INVESTIGATING POLARISATION AND SHAPE OF BEAM MICROWAVE SIGNALS AT THE ANKA STORAGE RING

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Abstract

At the ANKA synchrotron radiation facility measurements in the microwave range (10 to 12 GHz) employing a LNB (Low Noise Block), which is the receiving part of a Satellite-TV system, have been carried out. Experiments showed that the observed signal depends on the length of the electron bunches. Furthermore the temporal shape of the microwave signal depends on the detector's position along the accelerator. Due the LNB antenna's sensitivity to polarisation it was also possible to measure the polarisation along the several ns long signal, revealing polarised and non-polarised regions. This paper describes the experimental setup and summarises the observations of the systematic studies performed with the LNB system.

MICROWAVE RADIATION AT ANKA

Earlier experiments at ANKA, the synchrotron radiation facility of Karlsruhe Institute of Technology (Karlsruhe, Germany) showed that there is an electron beam correlated microwave signal visible at the infrared beamline IR1 [1], [2]. Further studies performed at the IR2 beamline and at the synchrotron light monitor port (SLM) confirmed these first observations. The detection of microwave radiation is an interesting fact since the coherent synchrotron radiation (CSR) suppression threshold frequency at ANKA can be calculated using [3]:

$$f_{\text{CSR,thr.}} = 2c\sqrt{\frac{h^3}{\rho}} \approx 60\,\text{GHz}$$

where c is the speed of light, $h = 32\,\text{mm}$ is the height of the ANKA vacuum chamber, $\rho = 5.559\,\text{m}$ is the ANKA bending radius. Although the waveguide cut-off at ANKA lies around 2.3 GHz.

DETECTION OF MICROWAVES

The LNB is a low-cost standalone microwave detector with a noise figure of ≈0.5 dB. Figure 1 shows a schematic drawing of the LNB. It consists of a feed horn that focuses the incoming radiation to the antenna within the horn. Afterwards a bandpass filter selects the receiving frequency band of television, which is then amplified by a low noise amplifier (LNA). The rf signal is mixed down using a local oscillator. The resulting difference frequency is separated from other mixing outcomes through another bandpass filter. A second LNA provides a clean signal above the noise level. This signal is a an exact but just frequency shifted replica of the input signal.

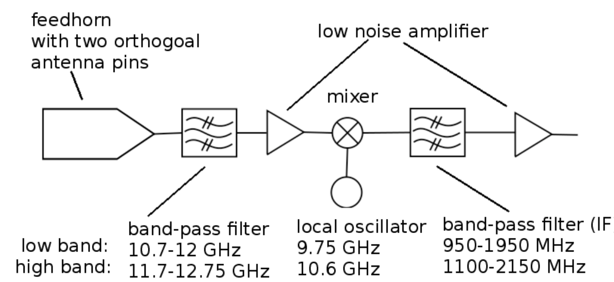

Figure 1: Schematics of the LNB principle. The central component is the rf-mixer to convert the signal to an easily handleable intermediate frequency of 2 GHz.

OBSERVATIONS

The results of microwave studies based on measurements at different positions (IR1, IR2, SLM) of the ANKA storage ring are presented here. The main point of attention was the characteristics of the detected microwave signal.

Polarisation Studies

The polarisation dependence of the signal at the IR1 beamline was measured to investigate the microwave signal's origin at the synchrotron radiation facility. The infrared beamline provides large aperture optics. Thus the transmission in the microwave range in form of free electromagnetic waves or waveguide modes of the beamline pipe is expected. In Fig. 2, on the left plot the typical LNB signal with a rise synchronously to a single electron bunch pass is shown. After the first rise the signal increases for around 50 ns and then decreases during the next 200 ns to the noise level. Hypothetically only the first rise of the signal is caused by CSR. And the long signal tail is taken to be scattered fields, which are caused by discontinuities of the vacuum chamber and propagate to the experiment. This was investigated by rotating the linearly polarised LNB detector around the beamline axis. Thus measuring the average signal intensity of the first 4 ns of the LNB Signal (marked blue) for different detector orientations. We observe that the signal is significantly polarised, as shown in Fig. 2 (middle). For zero rad we observe maximum intensity. The vertical plane is adjusted to 0 rad. The observed linear polarisation corresponds to the expected characteristics of the synchrotron radiation for long wavelengths. The same analysis was also done for the trailing signal beyond the first 4 ns marked red in Fig. 2. As it is shown on the right plot in Fig. 2, the signal does not have a clear polarisation preference. The signal rise at about 2 rad can be

