Electronic modulation of the FEL-oscillator radiation power driven by ERL

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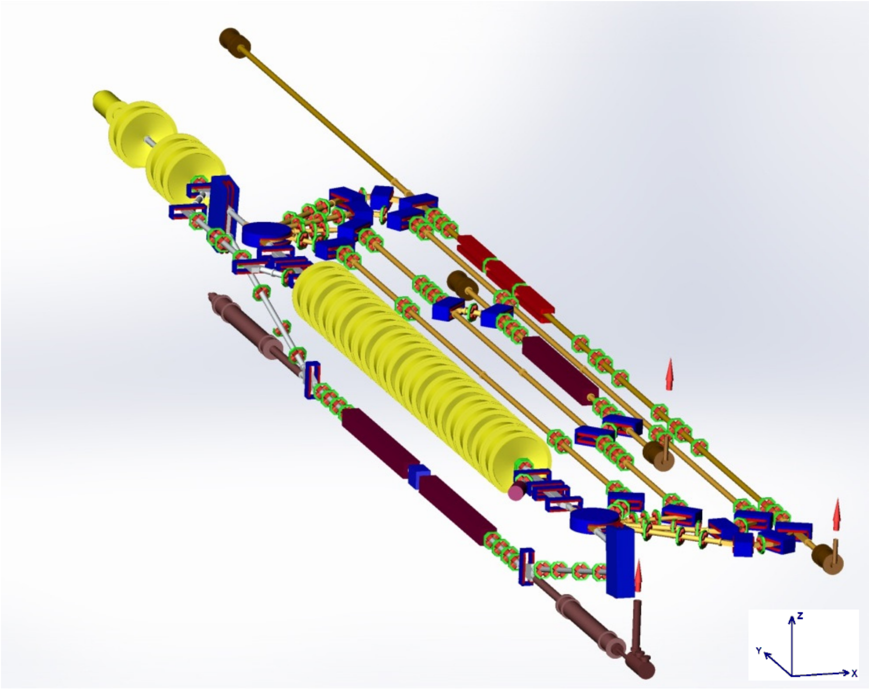
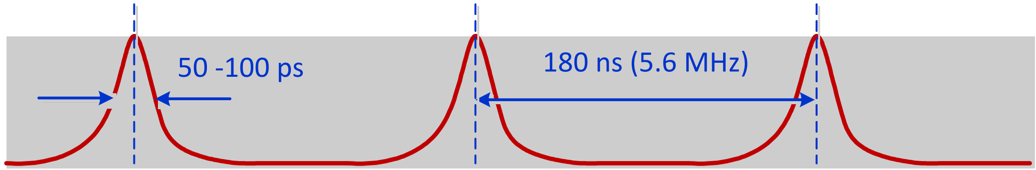
Outline

1. Motivation
2. Possible approaches to FEL power modulation
3. Implementation of power modulation at NovoFEL
4. Experimental results and possible applications
5. Conclusion

