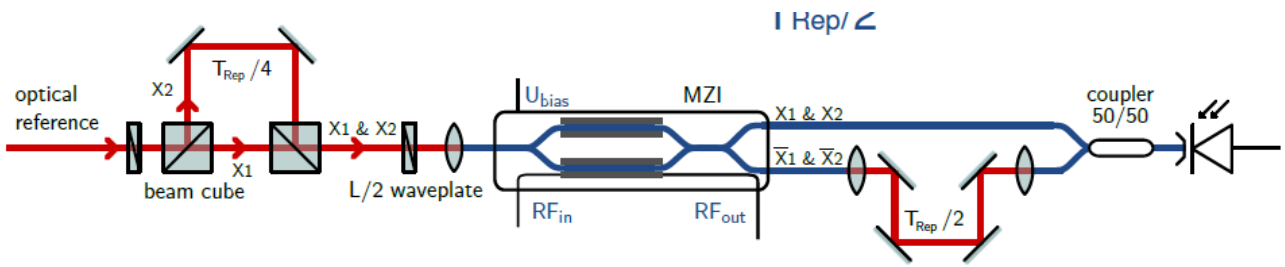
Phase Reference Distribution System

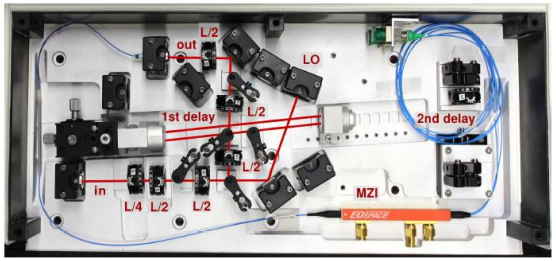


- Coax cable links combined with high-performance optical links
- Coax cable distribution: robust and reliable but loss limits distribution distance
- At each of 12 outputs of the optical system, the RF signal phase will be precisely adjusted to the optical reference
- In case of optical system failure, the coax distribution should still deliver signals but with limited performance

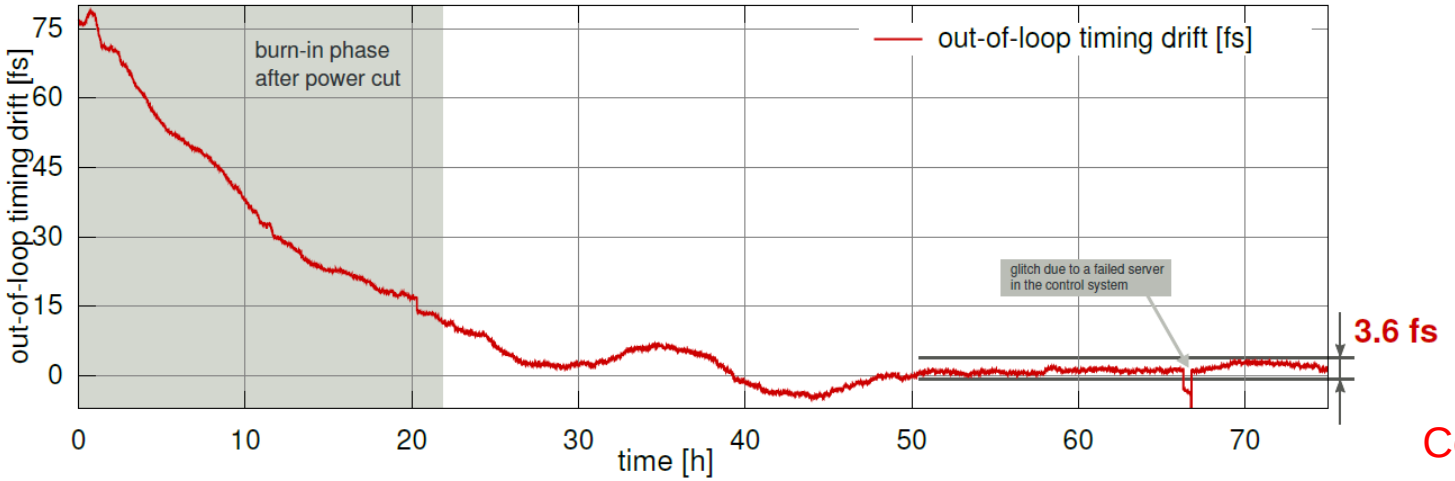
Optical Links and Laser-to-RF Conversion