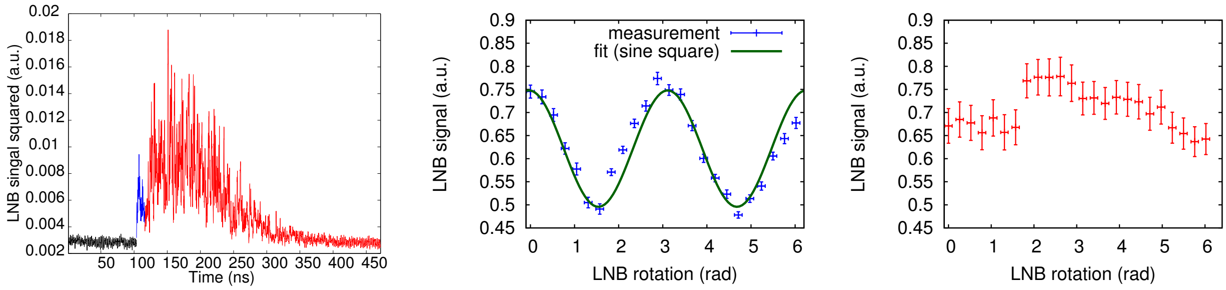

Figure 2: Left: Trace of the LNB detector signal. The blue part of the signal is used for the analysis shown in the middle plot and is clearly polarised. The red coloured long tail is not polarised. In the middle and right figure the change in signal strength due to a rotation of the detector and therefore changed detected polarisation is shown. For the first peak (blue part) the middle figure shows a sine squared behaviour. That is expected for the detection of polarised radiation with a polarisation sensitive detector. On the right figure the same analysis has been done for the red coloured signal tail, but the signal is significantlyless polarised.

explained through the decaying beam current. The change of the CSR intensity due to the change of charge was taken into account, but the small bunch length change corresponding to the current dependent bunch lengthening [5] was not. The observed polarisation property at the IR1 beamline is an indication for the combined nature of the signal source.

Geometrical Characteristics

In addition to polarisation also the geometrical properties of the microwave source at ANKA were investigated. The dependence of the signal intensity on the longitudinal distance between source and detector can give a useful hint to the nature of the signal origin. Figure 3 shows this measurement with a decay of the signal. Purely geometrical considerations lead to a hyperbolic signal dependence. The reason is that the constant surface detector covers only a set amount of the irradiated solid angle which decreases with the distance to the source. Lateral movement of the microwave detector is shown in Fig. 4. The result cannot be explained by a single Gaussian distributed source, but well using a sum of 2 Gaussians. This fact supports the hypothesis of two signal sources, made in the polarisation chapter.

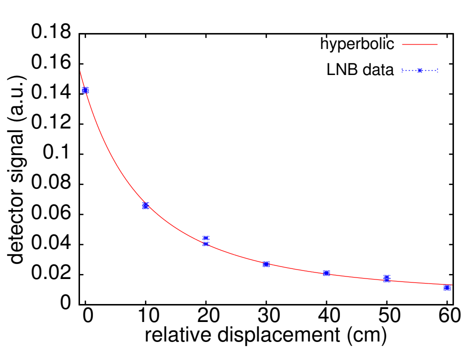

Figure 3: Increasing the longitudinal between source and detector the measured signal decreases. A reasons could be the divergence of the radiation (hyperbolic).

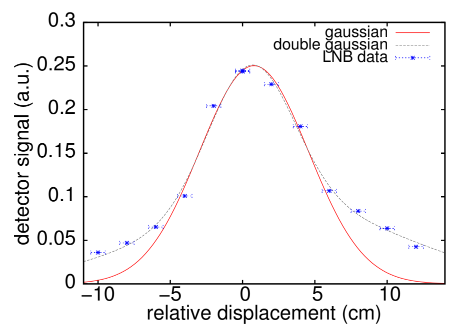

Figure 4: Variation of the signal strength for horizontal displacement of the detector in front of the source. There is still signal beside the window (< 7.5 cm), suggesting a wide angle of aperture and no parallel radiation. Furthermore a stepwise fit of two Gaussians suggests that there are two radiation source points.

