OBSERVATIONS OF MICROBUNCHING INSTABILITIES FROM A THz PORT AT DIAMOND LIGHT SOURCE*

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Abstract

Diamond Light Source is a third generation synchrotron facility dedicated to producing radiation of outstanding brightness. Above a threshold current, the electron bunches are susceptible to the phenomenon known as the microbunching instability. This instability is characterised by the onset of radiation bursts, the wavelength of which is shorter than the bunch length. Near threshold, the bursting occurs quasi-periodically, however at higher currents, the bursting appears randomly. The high frequencies involved in these emissions make detection and analysis challenging. A port specifically for the investigation of mm wave emissions has recently been built at Diamond. Ultra fast Schottky Barrier Diode detectors have been installed to observe the instability on a turn by turn basis. The onset and evolution of the bunches have been investigated.

INTRODUCTION

The microbunching instability is a phenomenon which has been observed at many accelerator facilities around the world including Diamond Light Source [1, 2], ALS [3], BESSY-II [4], the VUV ring at BNL [5], and many other facilities [6]. The primary characteristic of the instability is bursts of coherent synchrotron radiation (CSR) with a wavelength shorter than the longitudinal bunch length. The bursting appears quasi periodically at the bunch current threshold of the instability, however, at higher currents, this changes to an apparently random bursting sequence. This instability can be produced in numerous operational modes at Diamond Light Source, and is strongly dependant on bunch current which consequently limits the storage ring performance. The phenomenon is strongly present under low-alpha optics, a setup which has been demonstrated at Diamond [7].

The underlying cause of the instability is unknown and is an active and ongoing research topic. To this end, our short term goal is to obtain greater understanding of the operational conditions of the storage ring which results in the instability's appearance. To accomplish this, a new viewport has been installed, dedicated to mm-wave detection and observations. We present a series of measurements taken with two Schottky barrier diode detectors investigating the onset and evolution of the instability.

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EXPERIMENTAL SETUP

The new viewport has been installed after bending magnet B06 resulting in a path length from magnet to viewport window of approximately 4m. The port has been designed specifically to transport the radiation into a plane that is both vertically lower and parallel to the plane of the beam pipe, as shown in Fig. 1.

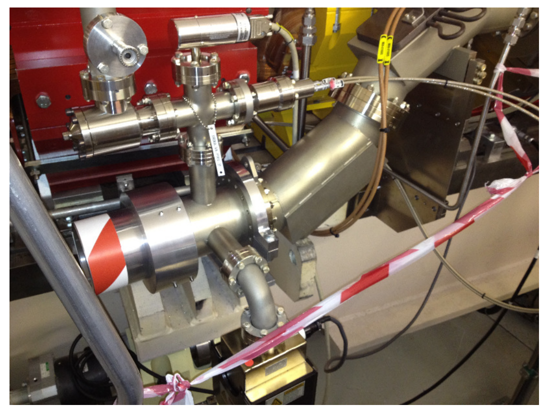

Figure 1: Dedicated mm-wave viewport at Diamond Light Source.

A water-cooled copper mirror reflects the mm and sub-mm wavelengths whilst also absorbing the high intensity x-ray radiation produced from the bunch in the bending magnet. A second stainless steel mirror reflects the radiation such that it is parallel to the beam pipe plane. The viewport is an 89mm diameter fused silica window. Three linear stages are attached to an optical table which is positioned in front of the port. The three stages provide a 100cm longitudinal and 25 x 25cm transverse position range.

Table 1: Specifications of Two Ultra-Fast Schottky Barrier Diode Detectors (Terminated into 10kΩ)

Detector Model	DXP-12	WR3.4ZBD
Frequency Range	60-90 GHz	220-330 GHz
Wavelength	3.33 - 5 mm	0.9 - 1.4 mm
Responsivity	486 mV/mW	1042 mV/mW

Two Schottky Barrier Diode (SBD) detectors, each with a gain horn antenna, were attached to the horizontal transverse stage, oriented to receive the horizontal polarisation. The detector's responsivity is reduced from maximum due to an impedance mismatch between the detector and the