1. Initial motivation





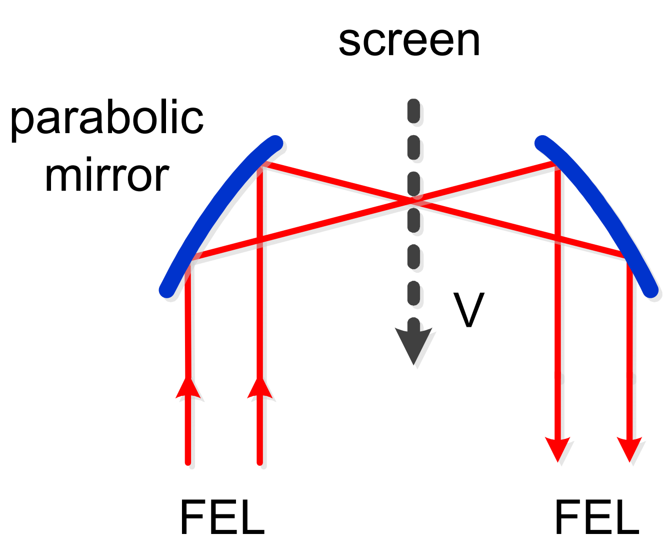
The 1st FEL radiation time structure

- In some experiments users need to reduce the average power but keep the peak one.
- All three FELs of the NovoFEL facility are FEL oscillators and they operate in CW mode.
- Repetition rate of radiation pulses depends on the optical cavity length and almost cannot be adjusted.
- In CW mode average radiation power can be reduced only together with the peak power.

2.

Possible ways to modulate high-power THz radiation

Mechanical

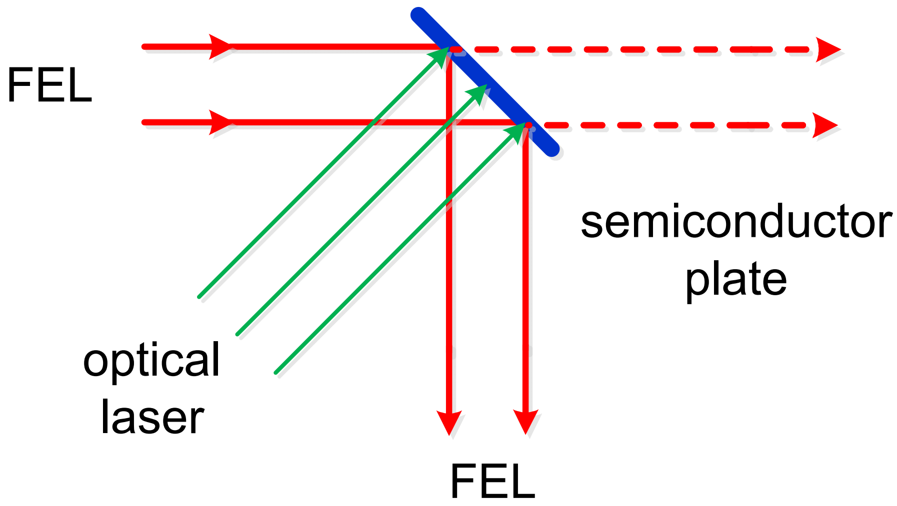


λ ~ 200 μm -> d ~ 1 mm

τ ~ 10 μs -> V = d/ τ ~ 100 m/s

difficult adjustment

Optical



external laser is required

reflectivity is not 100%

2.

"Ideal Final Result" for users

- All external modulation schemes imply substantial modification of user stations.

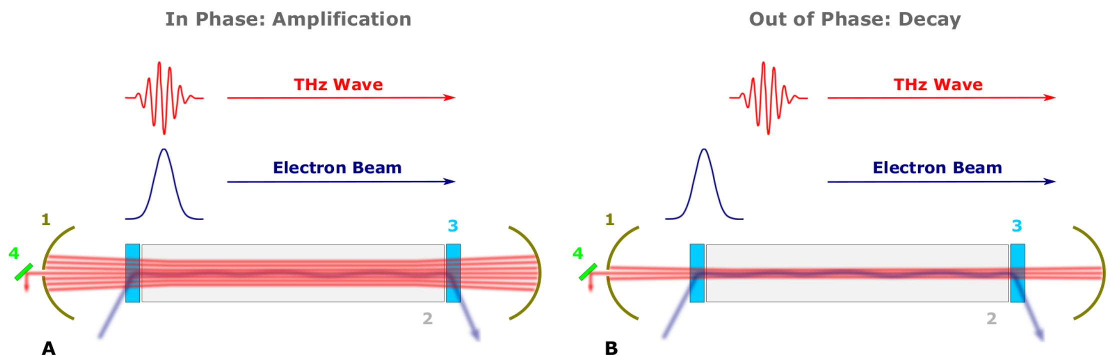
- Any manipulations with the radiation beam can potentially result in decreasing of its quality.

