14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA175

IMPROVED SIGNAL DETECTION OF THE STEADY-STATE MICROBUNCHING EXPERIMENT AT THE METROLOGY LIGHT SOURCE

A. Hoehl, R. Klein
Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany
A. Kruschinski, J. Feikes, J. Li
Helmholtz-Zentrum Berlin (HZB), Berlin, Germany

Abstract

The concept of steady-state microbunching (SSMB) as a new scheme for the production of high-average power synchrotron radiation has been demonstrated at the Metrology Light Source in Berlin-Adlershof (MLS).

At the MLS the same undulator section is used for the generation of the microstructures onto the electron bunch as well as for the detection of the resulting coherent radiation from the microbunches one turn later. Due to the enormous difference in the pulse energy of the microbucket generating laser and the coherent undulator pulses showing up 160 ns later, the detection is not straight forward. We show in detail the detection scheme, mostly based on fast electro-optical switches, and the triggering scheme of the experiment.

INTRODUCTION

A storage-ring-based scheme called steady-state microbunching (SSMB) was proposed in [1] to combine coherent emission, as e.g., in case of an FEL, with high repetition frequency for the generation of high average power in a spectral range as far as the VUV and soft X-ray.

SSMB is based on the idea that by a phase space manipulation of the electron beam, microbunching forms and stays in a steady state. So SSMB can be ultimately viewed as s a conventional storage ring but with the role of a radiofrequency (RF) cavity for bunching replaced by a laser modulator. The first important step of developing such a promising light source was to demonstrate the viability of the SSMB mechanism, which means to verify the phase stabilization principle in the optical wavelength range by using a laser modulator to form optical potential well and to longitudinally focus the beam. A first proof-of-principle experiment for the demonstration of this goal was recently successfully performed [2].

The proof-of-principle experiment was performed at the Metrology Light Source (MLS) of the Physikalisch-Technische Bundesanstalt in Berlin [3]. The MLS is the first ring optimized for the low momentum compaction or low-α operation, i.e., the lattice is quasi-isochronous, motivated by the generation of coherent terahertz radiation. It has a circumference of 48 m and two straight sections, one equipped with a 500 MHz RF cavity, and the other one with a 4 m long undulator with a period length of 125 mm and 32 periods, which is used in the SSMB experiment as both the modulator and radiator. A single-shot 1064 nm laser (FWHM 8 ns) with a peak power of MW level is sent into the undulator to co-propagate resonantly with the 250 MeV electron beam that is structured in bunches with a length of approximately 1 ps.

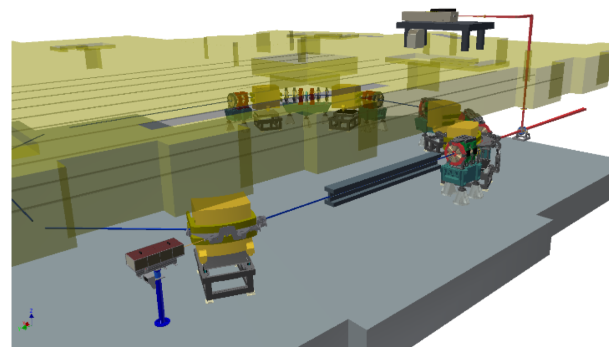

Figure 1: Schematics of the setup: The laser is operated inside the storage ring bunker and overlapped with the electron beam in the undulator straight section. The detection setup is placed in the MLS experimental hall.

After one complete revolution, the energy modulation imprinted by the laser is transformed into microbunching with a period equal to the laser wavelength. This is achieved by carefully tuning the small momentum compaction of the ring. The so created micro bunches then radiate coherently at the laser frequency and its higher harmonics when traversing the same undulator again. The experiment setup is schematically shown in Fig. 1.