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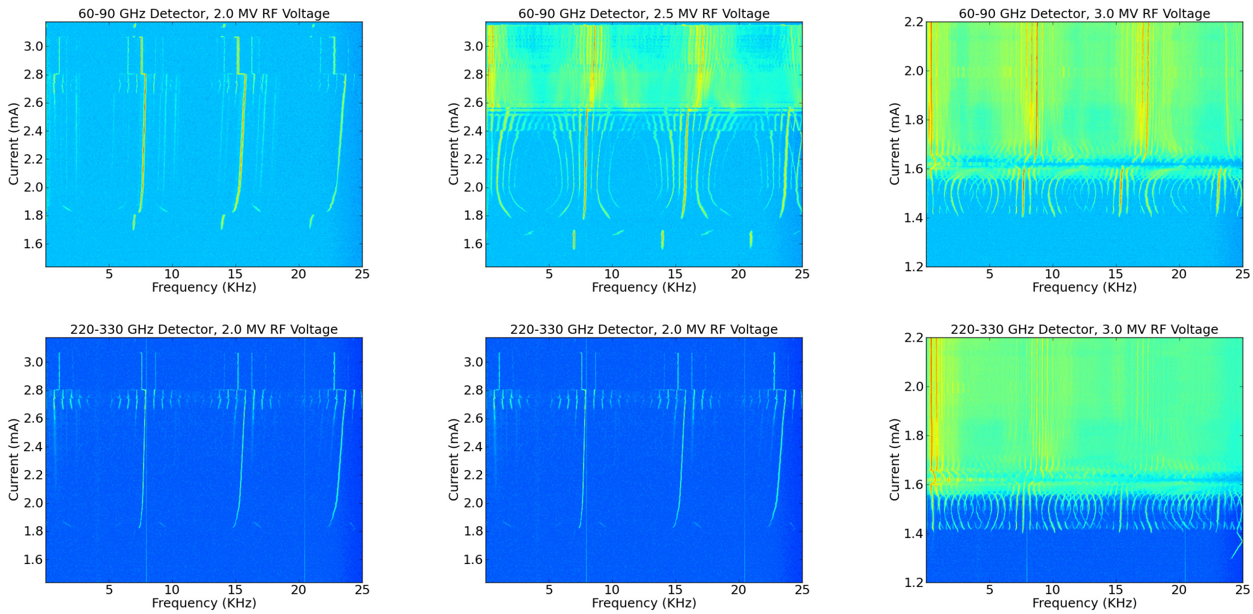

Figure 2: Spectral display from 60-90 GHz (top row) and 220-330 GHz (bottom row) detectors for RF voltages of 2.0 MV (left), 2.5 MV (middle), and 3.0 MV (right).

amplifier. The values shown were calculated by measuring the diode's I-V characteristics and using formulae in [8]. The characteristics of both detectors are summarised in table 1. The lower frequency detector is from Millitech, and the higher frequency detector from Virginia Diodes. Both detectors were amplified using HVA-S amplifiers (custom made from Femto), providing 60 dB gain in a DC to 1 MHz bandwidth. A 25 m high quality RF cable (LMR-240) transported the signal to an Agilent N9020A Signal Analyser, with the output being displayed in the Diamond control room via Agilent 89601B Vector Spectrum Analyser (VSA) software. During the experiments, the signal analyser was set to measure 16384 samples (2^{14}) at a resolution bandwidth of 10 Hz. The spectrum was recorded as a 10 sample average every 1.75 seconds. The bunch current was ramped up to maximum of $\approx$ 5 mA, corresponding to 9.4 nC. The decay lifetime of the bunch was shortened to around 20 minutes using horizontal collimators.

MICROBUNCH INSTABILITY OBSERVATIONS

For the spectral measurements, the detectors were moved to a position where the peak voltage output from each detector was approximately equal at a high bunch current. The storage ring was set to a single bunch fill pattern, at the bunch revolution frequency of 533.8 kHz. Fig. 2 shows the signals obtained from both detectors for RF voltages of 2.0 MV (left), 2.5 MV (middle), and 3.0 MV (right). The data shows the presence of strong sidebands in both detectors around the modulation frequency (represented as 0 kHz). The threshold current decreases with increasing RF voltage as expected due to the shorter bunch length produced at higher voltages, however the threshold appears to vary between the two detectors, due to a reduced signal intensity from the 220-330 GHz detector.

Increases in current reveal further features from the instability. During the 2.0 and 2.5 MV tests, a discontinuity region appears shortly after the threshold where no bursting is present, before the bursting resumes but with the sidebands at higher frequencies. The appearance of sidebands around the main sidebands also commences. These secondary sidebands shift with increasing current, causing the notable curved features seen in Fig. 2. The observed signal corresponds with the quasi-periodic bursting previously seen. At higher currents, there is another shift in frequency of the main sidebands. In the 2.5 MV and 3.0 MV tests, this also coincides with an overall increase of signal intensity across the measured bandwidth causing the secondary sidebands to become indistinguishable from the overall signal. This increase in signal across the entire measured bandwidth suggests that the bursting has lost its quasi-periodicity and the radiation is emitted in a random pattern. The bunch current where these features appears varies with RF voltage, with higher voltages displaying the effects at lower currents. The current range for the 3.0 MV test was displayed only between 1.2 and 2.2 mA to show the spectral features as higher currents revealed no additional changes in the spectrum. The cause of the observed features is unclear as the emission spectrum from the instability is still under investigation. There is an evident relationship between the instability onset and RF voltage which agrees with previous experiments in [2, 7].