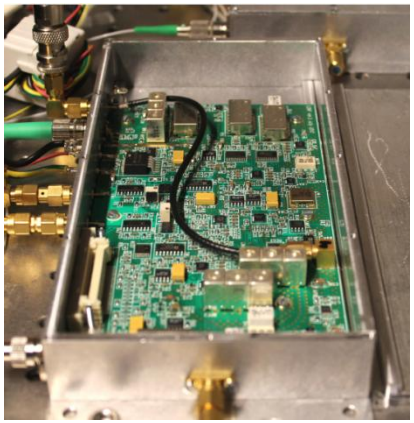
- Basically the L2RF setup is a precise phase detector used to synchronize the RF signal to optical pulses





Long term drift measurement





Courtesy: T. Lamb

See paper TUPC33 at IBIC2013

Coax Cable Parameters

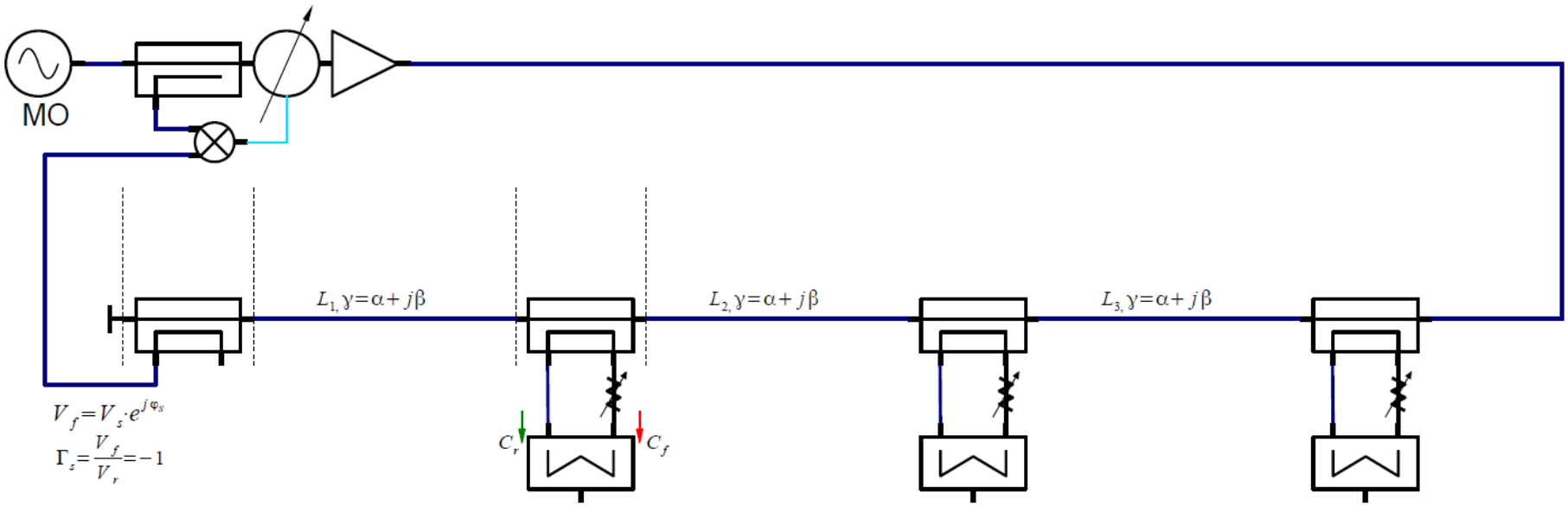
Diameter	1 5/8"	7/8"	1/2"	3/8"	0.19" (inside rack)
Cable	LCF158-50JATC	LCF78-50JATC	LCF12-50JFN	LCF38-50J	Phase master 190
attenuation @ 216MHz [dB/100m]	1	1,7	3,2	5,1	~13
attenuation @ 1300MHz [dB/100m]	2,62	4,55	8,3	13,07	~30
phase drift @ 20°C [fs/°C/m]		30	18	10	-60÷15
phase drift @ 25°C [fs/°C/m]	100	25	15	~0	12
phase drift @ 30°C [fs/°C/m]	100	21	11	-10	5
phase drift @ 35°C [fs/°C/m]		23	8		30