The first demonstration of SSMB as reported in [2] was limited by the signal detection because at the MLS the same straight section had to be used for the bunch modulation by the powerful laser and for the detection of the coherent signal 160 ns later, which is orders of magnitude below the laser intensity. Therefore, detection at the first harmonic was not possible because the laser shot would saturate or even destroy the detector used for the detection of the coherent signal. Moreover, because the signal path of the laser and the SSMB signal in the ideal case are colinear, a special separation of these two signals was also impossible. Therefore, a detection of the coherent signal by spectral filtering at the second undulator harmonics, i.e., at 532 nm, was at first the only viable solution.

IMPROVED SETUP

The disadvantage of the SSMB detection at the second harmonic is that the level of the second harmonic signal is more than two orders of magnitude lower than that of the

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA175

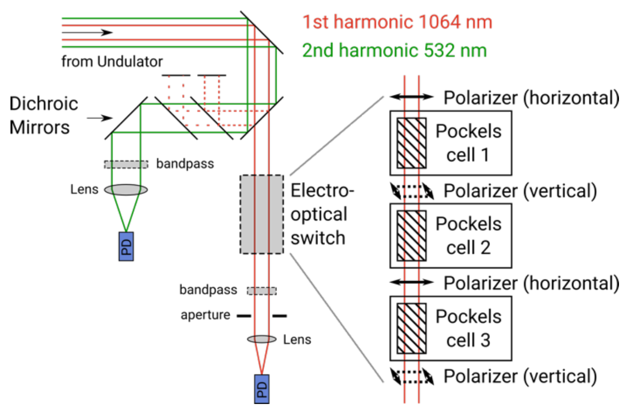

Figure 2: The signal detection setup is based on fast photodiodes. The powerful laser pulse has to be blocked for detection of the coherent signal by a series of three Pockels cells, because it has the same wavelength and direction. The coherent signal of the second harmonic can simply be singled out by optical filters.

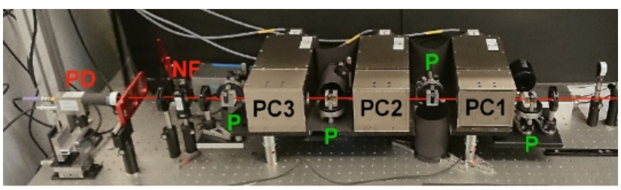

Figure 3: Signal detection setup at the undulator beamline: Three Pockels cells (PC) are placed between crossed polarizers (P). Additional filters (NF) can be placed in front of the photodiode detector (PD).

first harmonic. Therefore, a complex detection scheme for temporal filtering was set up. By means of fast optical switches, the detection path is blocked during the modulation of the beam by the strong laser pulse and is opened thereafter to the record the coherent signal, which is present 160 ns later.

Due to the high difference in signal level, a cascade of three Pockels cells is needed to achieve the necessary attenuation by a factor of 109. The new detector-side setup is schematically depicted in Fig. 2. The detection path at the second harmonics was also preserved. Figure 3 shows a picture of the realized setup.

During first experimental tests it was found that once the detection path is cleared, the remaining radiation from the cw seed laser enters the detection path and disturbs the measurement. In order to suppress the seed laser radiation, a fourth Pockels cell was set up to block the beam path on the laser side after the laser pulse has been fired, as schematically shown in Fig. 4. A photograph of the laser setup in the storage ring bunker is shown in Fig. 5.

The success of the experiment also depends on an exact timing of all the components. The timing scheme is illustrated in Fig. 6. Ultimately, the laser has to be triggered synchronously with the revolution frequency. The master clock is the RF frequency at approx. 500 MHz. From this a phase-locked signal of approx. 10 MHz is created by a highly stable frequency divider. Further frequency division

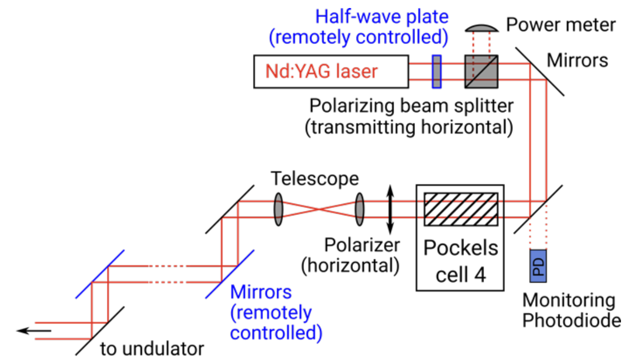

Figure 4: Setup inside the storage ring bunker: A Nd:YAG pulsed laser is used. The laser beam is blocked after the laser shot by a Pockels cell in order to prevent the seeding laser to enter the detection area.

