OBSERVATION OF MICROWAVE RADIATION USING LOW-COST DETECTORS AT THE ANKA STORAGE RING*

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Abstract

Synchrotron light sources emit Coherent Synchrotron Radiation (CSR) for wavelengths longer than or equal to the bunch length. At most storage rings CSR cannot be observed, because the vacuum chamber cuts off radiation with long wavelengths. There are different approaches for shifting the CSR to shorter wavelengths that can propagate through the beam pipe, e.g.: the accelerator optics can be optimized for a low momentum compaction factor, thus reducing the bunch length. Alternatively, laser slicing can modulate substructures on long bunches [1]. Both techniques extend the CSR spectrum to shorter wavelengths, so that CSR is emitted at wavelengths below the waveguide shielding cut off. Usually fast detectors, like superconducting bolometer detector systems or Schottky barrier diodes, are used for observation of dynamic processes in accelerator physics. In this paper, we present observations of microwave radiation at ANKA using an alternative detector, a LNB (Low Noise Block) system. These devices are usually used in standard TV-SAT-receivers and are very cheap. We determined the time response of LNBs to be below 100 ns. The sensitivity of LNBs is optimized to detect very low intensity ”noise-like” signals. This microwave radiation study shows the possibility to apply the LNB for bunch length monitoring.

INTRODUCTION

ANKA is a synchrotron storage ring at KIT (Karlsruhe Institute of Technology) in south-west Germany. The ANKA light source is operated in the range of 0.5 - 2.5 GeV. In user mode, ANKA normally operates at 2.5 GeV and generates synchrotron radiation at 16 dipole magnets with a critical energy of 6.23 keV. Moreover, there are presently three insertion devices installed in the straight sections for dedicated experiments. The typical spectral characteristic of incoherent synchrotron light shows a strong decrease of the radiation power at longer wavelengths. At some point, defined by the coherence condition [2]

$$f_{\text{CSR}} \leq \frac{c}{2\pi\sigma_z}, \tag{1}$$

with σ_z the bunch length, the CSR spectrum starts to dominate. The amplification factor in comparison to incoherent radiation equals approximately the amount of charged particles in the bunch. Operating at 2.5 GeV the nominal bunch length is $\sigma_z \approx 45$ ps, thus we expect CSR below 3.5 GHz. However the low frequency CSR is suppressed by the vacuum chamber inside the dipole magnets. The shielding cut-off frequency at ANKA has been calculated to be approx. 60 GHz [3]. In other words we do not expect any coherent radiation using default ANKA optics. Using dedicated low-α_c optics [4] we can reduce the momentum compaction factor (α_c) and accordingly the bunch length. Measurements using a streak camera has shown the shortening of the bunch length down to a few ps [5]. In the so called ”bursting regime” we observe CSR [6] up to far infrared radiation. Even when using low-α_c optics the CSR below the shielding cut-off frequency is expected to be suppressed. Nonetheless we were able to observe microwave radiation at frequencies far below 60 GHz at ANKA [7]. Furthermore, a signal correlated to the filling pattern was measured using the LNB. In 2002 studies of microwave radiation using zero bias diodes were performed at the VUV ring at the NSLS [8]. These studies clearly showed a case for the use of microwave radiation in longitudinal diagnostics.

DETECTOR DESCRIPTION AND EXPERIMENTAL SETUP

The detector used for this experiment was a standard LNB for TV satellite receivers. The LNB is a microwave mixer with an input frequency in the range of 10.7-12.75 GHz. There are two embedded local oscillators (LO), 9.75 GHz (low band) and 10.6 GHz (high band). Thus we can observe intermediate frequencies (IF) in two ranges: 950-2050 MHz and 1100-2150 MHz. The gain of the embedded amplifier is 50dB. The noise factor of the detector is below 1 dB and it covers a dynamic range of about 20 dB. In our setup the IF signal is fed via a standard coaxial cable into a LeCroy WM 8600A 6 GHz oscilloscope (see Fig. 1).

