OBSERVATION OF SYNCHROTRON RADIATION USING LOW NOISE BLOCK (LNB) AT ANKA*

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Abstract

Coherent synchrotron radiation (CSR) is observed at different light sources around the world. Generally CSR is produced by short bunches, when the bunch length is shorter or in the order of wavelength. There are different types of detectors for this range of spectrum. We can usually separate them in two categories: slow detectors like a golay cell, pyrometric detector or fast detectors like superconducting bolometer detector systems or mm-Wave Schottky diodes. The first category can be used for imaging or spectroscopy in the THz bandwidth. The second one allows to investigate e.g. dynamic processes of accelerator physics. The Hot Electron Bolometer (HEB) is a member of second group. It is very sensitive and has broad spectral characteristics. Unfortunately HEB detector systems are very expensive and have to be cooled using liquid helium. If the broadband characteristics are not important for the experiment (e.g. intensity measurements in time domain), it will be suitable to use Schottky diodes with a horn antenna as CSR detector. These detectors are considerably cheaper and have an acceptable fast time response, but are less sensitive, if used in the square law region. As a cheap alternative to Schottky diodes an LNB (Low Noise Block) can also be used (see Fig. 1). They are usually used for standard satellite receiver as the first part of the receiver chain. Due to mass production LNB are extremely cheap. Moreover, this detector is optimized to receive very low, noisy signals. In this paper we present our experience with LNBs at the ANKA storage ring in view of accelerator physics.

INTRODUCTION

ANKA is the synchrotron light source of the KIT (Karlsruhe Institute of Technology), Germany. Being a ramping accelerator, it can cover an energy range from 0.5 GeV at injection up to 2.5 GeV in UO (user operation mode). The rms bunch length in this mode was determined to be about 45 ps equivalent to 13.5 mm. Synchrotron radiation in UO shows the spectral characteristics of the incoherent radiation. The CSR will be expected if the following condition is satisfied: [1]

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

where σ_z is the bunch length. The corresponding frequency at ANKA is $f_{\text{CSR}} \approx 3.5$ GHz. But in the actual accelerator the CSR is shielded due to the vacuum chamber inside of the dipole magnets. The dipole chamber CSR cut-off wavelength is described by [2]:

$$\lambda_{\text{cut-off}} \approx 2\sqrt{\frac{h^3}{\rho}} \tag{2}$$

for h being the height of the vacuum chamber and ρ the radius of bending magnet ($h_{\text{ANKA}} = 32\,mm$, $\rho_{\text{ANKA}} = 5.559\,m$). Using ANKA values we get $\lambda_{\text{cut-off, ANKA}} \approx 4.9$mm and the equivalent frequency of $f_{\text{cut-off}} \approx 60$GHz. Correspondingly the CSR at the ANKA storage ring cannot be observed in UO. The power of the CSR for a certain wavelength depends strongly on the bunch length and shape. To generate CSR there are different techniques to manipulate both of them. For example seeding of substructures inside of a long bunch [3] or modifying the magnet optics of the ring to reduce the bunch length. At the ANKA storage ring we use the second one, a dedicated low-α_c-optics [4]. Using this we are able to reduce the momentum compaction factor (α_c) and accordingly the bunch length. The measurements using a streak camera shows the shortening of the bunch length down to a few ps depending on the chosen magnet optics [5]. Due to the short bunch length, the CSR is generated up to $f_{\text{CSR, ANKA}} \approx 1$ THz and therefore can be observed at ANKA. Furthermore, starting at a certain beam current threshold the f_{CSR} lies rather above this value because of the substructures on the bunch profile due to the microwave instabilities and CSR wakefields. This is the so called bursting radiation [8].

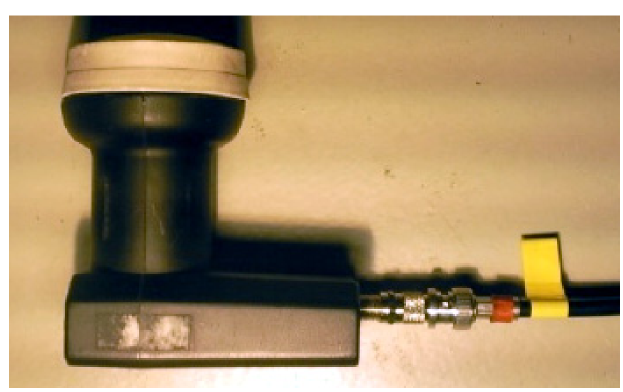

Figure 1: The LNB detector with frequency range 10.7-12.75 GHz is in principle a mixer downconverter.

