ULTRA-FAST MM-WAVE DETECTORS FOR OBSERVATION OF MICROBUNCHING INSTABILITIES IN THE DIAMOND STORAGE RING

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Abstract

The operation of the Diamond storage ring with short electron bunches using low alpha optics for generation of Coherent THz radiation and short X-ray pulses for time-resolved experiments is limited by the onset of microbunching instabilities. We have installed two ultra-fast (time response is about 250 ps) Schottky Barrier Diode Detectors sensitive to radiation within the 3.33-5 mm and 6-9 mm wavelength ranges. Bursts of synchrotron radiation at these wavelengths have been observed to appear periodically above certain thresholds of stored current per bunch. The fast response allows a bunch-by-bunch and turn-by-turn detection of the burst signal, which facilitates study of the bursts structure and evolution. In this paper we present our first results for various settings of alpha and also discuss future plans.

INTRODUCTION

Diamond Light Source has recently started an experimental programme for the generation of short radiation pulses in the storage ring. Dedicated low-alpha optics[1] have been developed and tested for users providing radiation pulses as short as 1 ps r.m.s. Both X-ray time resolved experiments and THz users are expected to benefit from such operating mode. In order to study microbunching instabilities and the potential for coherent emission at mm and sub-mm wavelengths, additional diagnostic instrumentation has been installed.

EXPERIMENTAL SETUP

Schottky Barrier Diode (SBD) detectors are common devices at microwave and mm-wave applications. In comparison to other detectors for mm and sub-mm-wavelengths like bolometers and Golay cells they have a very fast response, allowing turn by turn observation of emissions. The only alternative with similarly fast response are hot electron bolometers, which are more expensive, delicate and space consuming due to the required dewar. While at microwave frequencies SBD detectors are typically packaged with coaxial connectors, for mm-wave frequencies they are waveguide mounted, which limits their bandwidth. Coupling to free space fields is then achieved using a horn antenna, for instance of pyramidal design.

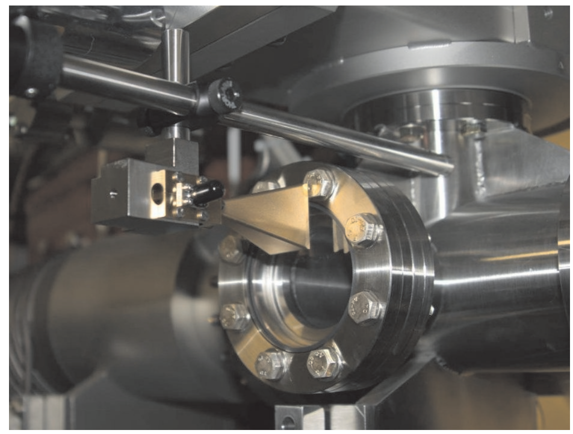

Figure 1: Photo of the 60-90 GHz detector with horn antenna mounted next to the visible light extraction.

Table 1: Specifications of the two Schottky Barrier Diode Detectors (terminated into 50 Ω) and Connected Standard Gain Horn Antennas [2, 3]

Detector Model	DXP-22-RPFW0	DXP-12-RPFW0
Frequency range	33-50 GHz	60-90 GHz
Video sensitivity	40 mV/mW	23 mV/mW
Video bandwidth	1 GHz	1 GHz
Horn Model	SGH-22-RP000	SGH-12-RP000
Gain [dB]	24	24
Input aperture	55 mm· 42 mm	30 mm· 23 mm

For the evaluation of SBD detectors to detect mm-wave synchrotron radiation emissions, we have mounted two types of detector with the according horn antenna near the window of the visible light extraction used for optical diagnostics (streak camera and fill pattern measurement from photon counting). The two detectors from Millitech differ in their frequency range, sensitivity and dimensions, and were mounted one at a time, as the current setup does not provide the space to mount both at the same time without interfering with the visible light transport. The frequencies of the two detectors have been chosen close to the vacuum vessel cutoff, estimated to be 54 GHz from the relation $f_c = 2h\sqrt{h/\rho}$ with our total vertical aperture $h = 38$ mm and the bending radius $\rho = 7.13$ m.

Figure 1 show the setup where the detector can be seen mounted off centre near the window, so that visible light which comes from a mirror inside the vessel [5] can still pass beneath the horn antenna. The detector is oriented to

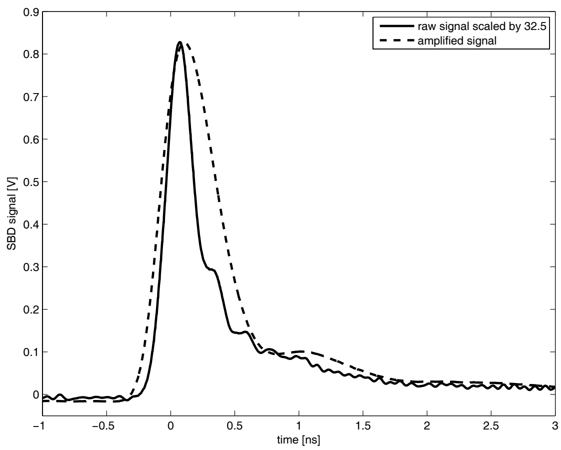

Figure 2: Pulse shape from 30-50 GHz detector without and with amplifier. Both traces are averages of 512 acquisitions triggered only on strong pulses.

