A MULTI-BAND SINGLE SHOT SPECTROMETER FOR OBSERVATION OF MM-WAVE BURSTS AT DIAMOND LIGHT SOURCE*

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Abstract

Micro-bunch instabilities (MBI) have been detected at many light sources across the world. The bursts produced as a result of this instability occur in the millimetre regime. More needs to be determined about the dynamics of MBI in order to confirm the simulations. Consequently, a single shot spectrometer has been created to investigate this instability at Diamond Light Source (DLS). Due to their low noise, ultra-fast response and excellent sensitivity, Schottky detector diodes make up this spectrometer. Currently, seven Schottky detectors are in place covering a range of 33-750 GHz. Unlike previous measurements carried out, each of the Schottky detectors has been characterised thus making the results obtained comparable to simulations. In this paper, we present the assessment of each Schottky detector in the spectrometer; the first results of the spectrometer's use in the beam and future plans for the spectrometer.

INTRODUCTION

Micro-bunching instabilities are common at many lights sources around the world [1–3]. They are known to limit the operation of the storage ring, as bursting can affect user experiments. As a result of this, light sources usually endeavour to avoid the conditions which result in these additional bursts. MBI produce coherent synchrotron radiation (CSR), bursts of CSR to be more precise. CSR from the whole bunch occurs when the wavelength of radiation exceeds the bunch length. CSR is also produced when structure in the longitudinal profile is of short length, and in this case the CSR can even enhance that structure further.

Since 2009, the Diamond storage ring is often operated in a dedicated low alpha mode [4], whereby the momentum compaction factor α is set to be between 17 and 70 times smaller than normal user mode. At DLS there are two varieties of low alpha modes to provide coherent radiation for THz/IR experiments and short-pulse radiation for pump-probe experiments. Due to the nature of the low alpha modes, i.e. the smaller bunch lengths, the MBI regularly occurs.

SCHOTTKY DETECTOR DIODES

Schottky Barrier Diodes (SBD) are best known for their fast response [5], low noise and excellent sensitivity. Operating at room temperature, SBDs are able to detect mm-waves and hence are often used as detectors within this wavelength range. The detector diodes that we have chosen are housed within waveguides and fed signal using horn antennas. A spectrometer has been designed using seven SBDs, with each detector covering a specific frequency band from 33-750 GHz. Table 1 shows the properties of the chosen SBDs.

Table 1: SBD Specifications

Detector Model	Stated Range	Sensitivity
DXP-22 [6]	33-50 GHz	1200 V/W
DXP-12 [6]	60-90 GHz	700 V/W
DET-08 [6]	90-140 GHz	600 V/W
WR5.1ZBD [7]	140-220 GHz	2000 V/W
WR3.4ZBD [7]	220-330 GHz	1500 V/W
WR2.2ZBD [7]	330-500 GHz	1250 V/W
WR1.5ZBD [7]	500-750 GHz	750 V/W

SPECTROMETER/DETECTOR ARRAY

DLS hosts a viewport which is dedicated to the investigation of CSR. The viewport transports the synchrotron radiation from bending magnet B06 to the viewport window. It is there that the detector array is placed on three motion stages for movement in x, y and z directions. The detector array is shown in Fig. 1 on its motion stages.

The plate shown (Fig. 1) is designed in such a way that all detectors are as close together as possible and observe as much signal as available. All horn antennas are at the same distance to the viewport to remove the risk of shadowing.

It is important for the cables between the detectors and the voltage amplifiers to be short. The input impedance of the amplifiers is high (10 kΩ), thus to accommodate a good signal-to-noise ratio around the revolution frequency, the cable capacitance must be low. In order to lower the capacitance, shorter cables were used, thus a plate housing the amplifiers was attached to the detector array allowing for minimal cable length. Following the voltage amplifiers the signals are carried out of the tunnel, where the signals are fed into a simultaneous 16-channel sampling digitiser.

