OPTIONS OF FLASH EXTENSION FOR GENERATION OF CIRCULARLY POLARIZED RADIATION IN THE WAVELENGTH RANGE DOWN TO 1.2 nm

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Abstract

With the present undulator (planar, period 2.73 cm, peak field 0.486 T) the minimum wavelength of 4.5 nm at FLASH is determined by the maximum electron beam energy of approximately 1.2 GeV. On the other hand, many perspective user applications require shorter wavelength radiation and circular polarization. In this paper we perform analysis of a helical afterburner for generation of short wavelength, helically polarized radiation. We consider two options, operation of the afterburner at the second (frequency doubler), and the fourth (frequency quadrupler) harmonics. Since even harmonic of the SASE FEL radiation are suppressed, there is no linearly polarized background radiation from the main undulator. Our simulations show that relatively high level of the radiation power can be achieved in the afterburner, about 60 MW in the frequency doubler, and about 5 MW in the frequency quadrupler.

INTRODUCTION

After an energy upgrade the soft X-ray FEL FLASH at DESY covers a spectral range between approximately 60 nm and 4.5 nm wavelength [1]. With the present undulator (period 2.73 cm, peak field 0.486 T) the minimum wavelength of 4.5 nm is determined by the maximum electron beam energy of approximately 1.2 GeV. On the other hand, many perspective user applications require shorter wavelength radiation.

Here we first remember about the so-called water window, i.e. the range between the K-Absorption edges of carbon and oxygen at 4.38nm and 2.34 nm, respectively. This would allow time-resolved studies of organic molecules below the carbon K-edge. Currently minimum wavelength of FLASH is above carbon edge. In principle, higher odd harmonics of SASE radiation can be used to get radiation in the water window. Relative contribution to the total power of FLASH is about 0.5% for the 3rd harmonic, and 0.03% for the 5th harmonic [2, 3]). A technique of effective frequency doubler can be used to increase radiation power to GW-level in the water window wavelength range [4–6], but up to now these proposals were not discussed for practical realization at FLASH. Here we attach brief description of an afterburner option operating at the 2nd harmonic of the fundamental [4, 5].

Another wavelength range of interest refer to K- and L-absorption edges of magnetic elements which spans from 2.5 nm to 1.4 nm (500 - 900 eV). The complete wavelength range can not be covered with the frequency doubler or the 3rd harmonic. The radiation power of the 4th harmonic is significantly suppressed [7], and only the 5th harmonic (having pretty low power, 0.03% of fundamental) can be used for experiments [8]. It is also important to have circular polarization for experiments with magnetic samples. Solution of the problem of radiation power and polarization can be installation of superconducting helical undulator after the main undulator. Helical undulator is tuned to a resonance with the 4th harmonic of the main undulator. Expected level of output pulse energy is about one microjoule. Since 4th harmonic of the SASE FEL radiation from the main undulator is suppressed, there is practically no background radiation with linear polarization.

THE 2ND HARMONIC AFTERBURNER

An option of second harmonic generation at TTF FEL using an after-burner has been under discussion for several years starting from [12]. Here we present the results of time-dependent simulations of the after-burner scheme. The parameters of the electron beam are given in [4, 5], and the parameters of the undulator and the output radiation are presented in Table 1.

In the after-burner scheme the spent electron beam leaving the main X-ray undulator passes an undulator tuned to the second harmonic. At the exit of the main undulator the

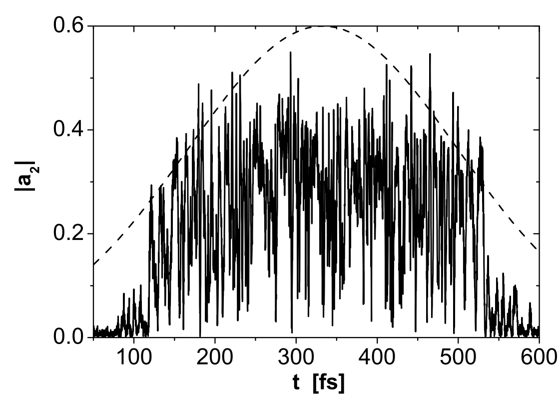

Figure 1: Amplitude of the second harmonic of the beam current at the exit of the main undulator radiating at 6 nm wavelength. The SASE FEL operates at saturation. Nominal beam parameters [4, 5] have been used for the simulation. The dashed line shows the bunch profile.