MOTIVATION

The measurements presented here were performed at the IR1 beamline at the ANKA storage ring. This beamline has been designed to investigate samples using broadband IR radiation. Starting a few years ago IR1 has been actively used by accelerator physicists for different studies using CSR. The reason of the increased interest in CSR is the dependence of the CSR spectrum on both longitudinal bunch length and shape [9]. This, together with progress of fast CSR detectors allows the observation of time resolved processes of longitudinal electron bunch dynamics

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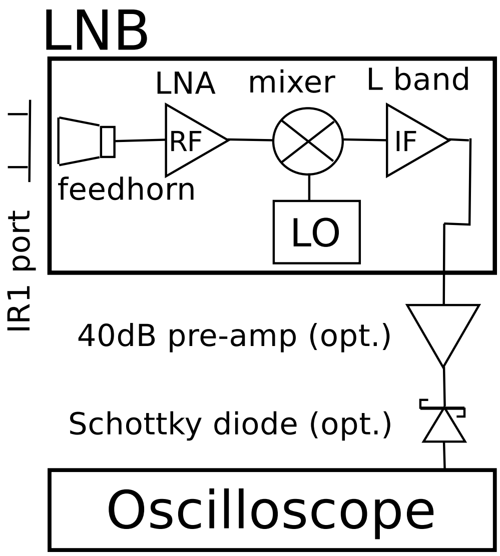

Figure 1: The experimental setup used for the measurement consists of the LNB, amplifier and oscilloscope. It is also possible to rectify the IF signal using a Schottky diode to display the radio frequency (RF) envelope.

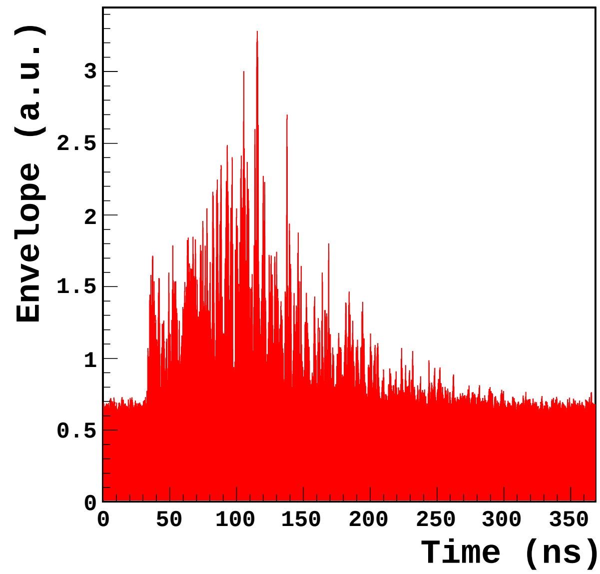

Figure 2: LNB response to a single bunch pulse. The shape was determined in offline analysis summing 100 envelopes (roofs) of single signal traces taken with a 6 GHz oscilloscope. The oscilloscope was triggered using the revolution clock of approx. 2.71 MHz ($T_{rev} \approx 368$ ns.)

[6]. Looking at the development of CSR detectors, we can observe two main trends: bolometric detectors have been developed to cover longer and longer wavelengths in the THz gap. Furthermore, new technologies like the hot electron bolometer (HEB) provide faster measurements with ps time resolution. On the other hand, RF scientists continually design detectors for higher frequencies. Recently both technologies overlap spectrally and hence can be cross-checked. While our group generally uses the HEB detector with CSR, for this study we were also interested in using a cheap RF detector. Although the frequency range of the LNB lies below the CSR shielding cut-off of ANKA, we tried to use the LNB due to its high sensitivity, the simple setup and the availability. A clear signal correlated with the filling pattern could be observed.

RESULTS AND DISCUSSION

The fact that we observed a signal using the LNB at IR1 shows first of all that the beamline transmits electromagnetic radiation in the frequency range between 9-12 GHz. The achromatic optics of IR1 consist of two similar toroidal mirrors. The smallest aperture of IR1 is the diamond window with a diameter of 20 mm located at the focus of both mirrors. We observed that the measured signal intensity at IR1 depends only slightly on the angle of the detector to the beam axis. Hence, we can conclude that the beamline acts at these low frequencies at least partially as a waveguide. The aperture of the diamond window acts in this case as a weak high-pass filter. In order to study the response of the LNB to a single bunch pulse, the storage ring was operated in single bunch mode. Unfortunately, the single shot waveform taken with the 6 GHz oscilloscope has to many noise-like artifacts. Averaging the microwave signal with a not negligible trigger jitter over many waveforms does not significantly improve the result. Of course a preamplifier can be used to increase signal/noise ratio, but that could introduce other artifacts. To overcome the noise problem, we measured the envelopes of 100 single waveforms and assembled them into a histogram (Fig. 2). The histogram shows a clear rise at 45 ns and then many spikes. The spikes have relatively short rise time $\leq$1ns. The duration of the entire signal with 200 ns is quite long, and the maximum of the signal appears approx. 100 ns after the first rise. It is important to note, that we generally observe edge radiation at the IR1 beamline. If we assume that the signal originates from CSR or Coherent Edge Radiation (CER) we would normally expect just one spike as a signal. It is also possible that the broad spike envelope (from around 50 - 220 ns) in Fig. 2 arises from multiple reflections inside the beamline vacuum chamber. However, the clear increase of the spikes around 110 ns cannot be explained this way. Assuming, that the source of the signal are wakefields inside the beam pipe, we could imagine that the increase of the spikes corresponds to resonant structures (generating the wakefields) in combinations of multiple reflections. The numerical calculations of the waveguide modes of the ANKA vacuum chamber predict the fundamental mode H01 to be at approx. 2.21 GHz. The mode density increases rapidly, so that the LNB band covers several modes capable to guide the waves along the vacuum chamber. In addition earlier the studies of the bunch spectrum with Annular Electrode [10] at ANKA have shown higher RF frequency harmonics up to several GHz. After all, the resulting signal could be the sum of these effects.