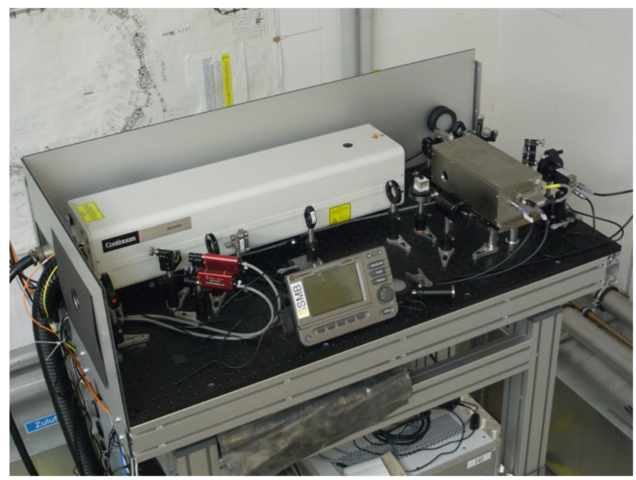

Figure 5: Optical table with the laser setup in the storage ring bunker.

by a factor of 8 million by a delay generator creates the 1.25 Hz frequency trigger signals for the laser and the various Pockels cell drivers with the ability to set the required delays independently. Moreover, the beam imaging systems of the MLS are also triggered to the revolution frequency in order to monitor the beam size only at the time of laser interaction. This is very useful to optimize the spatial overlap of laser and electron beam prior to the SSMB experiment by observing laser-induced beam blowup created if there is significant dispersion at the undulator.

Figure 7 shows an example of the coherent signal recorded at the fundamental harmonic with this improved setup. The upper trace illustrates the time flow: At $t = 0$ ns, the laser is firing when the series of three Pockels cells is driven to maximum attenuation. Still, the transmitted laser light is saturating the detector, but the recovery time is fast. Shortly before the expected coherent signal, after one revolution of the bunch, i.e., after 160 ns, the series of Pockels cells is switched to the maximum transmission, as indicated by the grey line indicating the Pockels cell trigger. The coherent signal at the first harmonic at 1064 nm is clearly recorded as are the signals from the following revolutions. The lower part of Fig. 7 shows the coherent signal

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA175

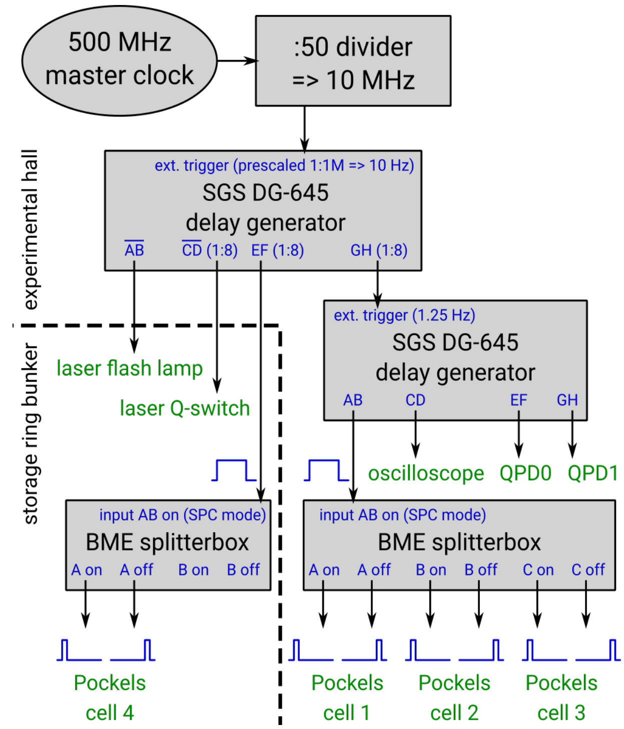

Figure 6: Trigger scheme of the experiment: the laser, the optical switches and the beam imaging systems (QPD0, QPD1) are synchronised to the revolution frequency of the bunches.

after one turn in more detail, resolving the individual signals from neighboring bunches that have interacted with the laser pulse.

