Amplifier phase noise measurement for bunch arrival time monitor

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Abstract:

The next generation of accelerators and light sources require timing systems with several femtosecond level precision for the synchronization of accelerator subsystems, diagnostics and photon experiments, and it also requires high precision timing diagnostics. Current state-of-the-art beam arrival-time monitors (BAMs) use electrical pickups, and their sensitivity is largely limited by the attainable bandwidth. The project aims to investigate the use of nonlinear optical materials with ultrafast response times (THz range bandwidth) to develop BAMs targeted at achieving femtosecond level precision in determining arrival times.

Compact Linear Accelerator for Research and Applications (CLARA)

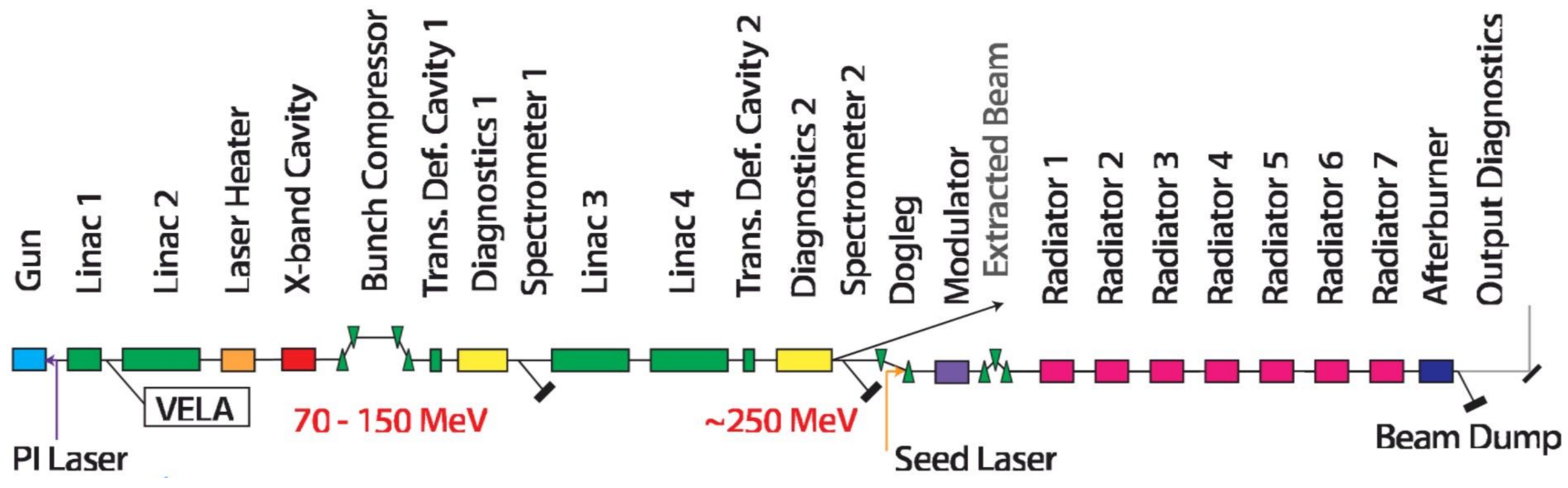


Figure 1. CLARA layout overview

CLARA [1] has been designed to be a dedicated flexible FEL test facility with the FEL wavelengths are in the visible and VUV. It will be a major upgrade to the existing VELA accelerator test facility at Daresbury Laboratory in the UK, and will be able to test several of the most promising new FEL schemes.

Parameter	***Operating Modes***			
	Seeding	**SASE**	**Ultra-short**	**Multibunch**
Max Energy (MeV)	250	250	250	250
Macropulse Rep Rate (Hz)	1-100	1-100	1-100	1-100
Bunches/macropulse	1	1	1	16
Bunch Charge (pC)	250	250	20-100	25
Peak Current (A)	125-400	400	~1000	25
Bunch length (fs)	850-250 (plat-top)	250 (rms)	<25 (rms)	300 (rms)
Norm. Emittance (mm-mrad)	⩽1	⩽1	⩽1	⩽1
rms Energy Spread (keV)	25	100	150	100
Radiator Period (mm)	27	27	27	27