Estimated Phase Drifts of 7/8” Cable Distribution in LINAC

	RF station	Phase drift caused by temperature change [ps]			
		-2,0 ºC	-1,0 ºC	+1,0 ºC	+2,0 ºC
L1	A1	-3	-1,5	1,5	3
L2	A2	-6	-3	3	5,9
	A3	-8,2	-4,1	4,1	8,1
	A4	-10,3	-5,2	5,1	**10,3**
L3	A5	-27,6	-13,7	13,7	27,3
	A6	-25,6	-12,8	12,6	25,2
	A7	-23,4	-11,7	11,7	23,4
	A8	-23,4	-11,7	11,7	23,4
	A9	-25,6	-12,8	12,6	25,2
	A10	-27,6	-13,7	13,7	27,3
	A11	-40,9	-20,4	20,3	40,6
	A12	-38,8	-19,4	19,3	38,5
	A13	-36,7	-18,3	18,3	36,5
	A14	-36,7	-18,3	18,3	36,5
	A15	-38,8	-19,4	19,3	38,5
	A16	-40,9	-20,4	20,3	40,6
	A17	-54,3	-27,1	27	53,9
	A18	-52,1	-26,1	25,9	51,8
	A19	-49,9	-24,9	24,9	49,8
	A20	-49,9	-24,9	24,9	49,8
	A21	-52,1	-26,1	25,9	51,8
	A22	-54,3	-27,1	27	53,9
	A23	-67,5	-33,7	33,6	67,2
	A24	-65,3	-32,6	32,6	65,2
	A25	-63,2	-31,6	31,5	63
L3	A26	-63,2	-31,6	31,5	63
	A27	-65,3	-32,6	32,6	65,2
	A28	-67,5	-33,7	33,6	**67,2**

- Phase drifts calculated for selected cables and for nominal operating temperature characteristic (data by Hans-Jörg Eckoldt) with span of 2°C
- Estimated values at the end of the sections
- Phase drift compensation is needed - interferometer