Bunch Length Dependence

The CSR spectrum depends on the electron distribution being the source of the radiation. The distribution can be estimated by a Gaussian and described by the number of electrons and the bunch length. The bunch length influences the coherent emission of the bunch [4]. Figure 5 shows the calculated spectrum for different bunch lengths. For a decreasing bunch length the spectrum becomes wider and the emitted power increases. The expected answer of an LNB can be deduced from the change of the spectrum within its narrow input band (black lines in Fig. 5). Figure 6 the signal expected for an increasing bunch length.

Because the beam current decays during a measurement, it is important to know how this influences the measured signal. Therefore, we did a measurement with constant bunch length to neglect the effect of bunch lengthening. Furthermore the choice to measure at long bunch lengths reduces the effect on the expected power, see the marked area in Fig. 6. The analysis uses the the average signal of one revolution (≈ 368 ns). For comparison the integrated, calculated CSR

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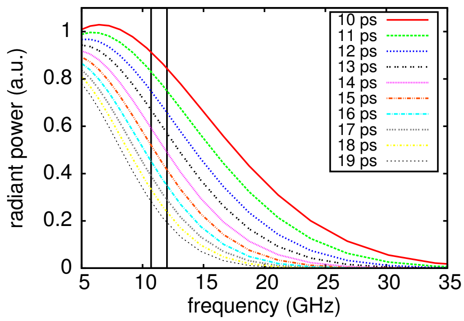

Figure 5: Calculated coherent synchrotron radiation spectra for different bunch lengths σ (in ps) and a constant number of electrons. The black lines indicate the receiving frequency band of an LNB.

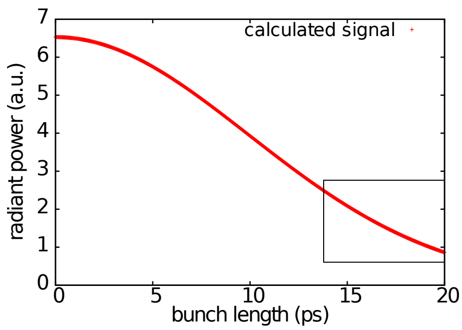

Figure 6: The expected response of an LNB to a variation in bunch length. The expectation is deduced from the behaviour of the spectrum. The signal increase with the decrease in bunch length gives a possibility to determine the bunch length from the signal strength.

power in the input band of the LNB, based on the measured bunch length and current is shown. The result is the confirmation of a quadratic current dependence as expected for CSR, shown in Fig. 7. With this knowledge the detector signal can be normalised to the bunch current. Figure 8 shows the resulting residual dependence on the bunch length. At larger bunch lengths the measured signal behaves like the expectation for synchrotron radiation, which is drawn in green. The expectation is again based on measured bunch length and current as well as the analytical formula to calculate the synchrotron radiation spectrum [4]. The drop of the signal for the lowest measured bunch lengths can possibly be caused by the twofold nature of the measured signal, i.e. reflect the fact that in this region the signal is not dominated by CSR.

SUMMARY

As a result of the studies presented above, the universality and usefulness of the small, low-cost microwave detector LNB can be emphasised. The observations show evidences for the two different microwave signal sources at the ANKA storage ring, which are supposed to be CSR-microwaves and wake fields. Using a correct calibration a bunch length measurement with LNB signal can be approached.

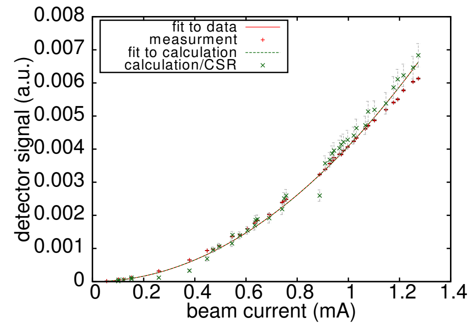

Figure 7: Quadratic dependence of the measured signal on the beam current. The green crosses are the expectation based on measured accelerator parameters and calculated from changes in the synchrotron radiation spectrum.

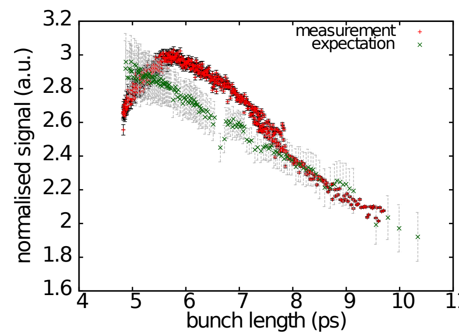

Figure 8: The normalised signal increases as expected to smaller bunch lengths. But shows an unexpected change in behaviour towards the lowest measured bunch lengths.

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