Table 1: 3 nm Option with Frequency Doubler

Undulator		
Type	planar	helical
Period	1.95 cm	1.95 cm
Gap	10 mm	12 mm
Peak magnetic field	0.39 T	0.26 T
Undulator length	2 m	2 m
Coherent radiation		
Wavelength	3 nm	
Energy per pulse	15 μJ	
Peak power	60 MW	
Bandwidth (FWHM)	0.4%	
Pulse duration (FWHM)	250 fs	

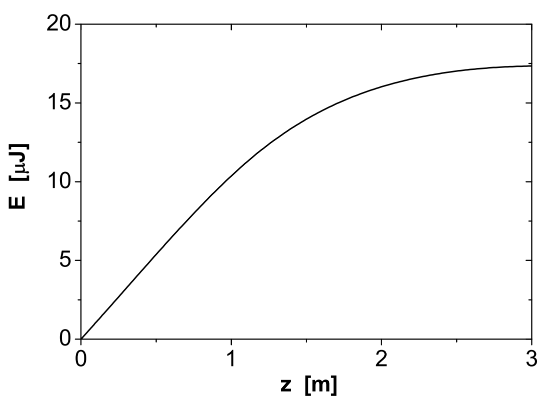

Figure 2: Energy in the radiation pulse versus undulator length in the frequency doubler. The radiation wavelength is equal to 3 nm.

electron beam has a pronounced amplitude of density modulation at the second harmonic which serves as input signal for the second-harmonic undulator (see Fig. 1). When the electron beam enters the after-burner radiator, it readily starts to produce radiation. However, the power growth saturates quickly at 2 meters, as it is seen from Fig. 2. This is due to the large energy spread induced in the main undulator (see Fig. 1). Figure 3 presents the temporal and spectral structure of the radiation pulse at the exit of the after-burner. We find that the FWHM pulse duration is relatively large, about 250 fs. The spectral width is also large, about 0.4%, and is driven by the FEL process in the main undulator. Finally, the level of output radiation power is about 60 MW, i.e. about 3% of the power of the fundamental frequency of the main undulator.

THE 4TH HARMONIC AFTERBURNER

Here we present the results of time-dependent simulations of the after-burner scheme for production of the 4th harmonic at FLASH [9]. The parameters of the electron beam are given in Table 2, and the parameters of the undulator and the output radiation are presented in Table 3. Parameters of superconducting undulator are close to those of a device developed in the framework of International Linear Collider [10]. In the after-burner scheme the spent electron beam leaving the main X-ray undulator passes an undulator tuned to the 4th harmonic. At the exit of the main undulator the electron beam has a pronounced amplitude of density modulation at the 4th harmonic which serves as input signal for the 4th harmonic undulator. When the electron beam enters the after-burner radiator, it readily starts to produce radiation. The power growth saturates at 2 me-