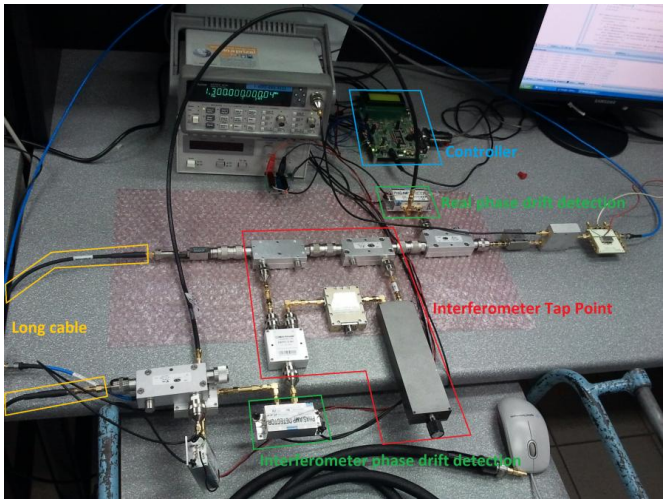
Interferometer Link

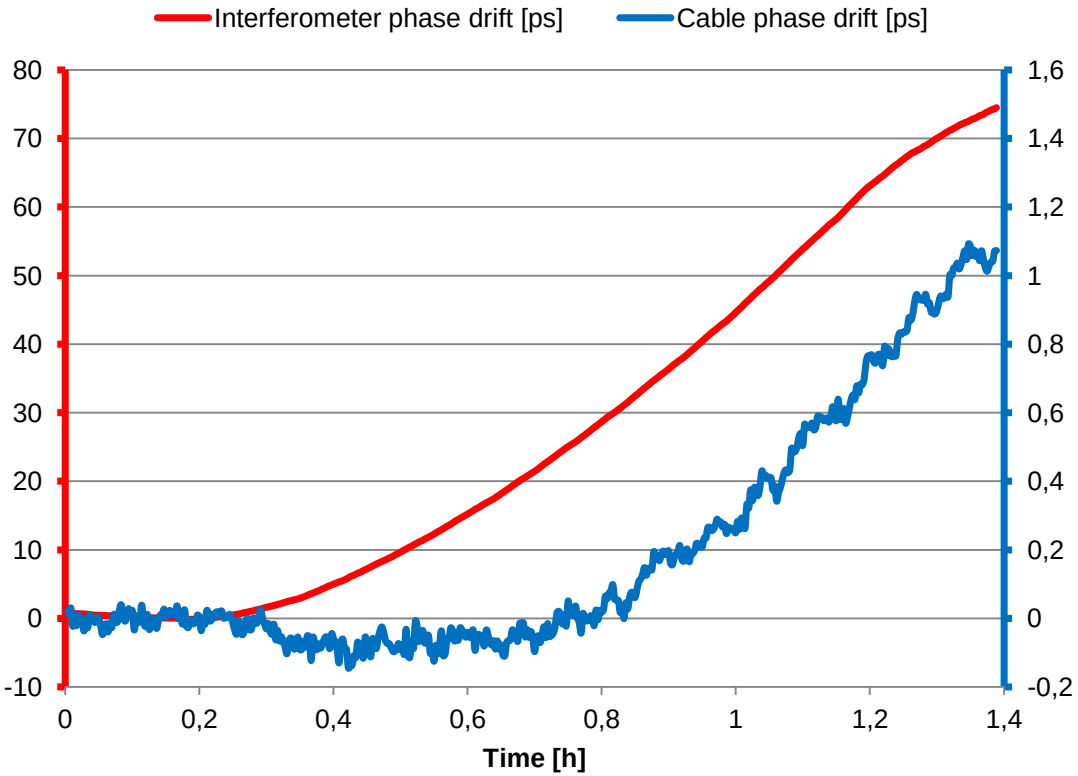


- Idea of phase averaging reference line by Brian Chase and Ed Cullerton
- Performance limited by cable loss and coupler directivity
- Feasible distribution distances up to
  - 150m (7/8” cable, 1.3 GHz, 3 tap points)
  - 250m (7/8” cable, 1.3 GHz, 1 tap point)