DATA ANALYSIS

For a specified period of time, the data are captured with an external 5 Hz trigger. The data are then analysed in MATLAB. Due to limited bandwidth Ethernet, from the digitiser to the relevant computer for processing, it is impossible to continually stream data from the digitising unit to our computers for analysis, hence the snapshots of data being acquired. A digital down conversion (DDC) of the data is carried out, with the analysis locking in at the revolution frequency of the storage ring, (533.820 kHz). The information

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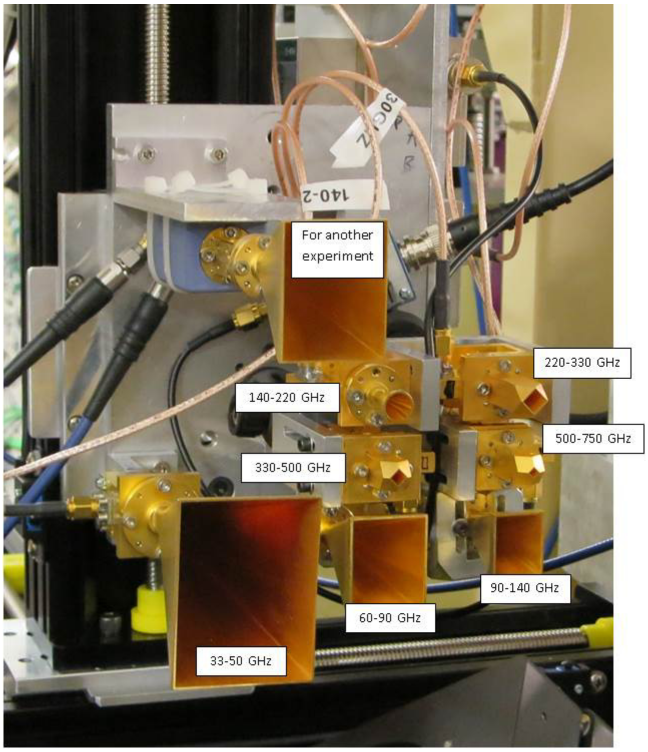

Figure 1: Layout of Detector Array Plate.

around the revolution frequency is investigated as it has a much better signal-to-noise ratio than the data around the DC component.

The DDC was carried out as follows within MATLAB: the DC component is removed by subtracting the mean of the signal from the original; the entire spectrum is frequency shifted using $e^{i\omega_r t}$, where ω_r is the revolution frequency, so that the region of interest (around 533.820 kHz) is at the start of the spectrum and finally the spectrum is low pass filtered to 16.6 kHz and then decimated. Using the sensitivity values for each of the detectors [6, 7], the signal can be depicted in terms of power.

MBI OBSERVATIONS

As mentioned above, MBI are most common in low alpha mode, due to the longitudinal compression of the bunch. The data presented here were obtained when the storage ring was set to a range of α with only a single bunch present in the ring. By having only a single bunch in the ring, it allows the SBD array to observe what happens to the bunch with every revolution around the ring.

Three cases of the data are presented here, they were chosen for the maximum values of bunch currents for each of the low alpha occurrences; 24 µA, 56 µA and 100 µA. Each case is with 'a single bunch' and are at three different negative values for the momentum compaction factor: $\alpha = -2.4 \times 10^{-6}$, $\alpha = -4.5 \times 10^{-6}$ and $\alpha = -9.9 \times 10^{-6}$ with each value of α having an associated synchrotron frequency, fs = 330 Hz, fs = 460 Hz and fs = 675 Hz, respectively. For a period of 10 ms, the time evolution of the bursting for each SBD is shown in Fig. 2. It can be clearly seen that the SBD for the 60-90 GHz band (red) observes the most signal. The low signals