The radiation from bunches further away that have not intereacted with the laser cannot be observed, because the intensith is much lower due to radiation's incoherent nature. Additionally, it is more broadband and thus suppressed by the narrow bandpass filter in the detection path.

This sensitive detection at the first harmonics now allows for the detailed investigation of the SSMB process, e.g. the dependance on different parameters as is reported elsewhere [4].

CONCLUSION

The new setup for the direct detection of the coherent signal from the micro-bunches created with the SSMB proof-of-principle experiment at the fundamental harmonics operates reliably. This opens the possibility of signal detection with a much higher sensitivity because the signal level at the fundamental harmonics is more than two orders of magnitude higher than in the case for detection at the second harmonic. This enables thorough investigations of the influence of storage ring parameter variations on the coherent signal and helps to understand the underlying mechanisms more deeply.

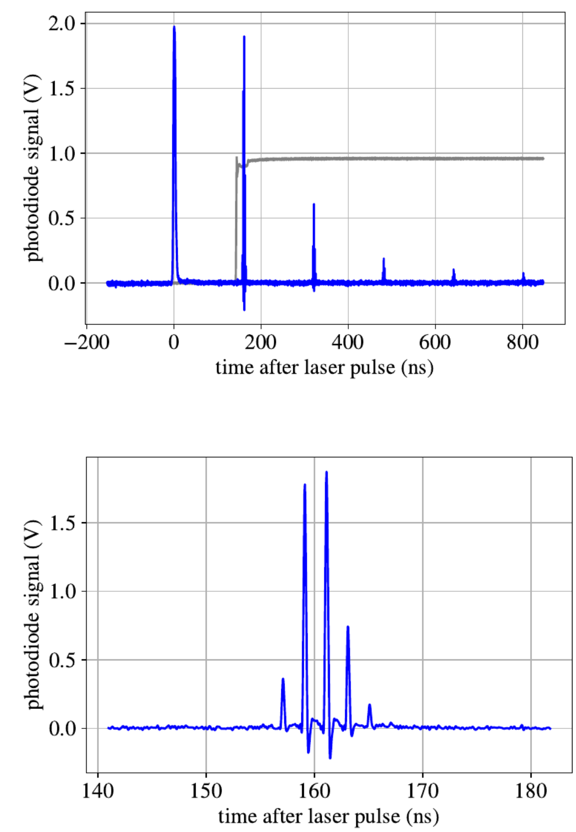

Figure 7: Sample of recorded signal; top: At t=0 ns, the optical switch is still closed and only the attenuated laser shot is recorded. Shortly before the arrival of the coherent signal at 160 ns, the optical switch has been opened (grey trace); bottom: coherent signal after one revolution showing the electron bunches which interacted with the laser beam.

REFERENCES

[1] D.F. Ratner and A.W. Chao, "Steady-State Microbunching in a Storage Ring for Generating Coherent Radiation", Phys. Rev. Lett. 105, 154801 (2010).

[2] X. Deng *et al.,* "The First Experimental Demonstration of the Mechanism of Steady-state Microbunching", Nature, Volume 590, Issue 7847 (2021).

[3] J. Feikes *et al.* "Metrology Light Source: The first electron storage ring optimized for generating coherent THz radiation", Phys. Rev. ST Accel. Beams 14, 030705 (2011).

[4] A. Kruschinski *et al.*, "Exploring the Necessary Conditions for Steady-State Microbunching at the Metrology Light Source", presented at the IPAC'23, Venice, Italy, May 2023, paper MOPA176, this conference.