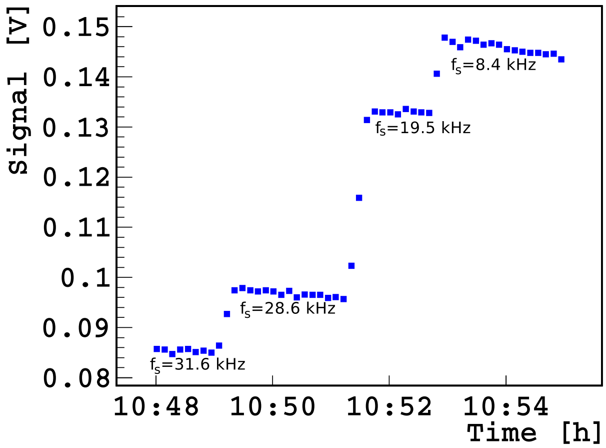

Figure 3: The microwave signal at the IR1 beamline of the ANKA storage ring taken during the low-α_c squeeze procedure. The level of the microwave signal corresponds to the bunch length. We have used preamplifier and Shottky diode setup for this measurement.

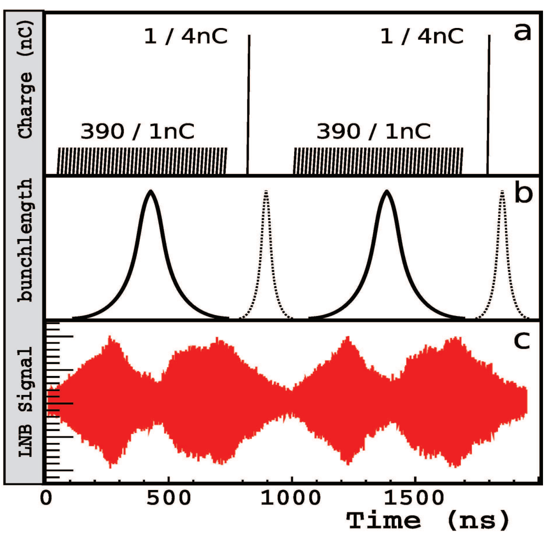

Figure 4: a) Bunch filling pattern of SLS consisting of a train of 390 1 nC bunches with 2 ns spacing and a 4 nC single bunch in the gap. b) bunch length versus bucket number. c) LNB signal of two revolutions at the SLS IR beamline.

During the step by step change of the ANKA low-α optics (squeeze), we see a step by step increase of the LNB signal, see Fig. 3. The squeeze was performed in four steps with an orbit correction in between. The decrease of synchrotron frequency in Fig. 3 corresponds to the shortening of the bunch length.

We also performed similar LNB measurements at the IR beamline (X01DC) of the Swiss Light Source (SLS) at Paul Scherrer Institute in Switzerland. Figure 4c shows the microwave signal of two revolutions. The SLS was running in "camshaft" mode [11] as depicted in Figure 4a. The filling pattern consisted of 390 1 nC bunches with 2 ns spacing and a single bunch with a charge of 4 nC in the gap. Due to the third harmonic cavity of SLS the bunch length strongly depends on the bucket number shown in Figure 4b. The bunch length increases from both edges of the train (40 ps) to its center (<100 ps) [12]. The dependence of the LNB signal on the bunch length can clearly be observed.

SUMMARY

Microwave radiation below the vacuum chamber shielding cut off has been observed at 1.3 and 2.5 GeV at ANKA, and at 2.4 GeV at the SLS. The radiation was detected using the LNB, which is a low cost and very sensitive microwave detector. Once the detector characteristics have been fully understood, it will be possible to develop new diagnostic techniques using an LNB. With a correct calibration of the LNB signal, for example, it should be possible to continuously monitor bunch length changes in the ANKA storage ring.

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