- The ideal solution for users would be that one in which the FEL lasing can be instantly turned on and off in controllable way without any alteration of the user equipment.

2.

- In **FEL** lasing stops when the beam current is turned off but in **ERL** fast switching of the current is not possible because of transient effects.

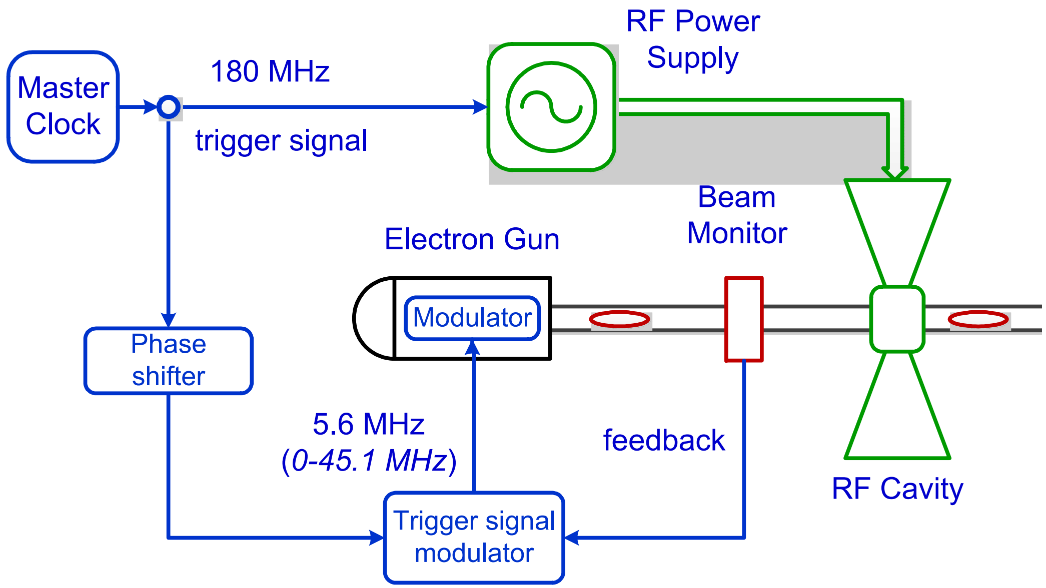
- In **FEL-oscillator** lasing is possible only when radiation and electron bunches come to undulator simultaneously. Periodic delay of the electron bunch can stop lasing.



- Periodic bunch delay is equivalent to reduction of repetition rate but this reduction can be done very small (1% is sufficient to suppress lasing completely).

3.