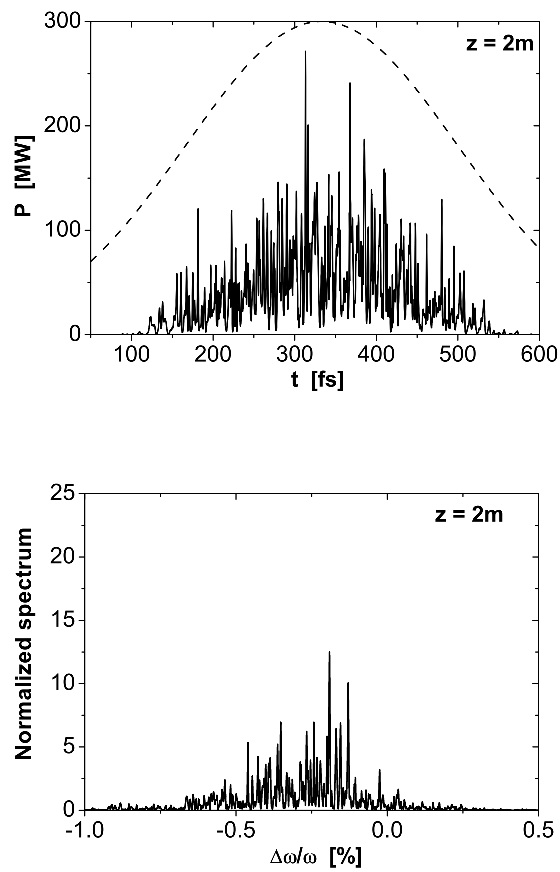

Figure 3: Time structure (top plot) and spectral structure (bottom plot) of the 3 nm radiation pulse for a 2 m long frequency doubler. The dashed line shows the bunch profile.

Table 2: Expected parameters of electron beam at FLASH

Energy	400-1200 MeV
Peak current	2000 A
Normalized rms emittance	1.5 π mm-mrad
rms energy spread	0.25 MeV
rms bunch length	50 μm
External β-function	6 m

Table 3: Parameters of the frequency quadrupler at FLASH

Undulator (4th harmonic)	
Type	helical SC
Period	0.9 cm
Gap	5 mm
Peak magnetic field	0.68 T
Undulator length	1-2 m
Coherent radiation	
Wavelength	1.2-15 nm
Energy per pulse	1 μJ at 1.5 nm
Peak power	5 MW
Bandwidth (FWHM)	0.3%
Pulse duration (FWHM)	200 fs

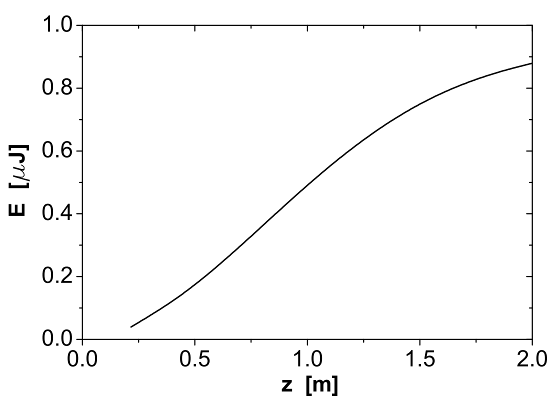

Figure 4: Energy in the radiation pulse versus undulator length in the frequency quadrupler. Undulator period is equal to 9 mm. The radiation wavelength is equal to 1.5 nm.

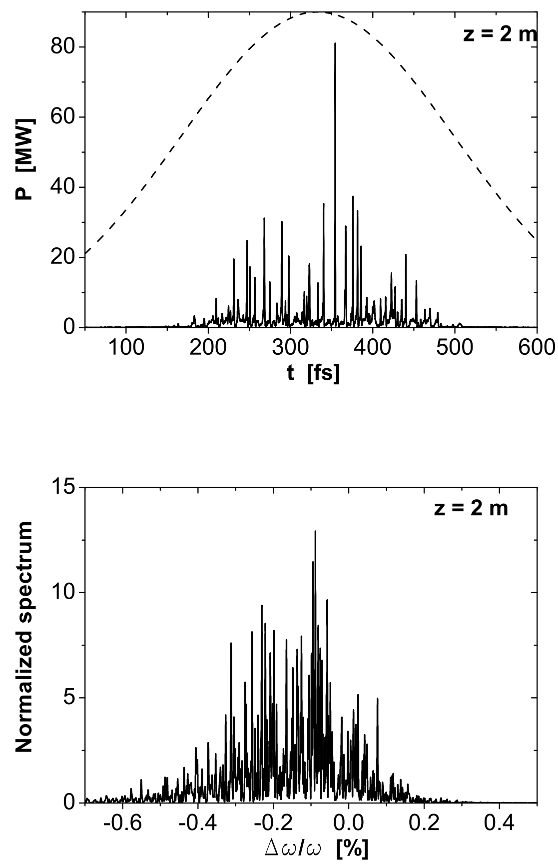

Figure 5: Temporal and spectral structure of the 1.5 nm radiation pulse for a 2 m long frequency quadrupler. Undulator period is equal to 9 mm. The dashed line shows the bunch profile.

ters, as it is seen from Fig. 4. This happens due to the large energy spread induced in the main undulator. Figure 5 presents the temporal and spectral structure of the radiation pulse at the exit of the after-burner. We find that the FWHM pulse duration is about 250 fs. The spectral width is about 0.3%, and is driven by the FEL process in the main undulator. The level of output radiation power about 5 MW, i.e. about 0.3% of the power of the fundamental frequency of the main undulator.