Prototype Interferometer Link Tests

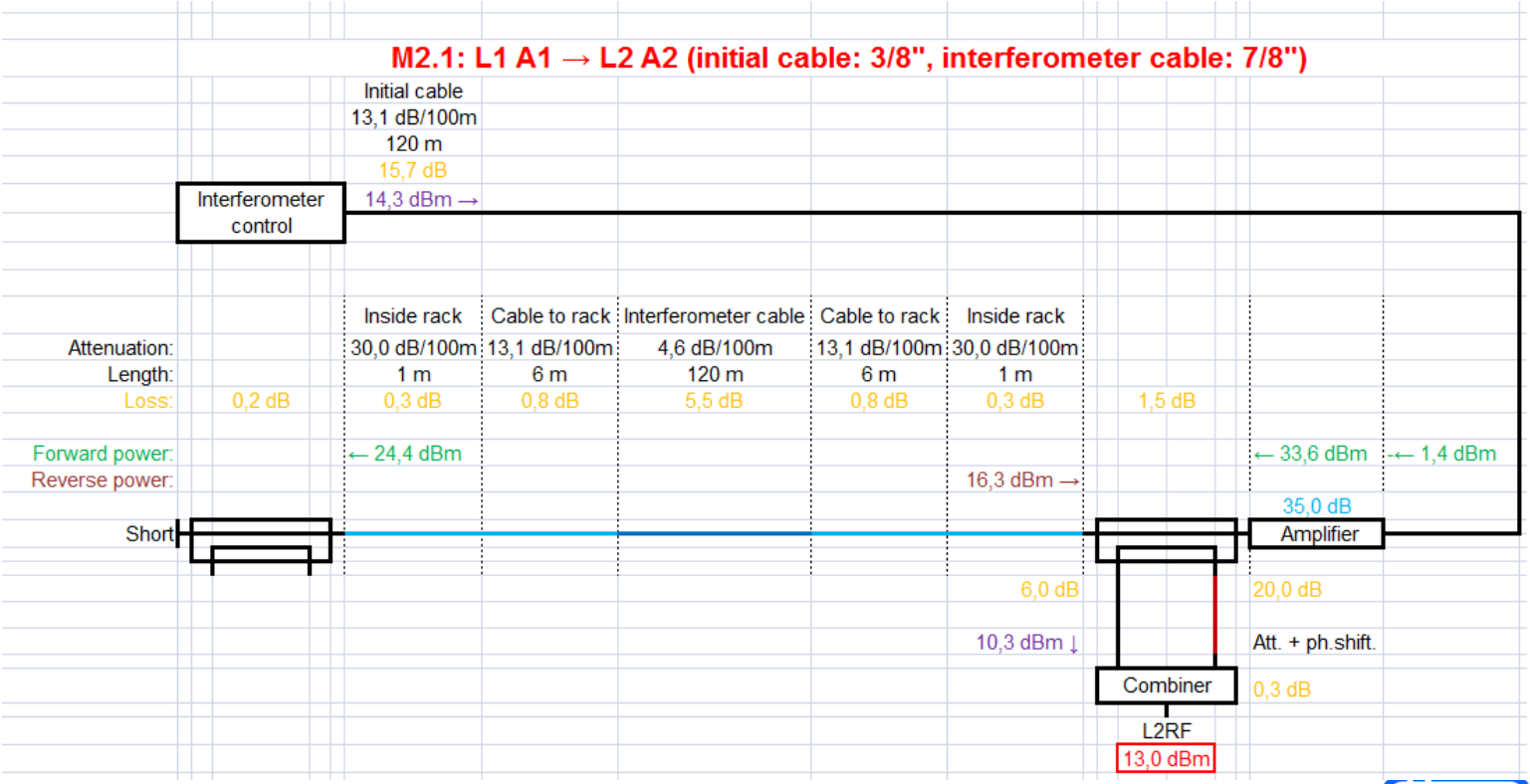
- Tested on the bench, no temperature stabilization
- Cable drifts up to 30 ps are compensated to 80 fs p-p over long term (suppression >300)
- This can be improved by stable mechanical design and temperature regulation
- Above 30 ps output phase drifts more (suppression 70 to 100), not well understood so far