Implementation of power modulation at NovoFEL

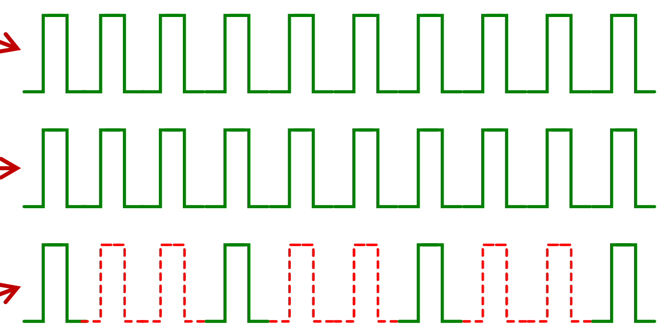


Master clock → generates 180 MHz trigger signal

Phase shifter → periodically bites each Kth pulse

Trigger signal modulator → triggers injection with each Nth pulse

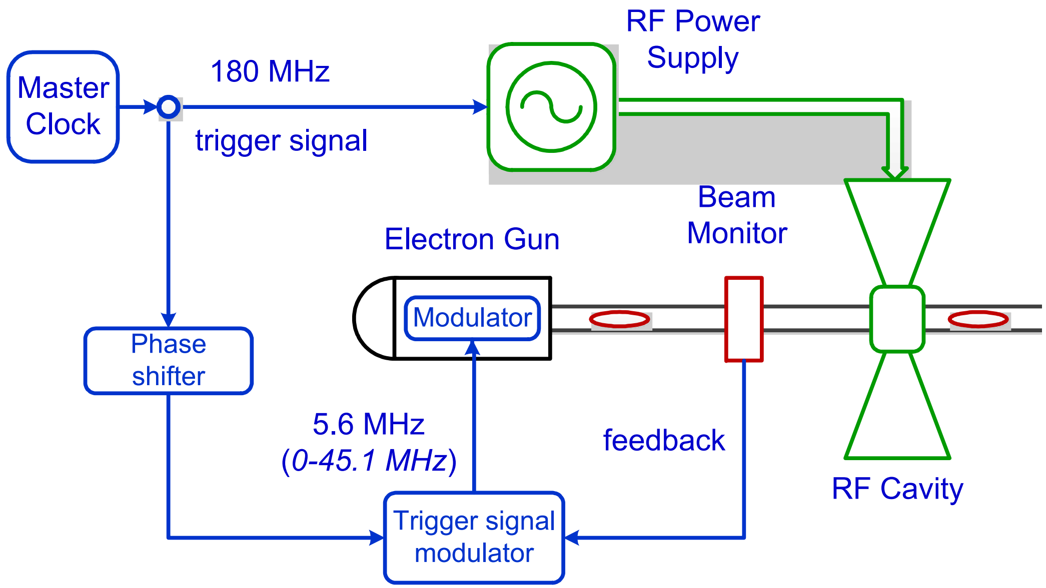
Phase Shifter is Off



(1st FEL N = 32; 2nd FEL N = 24; 3^{d} FEL N = 48)

3.

Implementation of power modulation at NovoFEL



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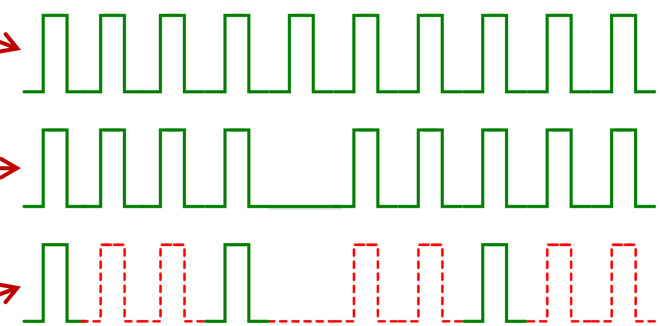

(1[st] FEL N = 32; 2[nd] FEL N = 24; 3[d] FEL N = 48)

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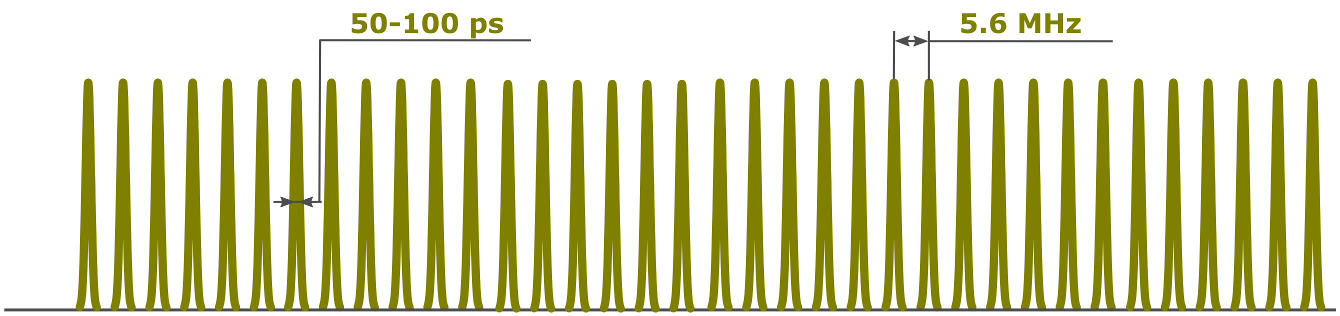
Time structure of radiation