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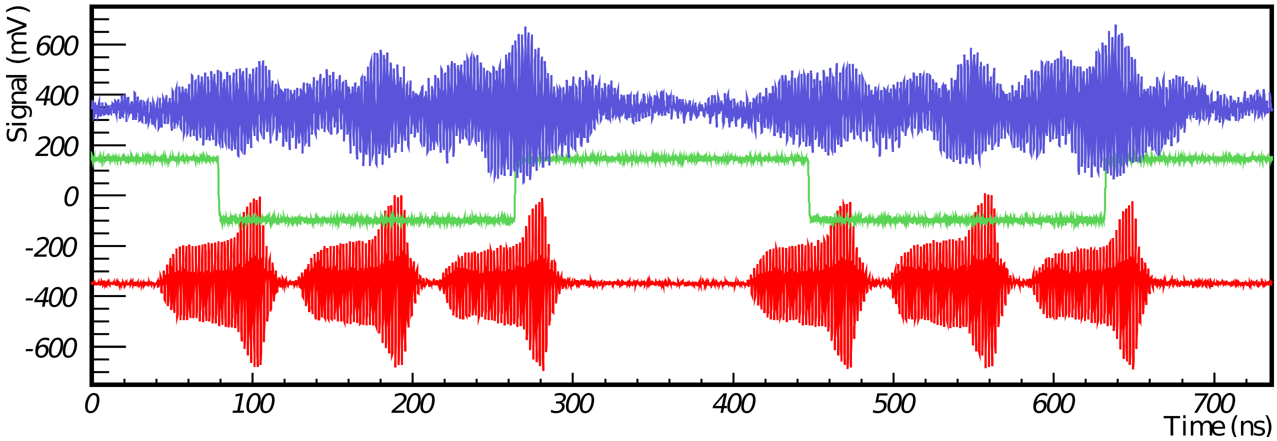

Figure 2: First observations of microwave signal using LNB on IR1 beamline at ANKA (blue, offset: +350 mV, mult. factor: 100). We can also see the revolution clock (green, offset: -100 mV, mult. factor: 1/10) and THz signal from HEB (red, offset: - 350mV, mult. factor: 1).

MOTIVATION

For a few years ANKA has offered beam time in low-α_c-mode for FIR and THz users and accelerator physics studies. The microwave studies presented here were performed at the IR1 beamline. The design of the IR1 was initially adapted for the needs of infrared spectroscopy and ellipsometry. The entrance edge of the bending magnet was chosen as the source due to better angular characteristics in comparison to a bending radiation in the FIR. The beamline optics consist of two flat and two toroidal metallic mirrors. The setup is a Gaussian telescope and correspondingly achromatic for Gaussian waves. This fact allows us to perform measurements using THz and microwave radiation at IR1. The accelerator physics studies performed at IR1 usually use THz detectors like a silicon bolometer, a Golay cell [7] or an ultrafast superconducting Hot Electron Bolometer [8]. The detectors are each selected for specific tasks (e.g. good temporal resolution, high sensitivity, etc.). Recently the interest in time resolved studies of CSR has increased. The main point of attention is the possibility to observe longitudinal dynamics of the electron bunches. Unfortunately, ultra fast THz detectors are very expensive and are rather complex in operation. E.g. the HEB detector system has a time response of about 165ps [9], but it has to be evacuated and cooled down to 4 K using liquid helium. Zero biased Schottky barrier diodes are about one order of magnitude cheaper than fast bolometers but they have only a small bandwidth and are less sensitive. Looking for a simple low-cost alternative an LNB was taken into account.

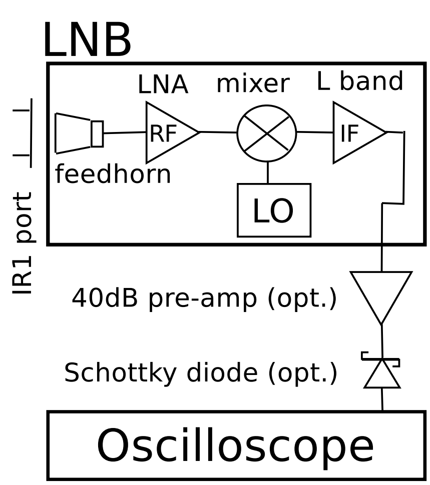

Figure 3: The experimental setup consists in principle of the LNB and oscilloscope. The output signal in the 1-2 GHz IF band can be rectified using a Schottky diode for a more convenient display of the rf envelope.