RF Loss

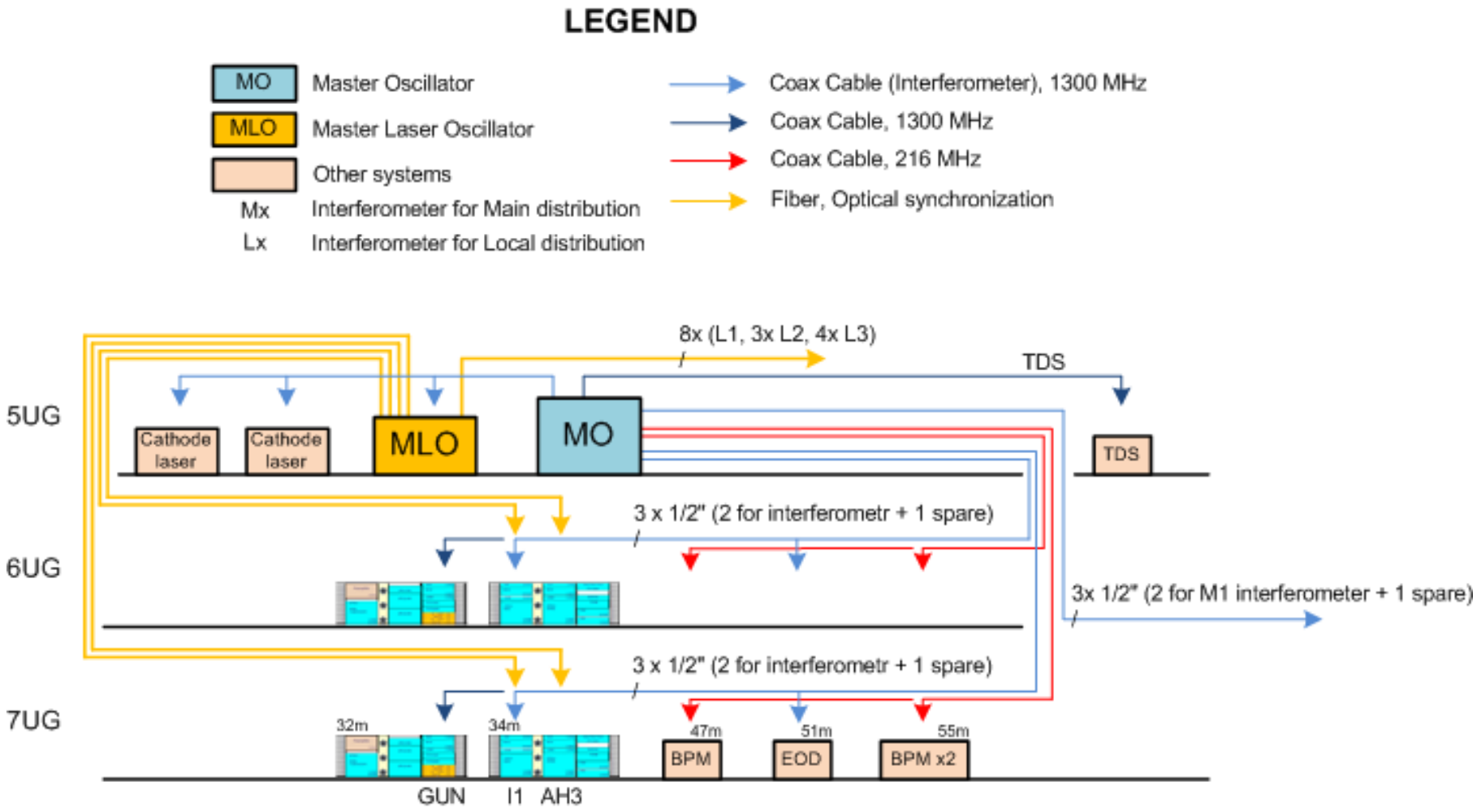
- One of biggest problems in coax cable distribution
- Interferometers must contain power amplifiers (in loop)
- Power budget was calculated for all links, example for 1 tap point link below



Long Distance Distribution – Current Status

- Worked out general concept with cable layout at RF stations
- Selected distribution cables: 7/8” for long distance distribution but may be changed to 1 5/8” after more interferometer experiments
- Demonstrated interferometer performance: very promising, still needs optimization, room for improvement
- Work on the design of Reference Module (REFM) boxes at tap points
- Work on the L2RF integration with interferometer links
- Prepared detailed installation and cabling plans

Injector Distribution – Example Link Layout Design



Summary

- System in advanced conceptual design stage
- MO concept established. Signal generation performance proven. Open point is redundancy switching
- Designed distribution scheme
- Inteferometers are tested. Promising results
- Preparation for final designs and installations in 2014

Thank you for your attention !