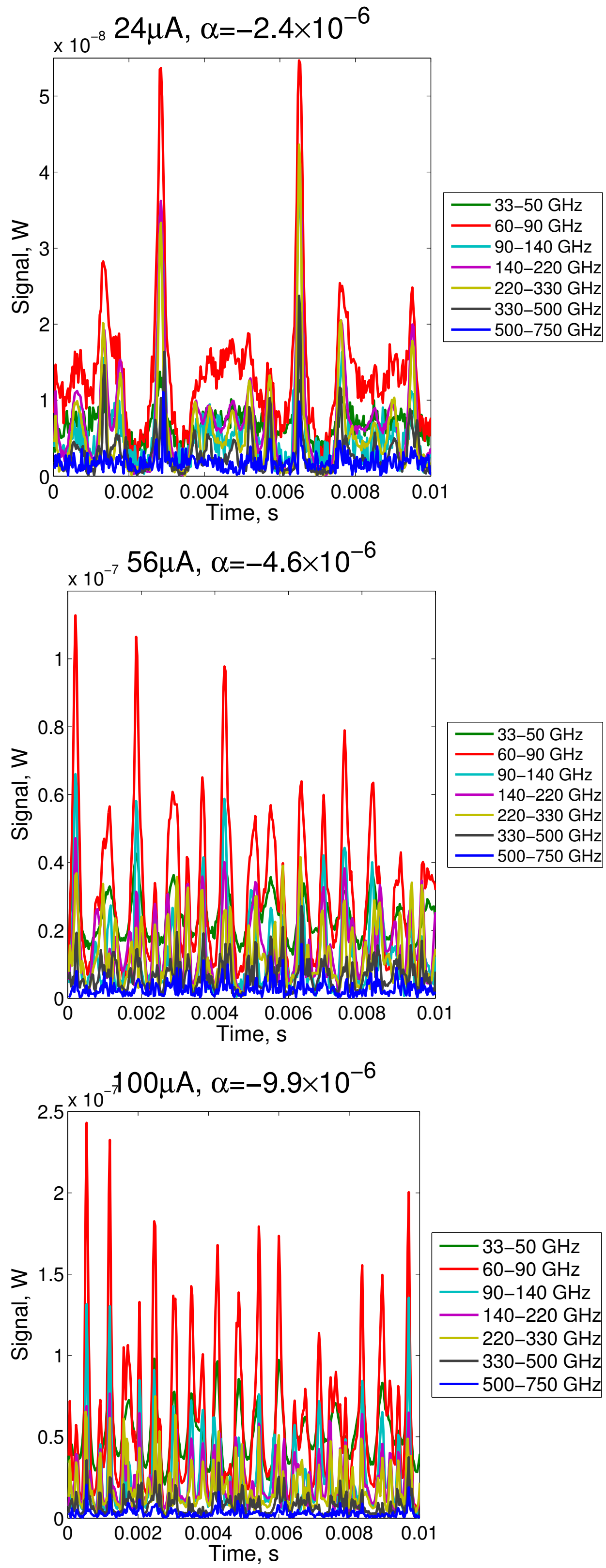

Figure 2: Time evolution of the bursting in each case.

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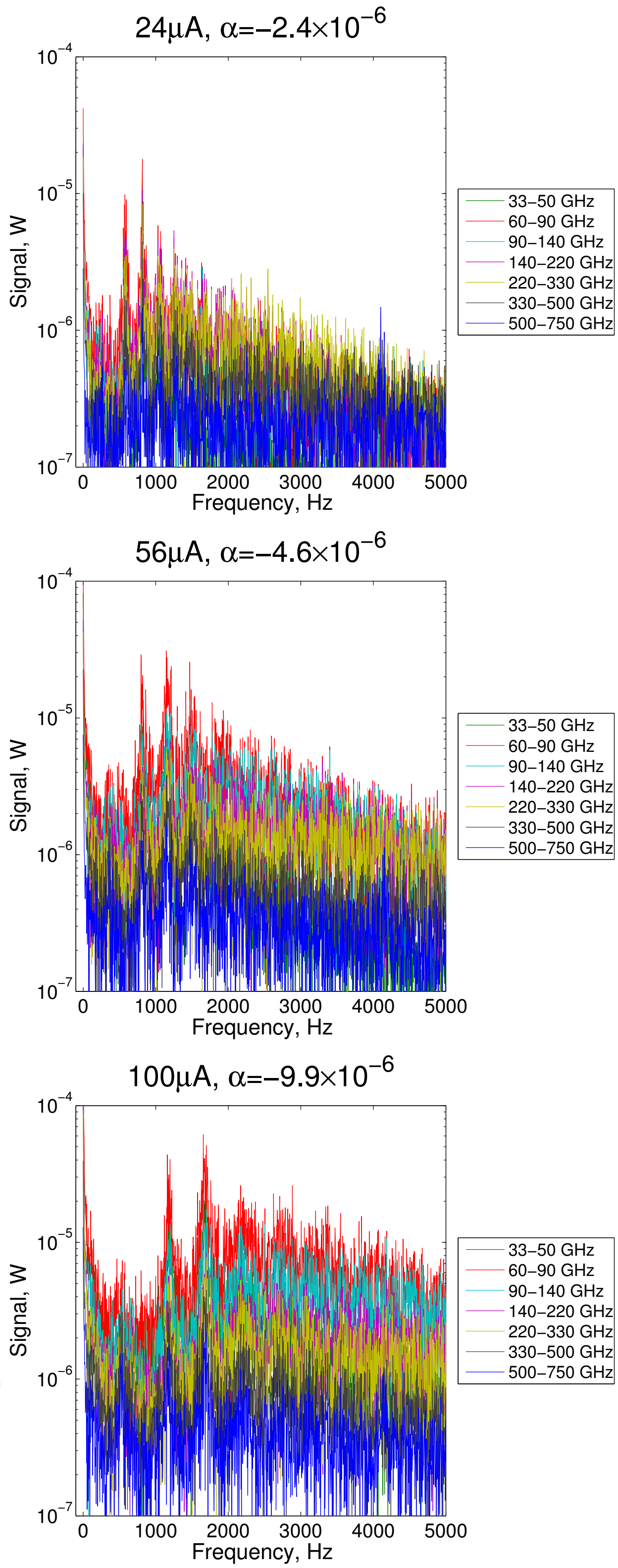