shifter is off



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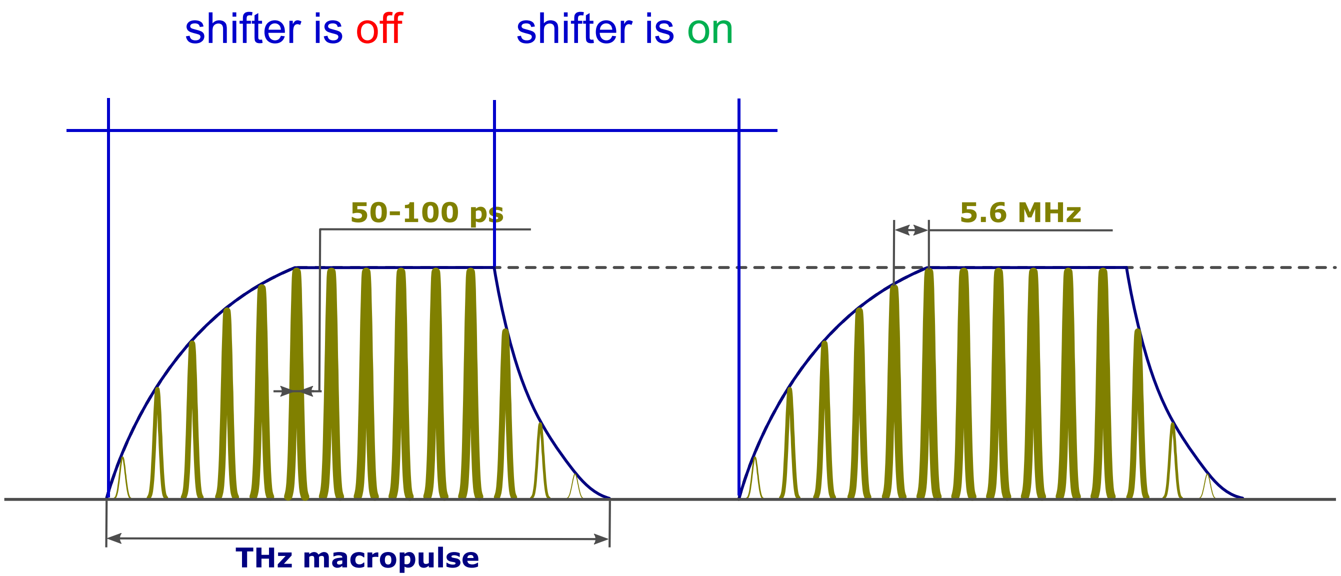