receive the horizontal polarisation. The detector signal was then transported through a 25 m long RG-213 cable to an Agilent DSO-91304A oscilloscope outside the storage ring tunnel. During later experiments and to increase sensitivity, a FEMTO HSA-X-1-40 amplifier with 40 dB gain in a 10 kHz to 1.1GHz bandwidth was added, at first near the oscilloscope and subsequently near the detector, with the latter greatly reducing noise pickup. A typical pulse shape from the detector receiving strong mm-wave pulses from a 5.6 nC single bunch is shown in Figure 2 illustrating also the influence of the amplifier on pulse shape and amplitude.

It was found that both the 30-50 GHz and the 60-90 GHz detectors produced comparable signals under similar conditions. It is not clear whether this means that there are actually emissions below the estimated 54 GHz vacuum pipe cutoff frequency, or whether the 30-50 GHz detector is sensitive to radiation at frequencies above its upper specification limit. Further experiments with a filter fitted on the lower frequency detector and both detectors in place at the same time will be carried out in the future.

OBSERVATION OF MM-WAVE BURSTS

Without the pulse amplifier, mm-wave emissions could only be detected from bunches above a certain charge threshold. For normal user optics with a momentum compaction factor $\alpha = 1.7 \cdot 10^{-4}$ and theoretical zero current bunch length of 11 ps r.m.s the charge threshold was at around 3.7 nC, while for low-alpha optics with a momentum compaction factor $\alpha = -1 \cdot 10^{-6}$ and theoretical zero current bunch length of 1 ps r.m.s the charge threshold was at around 100 pC.

Beyond these thresholds, the burst intensity increases and the structure and frequency of the bursts changes irregularly as can be seen in Figures 3 and 4. The emissions were bursts with a complex and partially irregular structure typically 1 ms long (with further structure at 80 μs intervals) with 2 ms spacing. We presume these bursts to originate from microbunching instabilities introducing coherently emitting structure into parts of the electron distribution inside a bunch.

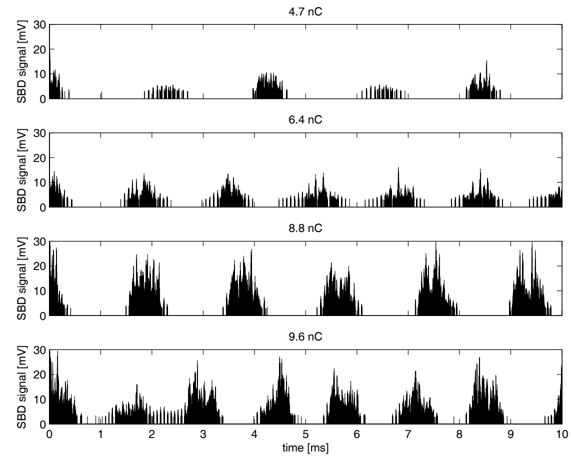

Figure 3: SBD signal (60-90 GHz, unamplified) for increasing single bunch charge with normal optics.

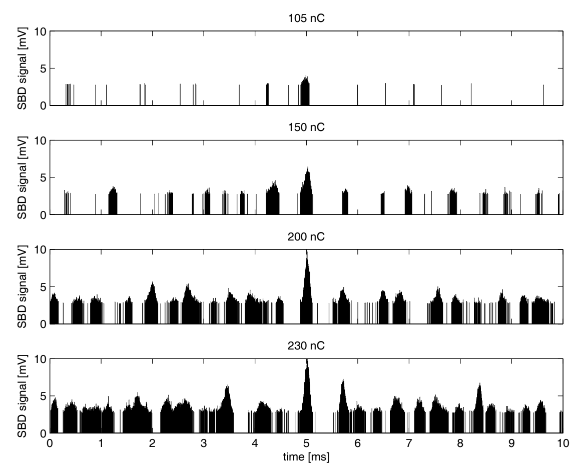

Figure 4: SBD signal (60-90 GHz, unamplified) for increasing single bunch charge with low-alpha optics.

On a longer time scale, 10-300 ms long periods of stronger peak intensity have been observed, still showing essentially the same structure of bursts. This can be seen in from the spectrogram in Figure 5 which shows the persistent spectral features at 500 Hz and 12 kHz corresponding to the time structure as described above.