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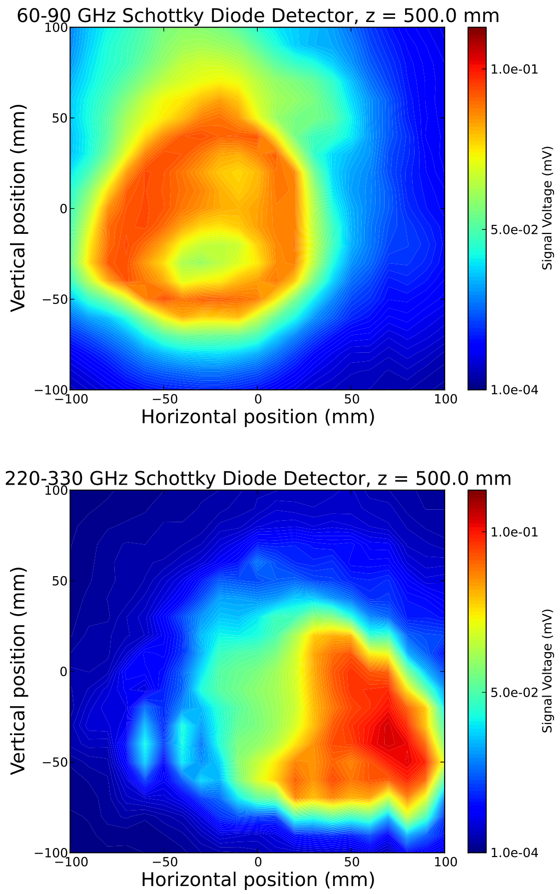

Figure 3: Transverse scan of peak voltage from the 60-90 GHz (top) and 220-330 GHz (bottom) detectors.

SPATIAL DISTRIBUTION OBSERVATIONS

Characterisation of the viewport is an important step necessary in understanding the observed signal from the instability. A transverse scan was conducted by moving the horizontal and vertical linear stages in a 20 x 20 cm grid in 1 cm steps, creating a 441 point array. At each point, the peak voltage from the detectors was recorded. The measurements were taken at a longitudinal position of 50cm on the stage plus an approximate 10cm distance between the stage and the viewport. Due to the long acquisition time of the measurements and the limited beam time available, the scan was conducted while Diamond was operating during low-alpha optics mode, which is known to create the instability. Fig. 3 shows the plots of the scans from the 60-90 GHz (top) and 220-330 GHz detectors. The offset of the distributions is due to the physical offset of the detectors on the stage platform. In the measured distributions, there appears to be a slight minimum at the centre of the 60-90 GHz distribution, and the peak of the 220-330 GHz distribution appears off centre. As Diamond was operated in low-alpha mode, several RF buckets were consequently populated, therefore the detectors were receiving radiation generated from several bunches. It is likely the signal from several bunches is saturating the detector, causing the apparent changes in intensity. Further investigation is required when Diamond is in single bunch mode to prevent any detector saturation.

CONCLUSIONS AND FUTURE WORK

We have presented the first measurements from a newly constructed and installed viewport dedicated to providing mm and sub-mm waves. Two ultra-fast Schottky Barrier Diodes have been used to detect mm-wave emissions from an electron bunch displaying the characteristic effects of the microbunching instability. Variations in the RF voltage have shown the instability threshold to decrease with increasing voltage due to a shorter bunch length at higher voltages. The presence of sidebands around the modulation frequency have been observed, along with discontinuity regions and shifts in sidebands with increasing bunch current. The effects have been observed from both detectors, with the higher frequency detector showing smaller signal intensity. A transverse scan of the radiation beam from low-alpha mode revealed gaussian like distributions, however, the high intensity of the beam is believed to have lead to saturation of the detectors.

In the future, we plan to conduct further experiments with the detectors during single bunch operation. Repeat measurements will be taken to ascertain the effects observed in the spectral scans are reproducable or are a feature of the operation conditions. Additional scans at various longitudinal positions should reveal further information on the spatial distribution of the radiation, while also detailing the divergence of the beam. The relatively narrow bandwidth of the SBD detectors currently prohibits a full investigation of the spectrum emitted as a result of the instability, however additional SBD detectors will be installed to probe emissions at other frequencies. A broadband pyroelectric detector will also be installed to probe the emissions at shorter wavelengths.

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