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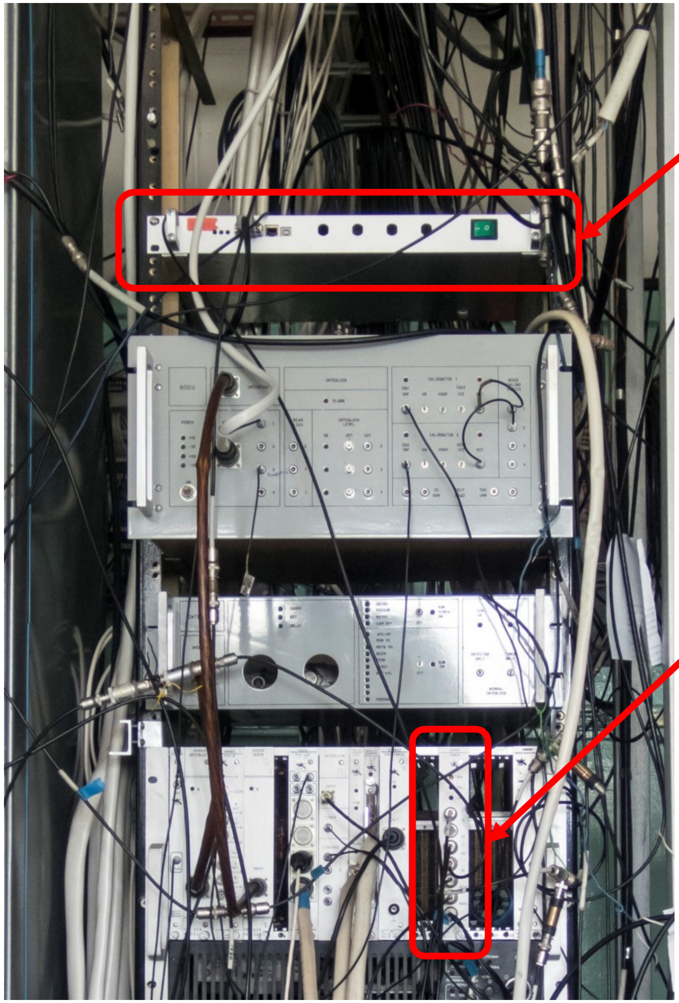
Implementation of power modulation at NovoFEL



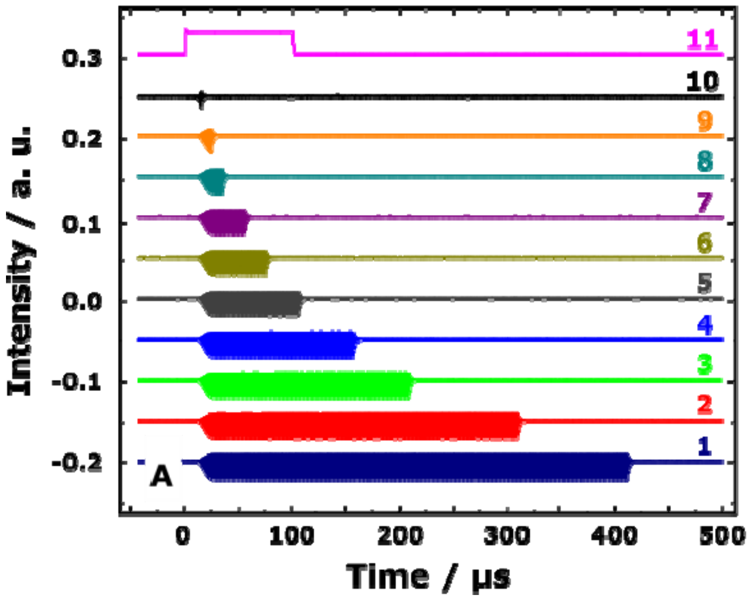
Phase shifter

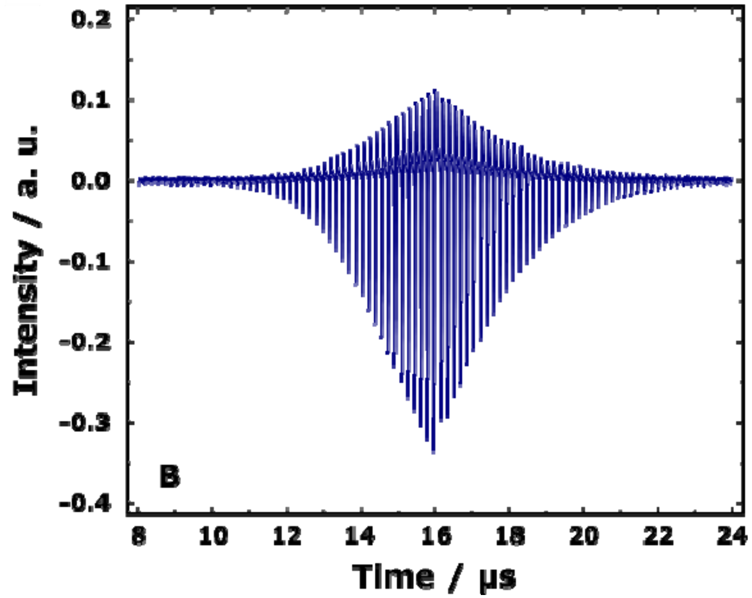
- is controlled through the CAN interface
- can be synchronized with external signal