Figure 3: A sample of the bursting in the frequency domain.

observed by the 33-50 GHz SBD (green) are as a result of the frequency band being below the CSR cutoff, calculated to be 63 GHz from Eq. 1, where the vertical height of the dipole vessel is 34 mm, h and the bending radius of the dipole is 7.1 m, ρ. The data is then put through a discrete Fourier transform into the frequency domain and shown in Fig. 3. The peaks seen in Fig. 3 can be explained by the harmonics of the synchrotron frequencies.

$$\lambda_{cutoff} = 2\sqrt{\frac{h^3}{\rho}} \tag{1}$$

More results and comparisons with streak camera and beam position data are presented at these proceedings by I. P. S. Martin [8].

FUTURE PLANS

The next step is to individually characterise each of the seven SBDs, against one absolute power meter. From these measurements the sensitivity of each of the detectors will be determined. This characterisation will be carried out in an identical way for each of the SBDs and will thus allow for the data taken with the detector array to be analysed wholly.

The data processing will be improved. Instead of sending all the data over the bandwidth-limited Ethernet, it will be streamed directly from the digitising unit to a local computer and analysed there, thus availing of wider band Ethernet.

CONCLUSION

Using our seven SBD spectrometer, MBI are detected at DLS across many frequency bands. As a result of their ultra-fast response, we are able to look at individual bunches, thus allowing for the dynamics of MBI to be investigated.

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REFERENCES

[1] M. Abo-Bakr, J. Feikes, K. Holldack, G. Wüstefeld, and H.-W. Hübers. Steady-State Far-Infrared Coherent Synchrotron Radiation detected at BESSY II. *Physical Review Letters*, 88(25):254801, June 2002.

[2] G Rehm, A F Morgan, R Bartolini, I P Martin, and P Karataev. Ultra-fast mm-wave detectors for observation of microbunching instabilities in the diamond storage ring. In *DIPAC*, pages 369–371, 2009.

[3] B Podobedov, G L Carr, S L Kramer, and J B Murphy. Longitudinal density modulation of unstable bunches emitting coherent IR. In *PACS2001*, volume 3, pages 1921–1923, 2001.

[4] I P S Martin, R Bartolini, G Rehm, J H Rowland, and C Thomas. Low alpha operation of the diamond storage ring. In *IPAC*, pages 4599–4601, 2010.

[5] R J Smith and R C Dorf. *Circuits, Devices and Systems*. John Wiley & Sons Inc., 5th edition, 1992.

[6] Millitech. Detector Specifications. Technical report, Millimeter-Wave Technology & Solutions.

[7] Virginia Diodes Inc. VDI User Guide. Technical report.

[8] I P S Martin, C Bloomer, L M Bobb, G Rehm, and R Bartolini. Reconstruction of Electron Bunch Motion During CSR Bursts using Synchronised Diagnostics. In *IPAC*, 2015.