Table 1. Main parameters for CLARA operating modes

Bunch arrival time monitor:

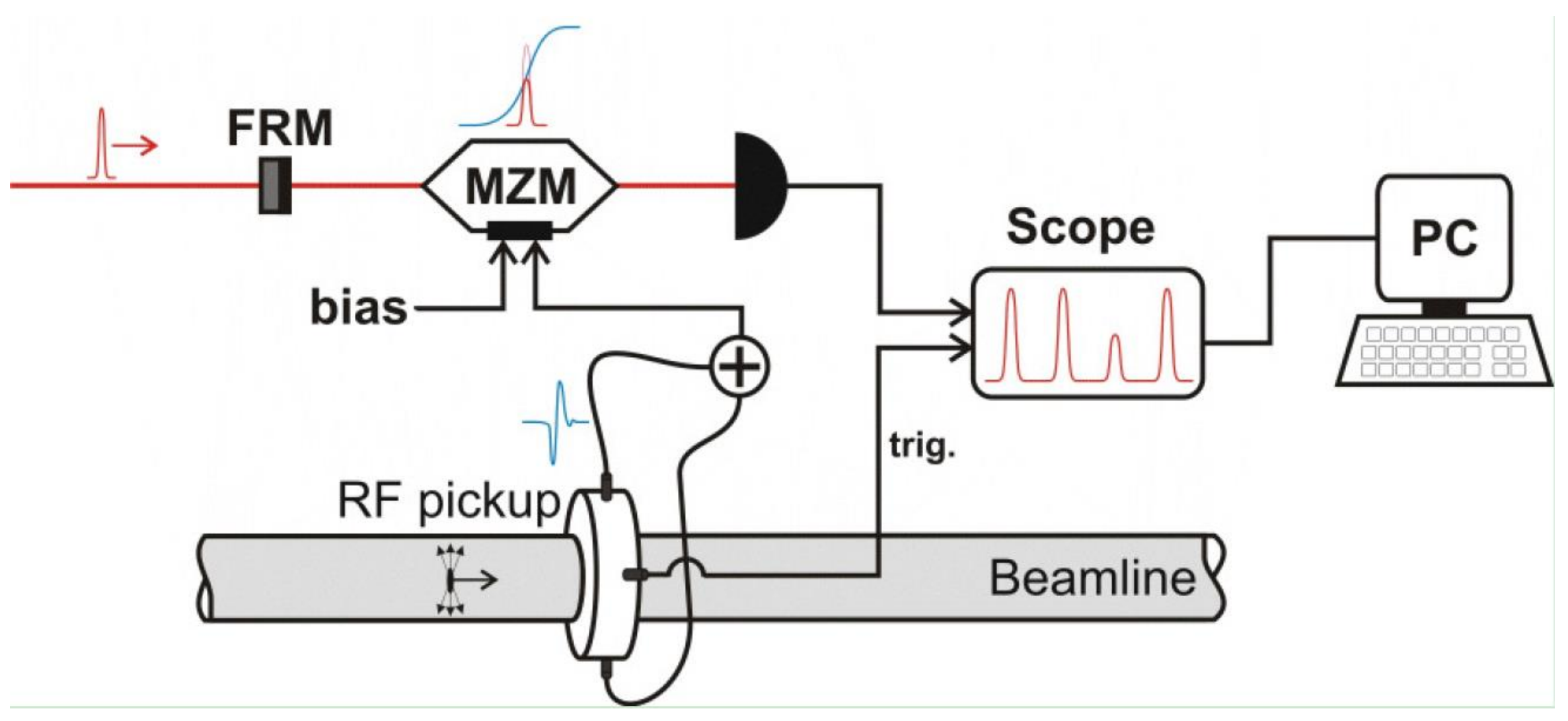


Figure 2. BAM scheme with RF pick up

Replaced by

RF pick up → EO pick up

New challenges:

-- Amplify laser pulse energy with low noise
-- Dispersion compensation
-- Define center of the bunch
-- Conversion back to RF
-- Reliability

Current state-of-the-art BAMs use electrical pickups [2] in the beamline to convert the Coulomb field of passing electron bunches into an electrical timing signal. The electrical signal can then be sampled by the distributed optical clock in an electro-optic modulator to convert beam timing deviations into optical pulse amplitude modulation which can be measured with higher fidelity. The time to amplitude conversion ratio defines the sensitivity of this technique, and is largely limited by the attainable bandwidth of the beamline pickups.