Trigger signal modulator

old design CAMAC unit

Experimental results





(A) Macropulses of THz (130 μm) radiation durations are (1) 400 μs; (2) 300 μs; (3) 200 μs; (4) 150 μs; (5) 100 μs; (6) 70 μs; (7) 50 μs; (8) 30 μs; (9) 20 μs; (10) 10 μs (multipled by 10); (11) trigger signal. Each subsequent pulse is vertically shifted;

(B) Macropulse with 10 μs duration. The individual pulses of THz radiation with the frequency of 5.6 MHz are clearly visible.

4.

Possible applications

Control of the average THz power in CW regime

- Average power can be stabilized
- Beam losses at recuperation stage can be reduced

Formation of short high-power THz macropulses

- Time resolved experiments can be performed
- Peak power can be conserved while decreasing the average one

Lock-in detection

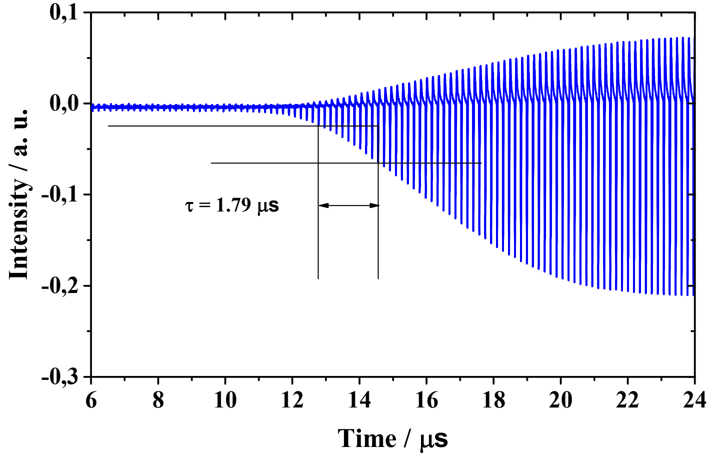
- Signal to noise ratio of measured values can be increased

FEL physics experiments

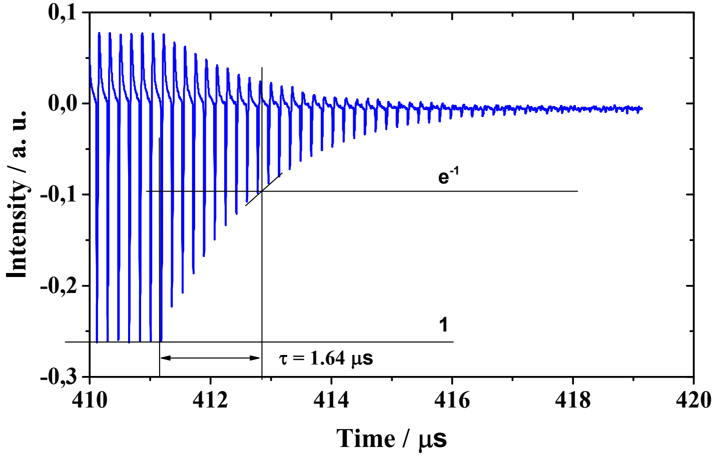
- FEL parameters can be measured including FEL gain and optical cavity losses
- Coherent radiation in electron outcoupling experiments can be observed

4.