Figure 7 shows the plot of the value of the undulator field versus undulator period providing resonance of the 4th harmonic of the radiation from FLASH undulator. Dependence of the radiation energy at the quadrupler exit versus undulator period is shown in Fig. 8. Radiation energy scales approximately quadratically with the undulator parameter.

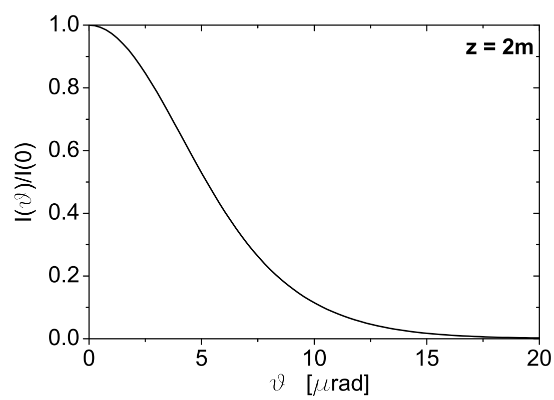

Figure 6: Intensity distribution of the radiation in the far zone. Undulator period is equal to 9 mm. Frequency quadrupler operates at 1.5 nm wavelength.

DISCUSSION

In conclusion we would like to attract attention to the problem of space available at FLASH. Realization of both options (hybrid permanent magnet doubler and SC quadrupler) seems to be problematic, there are only about four

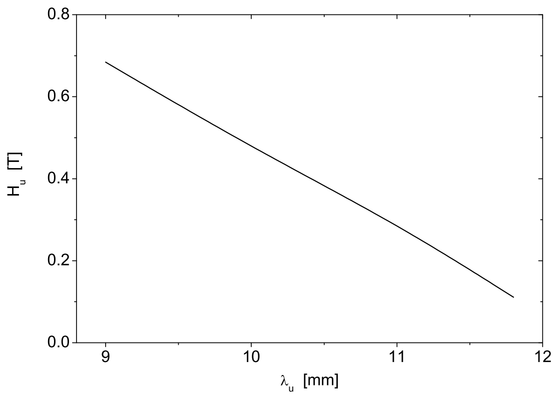

Figure 7: The value of the undulator field versus undulator period providing resonance of the 4th harmonic of the radiation from FLASH undulator. Frequency quadrupler operates at 1.5 nm wavelength.

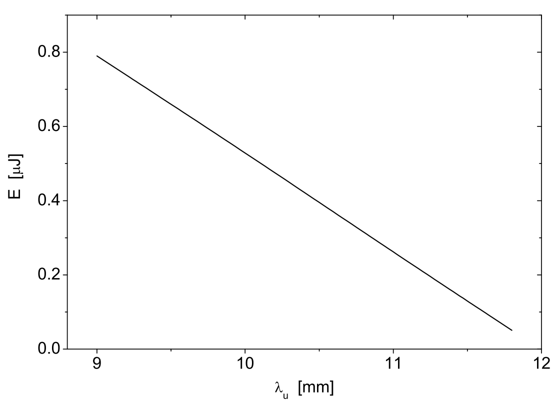

Figure 8: Radiation energy at the quadrupler exit versus undulator period. Length of the quadrupler is equal to 2 m. Frequency quadrupler operates at 1.5 nm wavelength.

meters of ”brutto” space. May be, it would be reasonable to install two superconducting undulators in the cryostat, for the 4th and the 2nd harmonic of the radiation (0.9 cm and 1.5 cm period, 1.5 meters long). Variable period undulator may be considered as well, but this technique is still in R&D stage [11]. This would allow to implement an option of biological experiments in the water window as well.

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