EO materials:

Our fibre laser output pulses at 1550 nm with 70 fs duration. At this wavelength, the performance (phase matching + EO coefficient) of GaAs and $\mathrm{LiNbO_3}$ crystals are better than ZnTe and GaP (which are good at 800 nm and 1 μm respectively). Especially, the r_{33} (31 pm/V) [3] of $\mathrm{LiNbO_3}$ is ~20 times higher than r_{41} of GaAs.

Timing jitter measurement:

Time domain description:

$$\mathrm{v(t)} = V_0 \sin(2\pi f_c t + \varphi(t))$$

Mean-squared spectrum:

$$\overline{\varphi^2(t)} = \int_{-\infty}^{+\infty} S_\varphi(f)df$$

Small modulation approximation:

$$\mathrm{L(f)} \approx S_\varphi(f)/2 \quad \text{[dBc/Hz]}$$

RMS timing jitter [4]**:** $\Delta t_{rms} = \dfrac{1}{n\omega_0}\sqrt{2\int_{f_1}^{f_2}\mathcal{L}(f)df}$

n is the measured harmonic

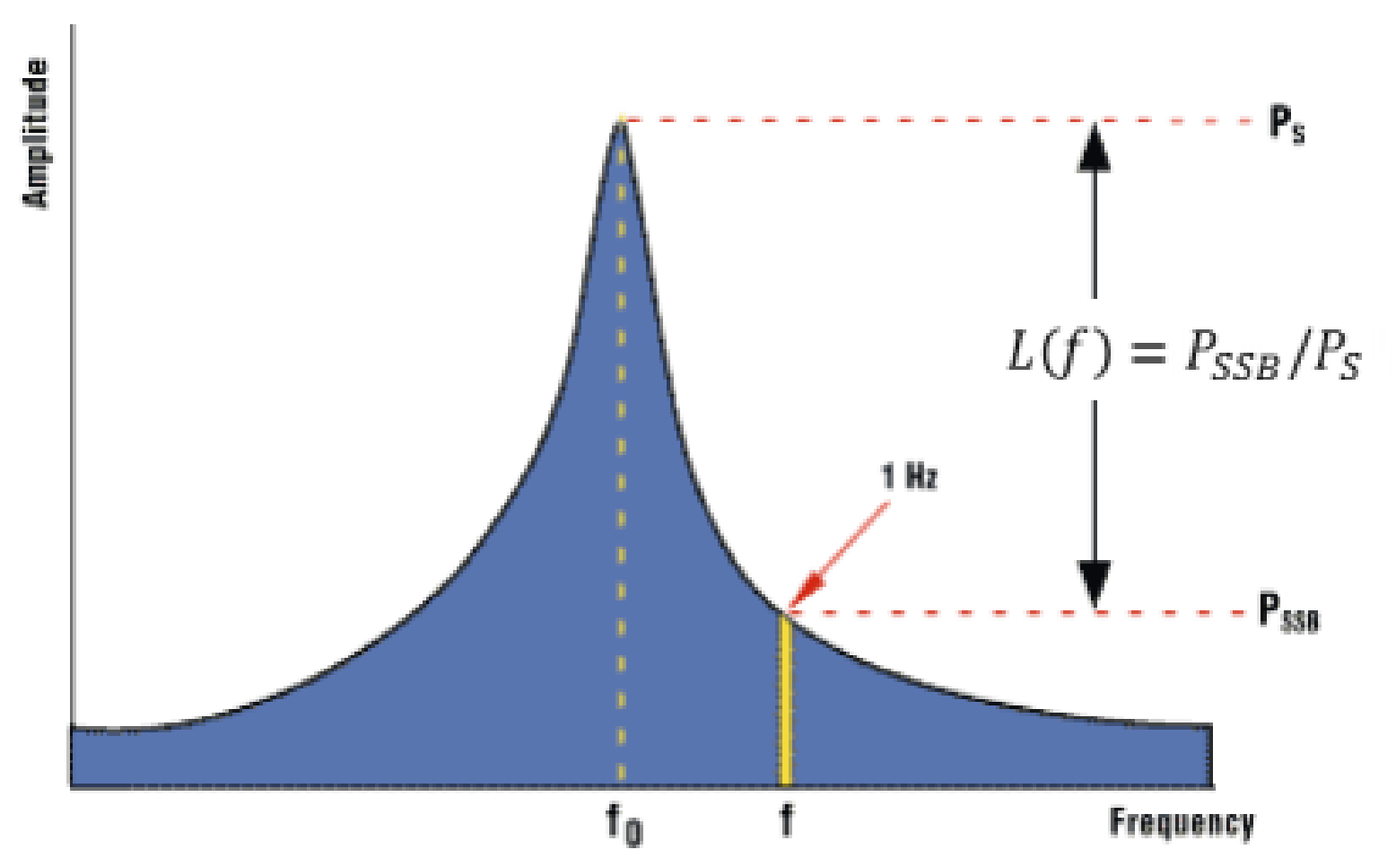
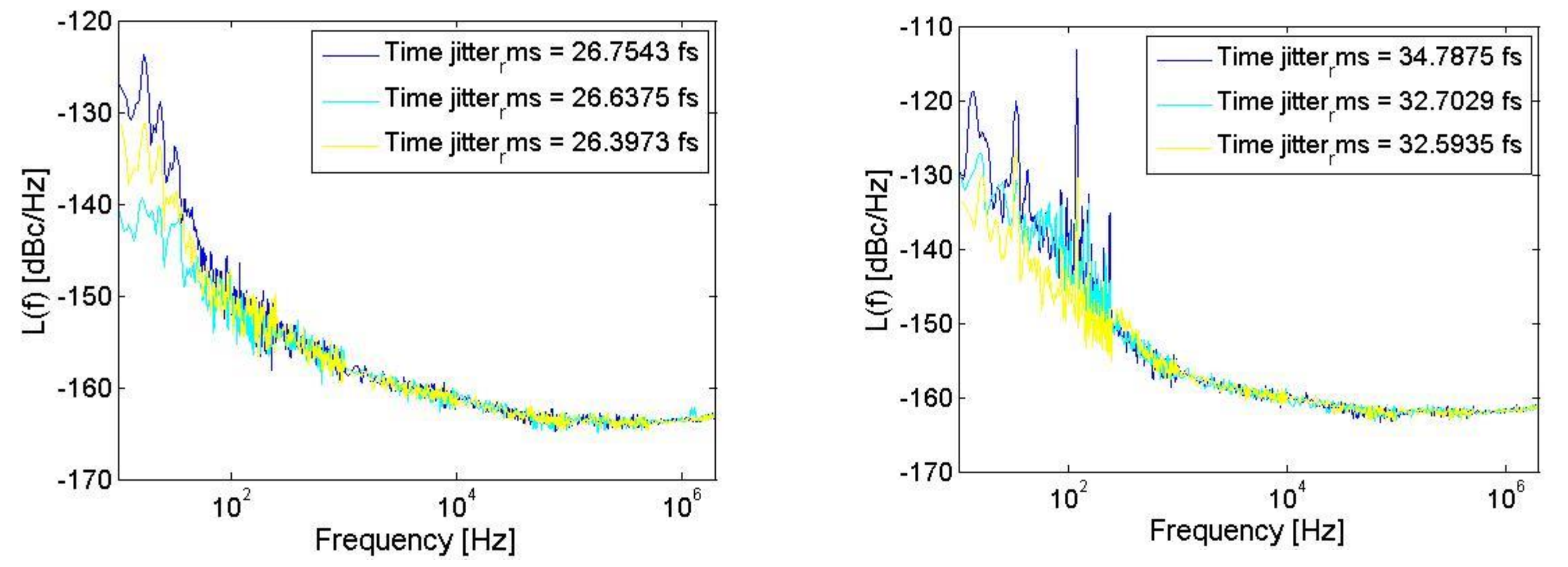