Measurement of the FEL parameters



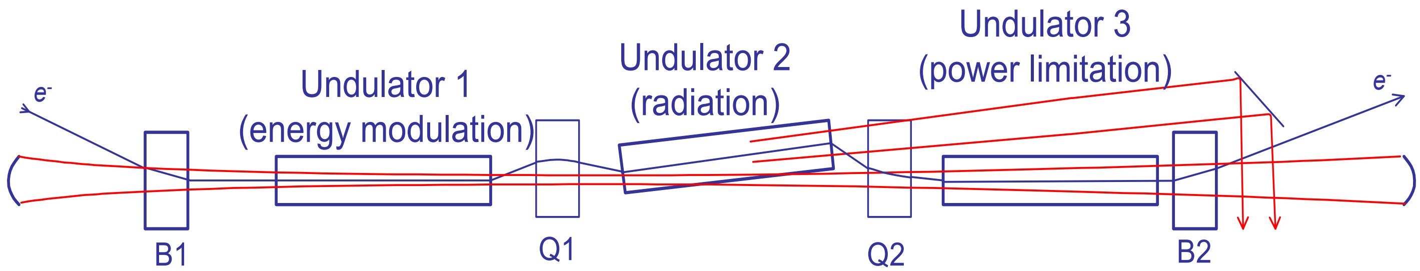
Gain calculation for the 1st FEL. Rise time is 1.79 µs, gain exceeds losses by 9.5 %.

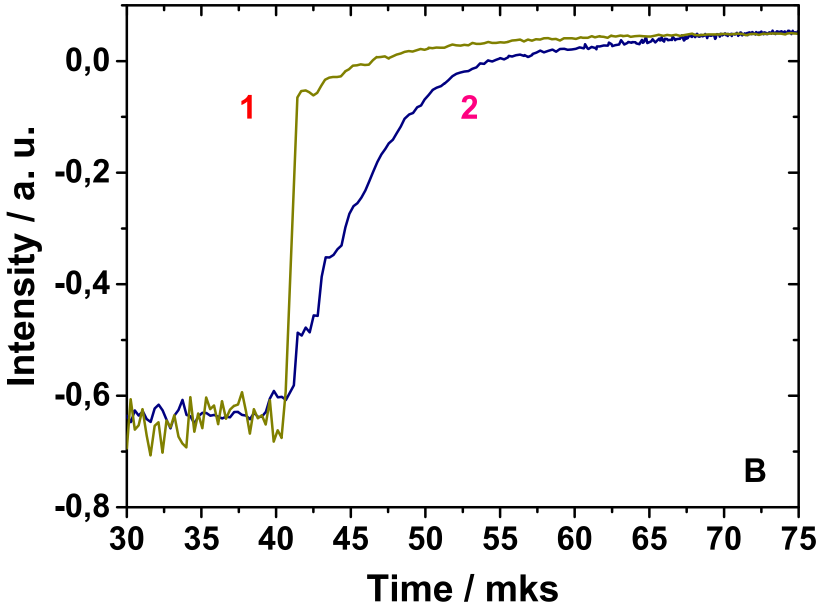


Calculation of the losses for the 1st FEL optical cavity. Decay time is 1.64 µs, round-trip losses are 10.3 %.

4.

Observation of coherent radiation





1 – coherent radiation of electron bunch from the 3d FEL undulator.

2 – radiation from the optical cavity.

Conclusion

- Approach to the creation of THz macropulses at any repetition rate and almost any individual pulse length was developed and implemented at NovoFEL.

- The electronic modulation system (EMS) implementing this approach was embedded directly into the electronic infrastructure of NovoFEL . It can be triggered directly on user stations.

- The EMS provides unique possibilities for users , e.g. control of the average power of THz radiation over a long period of time or creation of macropulses with duration as short as 10 μs.

- In order to characterize EMS, series of macropulses with different durations from 10 to 400 μs were measured at all three FELs of the NovoFEL facility.

- Now the EMS became very popular tool among our users.

The “EMS” Group

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Thank you for your attention!