DETECTOR AND EXPERIMENTAL SETUP

LNBs are normally used in TV satellite receiver. The signal is fed into a microwave mixer by the conical horn antenna using a band pass filter and a low noise amplifier. The nominal frequency range of the LNB ranging from 10.7-12.75 GHz (K_u-Band). The down mixing process use a local oscillator (LO) typically with 9.75 GHz (low band) or 10.6 GHz (high band). The intermediate frequency (IF) range of the mixer is 950-2100 MHz. The signal will be fed into the coaxial cable using L-band amplifier. The noise figure of the detector lies below 1 dB that is equivalent to the noise temperature of 75 K. The LNB is build to cover different transponder power and dish sizes, therefore it has a reasonable dynamic range of about 20 dB [6].

The experimental setup consists of LNB, a 40 dB L-Band Amplifier, TV receiver as power supply and a LeCroy WM 8600A oscilloscope (see Fig. 3). The IF signal was amplified and given to the oscilloscope. In some cases a Schottky diode as IF detector was used.

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OBSERVATIONS

The frequency range of the LNB lies below the dipole CSR cut-off frequency at ANKA. Nevertheless we tried to use the LNB due to the uncomplicated setup. This is the greatest advantage of the LNB. During the first measurement, we observed strong correlation of the signal with the filling pattern of the ring and also the THz signal, which was taken using the HEB detector system (see Fig. 2). Due to the IR1 beamline setup we expect a focused beam, but the power of signal depends only weakly on observation angle in the range of more than $\pm 45°$ off axis. That shows, that the vacuum chamber of the beamline acts as a waveguide at these frequencies. The strongest signal was observed on the axis. The S/N ratio depends strongly on angular position and distance from the z-Cut Quartz window of the IR1. We assume that this is the effect of diffraction or multiple reflections inside the beamline vacuum chamber. Running in a single bunch mode the corresponding microwave signal can be easily observed at ANKA using a LNB. (Fig. 4). The time response of the detector is below 100 ns. Using this setup we can easily resolve single turns. This can be used for multiturn analysis as well.

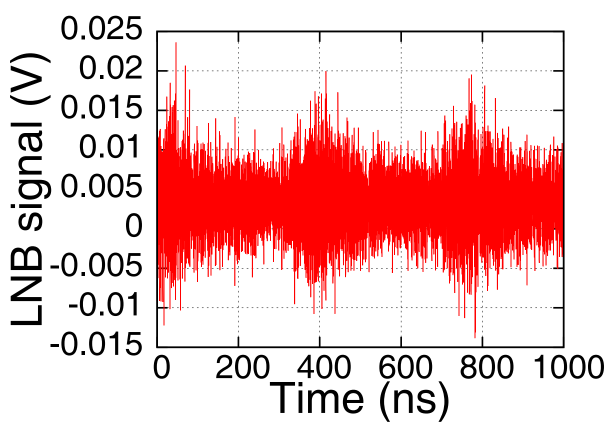

Figure 4: LNB signal after downmixing with three turns in single bunch mode at ANKA.

SUMMARY AND OUTLOOK

The microwave signal was observed at frequencies below CSR dipole cut-off frequency using LNB. We assume that the source could be the wakefields. On the other hand, it could also be CSR because the relationship (2) is only given for bending radiation, but the IR1 has edge radiation as the source. Due to this fact the relationship (2) may not be applicable for these conditions. Add to this the waveguide cut-off of the beampipe was numerically calculated to be around 2.2 GHz. In short, the nature of microwave radiation in K_u-band at the ANKA storage ring has not been understood fully, yet. The dependency of the LNB signal over beam current shows with slightly higher significance quadratic behavior (see Fig. 5). It is important to mention that we measured the amplitude of IF on the oscilloscope. That is proportional to the amplitude of electrical field of the rf wave. To get trustworthy results a linearity measurements of the LNB response should be performed. Summing up the LNB is a low cost, very sensitive microwave detector that can be used as diagnostic tool on synchrotron light sources.

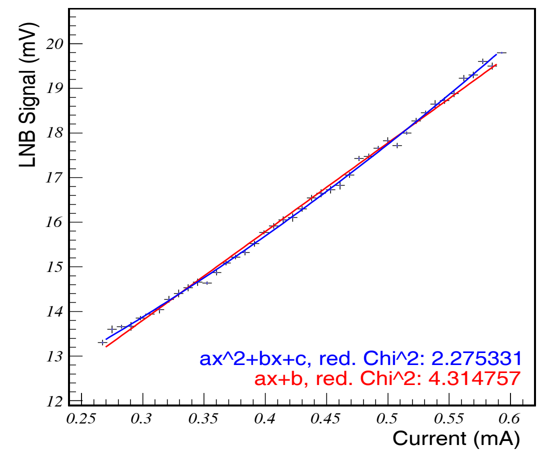

Figure 5: Decrease of LNB Signal vs. beam current shows a highly significant quadratic characteristic.

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