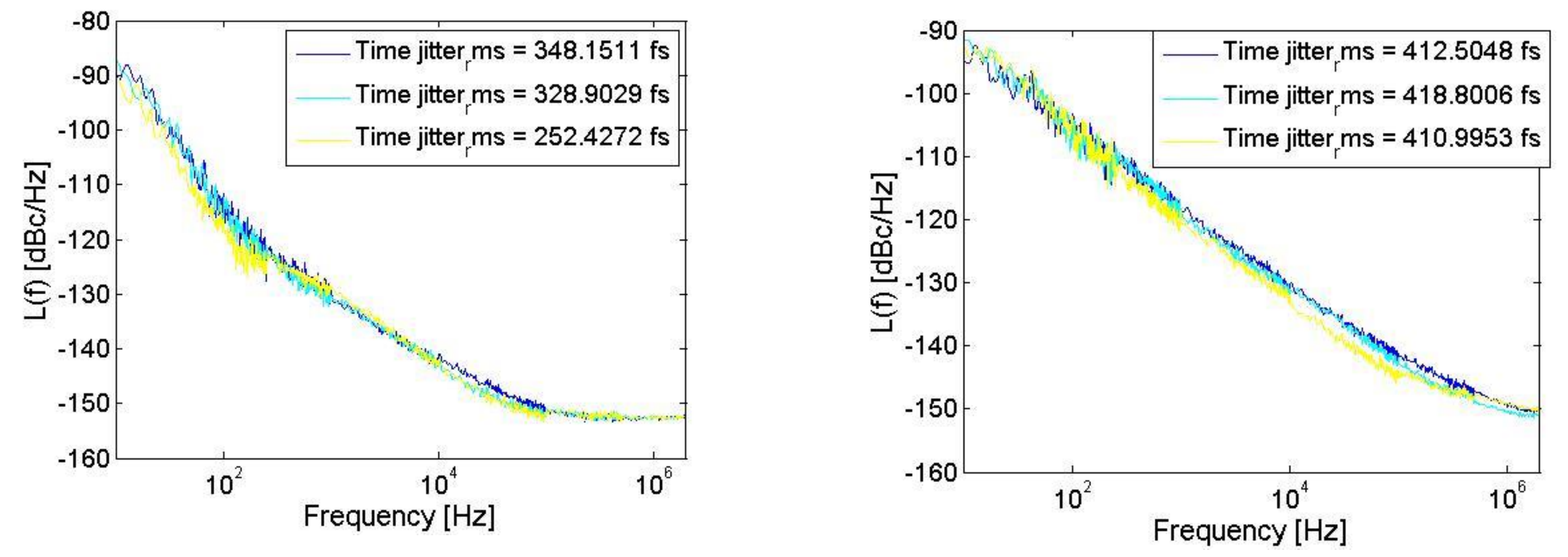
Figure 3. Single-sideband phase noise to carrier ratio

P_S: carrier power
P_{SSB}: sideband power in one Hz bandwidth at an offset frequency of center *f*



(a) Base band noise

(b) Amplifier 1



(c) Amplifier 2, 40 dB gain

(d) Amplifier 2, 50 dB gain

Figure 4. Timing jitter measurement at center frequency 81.25 MHz

Laser pulse propagation:

For an ultrafast laser pulse propagating in fibre, higher-order nonlinear effects and dispersion need to be considered. The split-step Fourier method is used to numerically model the propagation [5]:

$$A(z+h,T) \approx \exp(\frac{h}{2}\widehat{D})\exp(\int_{z}^{z+h}\widehat{N}(z')dz')\exp(\frac{h}{2}\widehat{D})A(z,T)$$

h --segment width; $\widehat{D}$ -- differential operator (dispersion, absorption);
$\widehat{N}$ --nonlinear operator;

Based on the calculation result, the maximum input power and the length of dispersion compensating fibre for the EO BAM can be determined.

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References:

[1] J.A. Clarke, et al., 'CLARA conceptual design report', JINST Vol. 9, No. 05, p. T05001 (2014)

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[5] G. P. Agrawal, Nonlinear Fiber Optics, 3th ed. (Academic, 2001).