OBSERVATION OF CONTINUOUS MM-WAVE EMISSIONS

With the amplifier fitted, it was also possible to observe the mm-wave signal emitted on every turn from each bunch, for instance in the normal user fill with 700 of 936 bunches filled to 670 pC on average, as shown in Figure 6. However, it can be seen from the inset that the

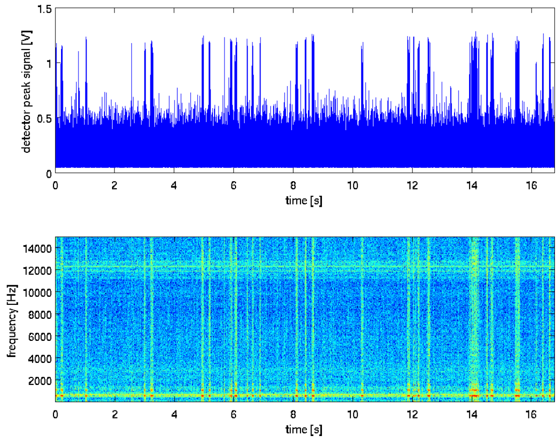

Figure 5: SBD signal (30-50 GHz, amplified) shows rare strong bursts with continuous weaker bursts between. Colour coded spectrogram is generated from block FFT of 2048 points at 500 kS/s.

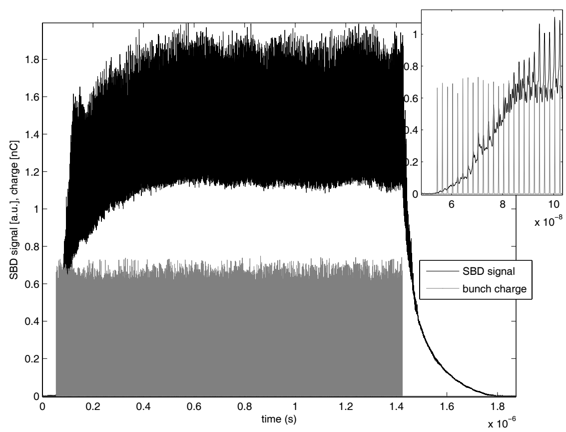

Figure 6: SBD signal (30-50 GHz, amplified) from normal 3/4 fill in user optics.

sensitivity of the detector appears to increase for the first few bunches. This is thought to be a result of self-biassing of the detector connected to the high pass input filter of the amplifier: As a voltage across the coupling capacitor builds up with subsequent bunches, the working point of the detector shifts. This will require further investigation as it clearly limits the ability to detect emissions from single bunches.

Still, with the increased sensitivity due to the added amplifier, it was possible to observe stable continuous emissions (see Figure 7) from a single bunch in low-alpha optics with a momentum compaction factor $\alpha = -3 \cdot 10^{-6}$ and theoretical zero current bunch length of 1.3 ps r.m.s. The intensity of these emissions increases faster than the charge in the bunch, ie the normalised intensity per charge increases. This could suggest partially coherent emissions, but will need further investigation.

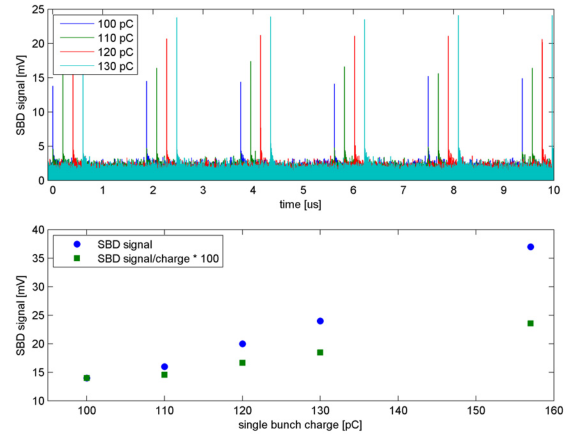

Figure 7: SBD signal (30-50 GHz, amplified) from every turn of an increasing single bunch in low-alpha optics.

CONCLUSION AND OUTLOOK

We have presented first measurements with an ultra fast mm-wave detector based on a compact Schottky Barrier Diode detector. The fast response and high sensitivity in combination with a pulse amplifier have allowed investigation of continuous and bursting mm-wave emissions over timescales of individual single bunch signals with sub-ns resolution to many seconds, documenting the complex structure of bursting emissions. Initial variations of parameters such as bunch charge or momentum compaction factor have shown the usefulness of the detector and helped optimising the setup, but clearly more rigourous investigations will have to follow.

Furthermore, we intend to move the detector into a location where more than one can be used at the same time and improve the extraction of mm-waves. To this end, we intend to build a special mm-wave extraction by modifying one of the beam port absorbers on an unused bending magnet port. This will also provide enough space to allow the installation of a Michelson or Martin-Puplett interferometer to characterise the spectral content of the mm-wave emissions further. In addition, with the IR beamline B22 becoming operational later in 2009 we should have one more valuable source of measurements.

REFERENCES

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