FIRST RESULTS FROM THE LHC SCHOTTKY MONITOR OPERATED WITH DIRECT DIODE DETECTION

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Abstract

The LHC is equipped with a Schottky diagnostic system based on 4.8 GHz resonant pick-ups. Their signals are processed according to a three-stage down-mixing scheme, working well in most beam conditions. An important exception is the period of energy ramp of proton beams, when the noise floor of the observed beam spectrum increases dramatically and the Schottky sidebands disappear. To study beam spectra in such conditions the signals from the Schottky pick-ups were split and the second half of their power was processed with a copy of the LHC tune measurement electronics, modified for this application. The experimental set-up is based on simple diode detectors followed by signal processing in the kHz range and 24-bit audio ADCs. With such a test system LHC beam spectra were successfully observed. This contribution presents the used hardware and obtained results.

INTRODUCTION AND MOTIVATION

The LHC Schottky system operating at 4.8 GHz is based on a design of the 1.7 GHz Tevatron Schottky system and it was designed in collaboration with Fermilab National Accelerator Laboratory (FNAL) within the framework of the American LHC Research Programme (LARP) [1,2,3]. The system has four channels for both, horizontal and vertical planes of either LHC beam. Each channel consists of two pick-ups built as ≈ 1.2 m resonant slotted waveguides located on the opposing sides of the LHC beam trajectory with the aperture of ≈ 60 mm. The pick-up signals are subtracted by a passive hybrid circuit and the resulting signal is processed in an electronic chain with three down-mixing stages, optimised to obtain a 100 dB input dynamic range. Already during the commissioning of the system with LHC proton beams it was observed that the beam spectrum at 4.8 GHz has by far more coherent content than foreseen, resulting in an unexpected high signal level at the output ports of the pick-up. This was addressed by minimizing the hybrid coherent output signal by balancing its input signals using phase shifters and variable attenuators. However, those remedies were not efficient during energy ramps of proton beams, when Schottky spectra were disappearing in the raising noise floor. Despite important efforts this phenomenon has remained not explained with the hypothesis that it may be related to the fact that during the energy ramp the length of the bunches is increased with a longitudinal blow-up achieved by introducing controlled phase noise inside the LHC RF system.

To test this hypothesis another system capable to observe Schottky spectra was prepared. A copy of the hardware of the LHC base-band tune (BBQ) measurement system based on diode detectors has been modified to operate at 4.8 GHz in order to attempt to observe transverse Schottky spectra using the direct diode detection method [4]. This paper describes the new hardware set-up and presents the first obtained results.

THE HARDWARE

The electronics used during the experiment consisted of diode detectors optimised for 4.8 GHz operation connected to the BBQ analogue front-end modified for observing LHC Schottky spectra. The block diagram of this experimental set-up, referred to as Schottky BBQ (S-BBQ), is shown in Fig. 1, alongside with simplified frequency characteristics in the key nodes of the filtering chain.

The Schottky pick-up signals are split with power splitters with their outputs being connected to both, the regular LHC Schottky system and to the S-BBQ diode detectors. The low frequency detector output signals are sent to the analogue front-end (AFE) through ≈ 1.5 m coaxial cables whose capacitance is the dominant part of the diode detector capacitance. The AFE bandwidth was enlarged from the original $(0.1;0.5)f_r$ to $(0.2;2.0)f_r$ in order to accommodate four Schottky sidebands. Also S-BBQ AFE has a second $2f_r$ notch filter built in place of one low-pass section, resulting in lowering the AFE low-pass filter order from original 6 to 4. Except those modifications, the S-BBQ AFE is built as any front-end used for LHC tune measurement [4].

Most of the development effort required to operate the BBQ system at 4.8 GHz was invested in construction of adequate diode detectors. While there is a large choice of RF Schottky diodes operating well at this frequency, the

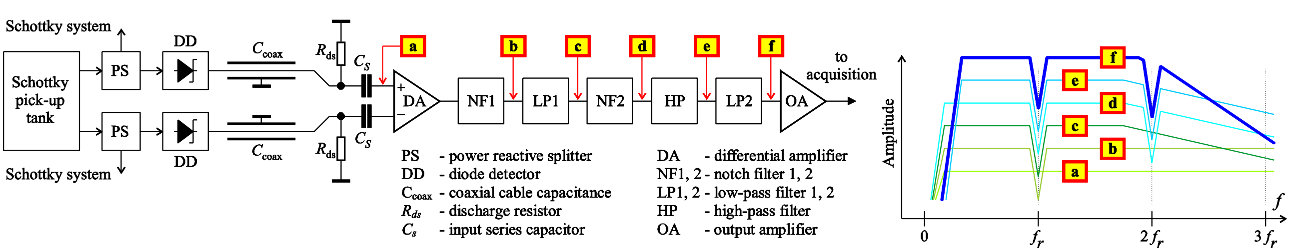

Figure 1: Block diagram of the experimental Schottky BBQ set-up with sketches of the frequency characteristics.

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challenge was to build detectors supporting large input signals and having reasonable input impedance, to not perturb significantly the operation of the regular Schottky system connected to the same power splitters. The summary of the achieved results is presented in Table 1.

Different diodes were tried in single- or double-diode configuration. An interesting result was achieved for "hetero-double-diode" detector containing two different diodes, namely HSMS286 with small capacitance and small maximum reverse voltage (V_R) and HSMS280 with larger capacitance and V_R of 70 V. This detector shows quite good combination of the required parameters. Unfortunately it was not possible to measure it in the lab with input voltages high enough to operate HSMS286 diode in the Zener regime, when degradation of S11 can be expected.

Please note that most of the detectors have higher output voltage at 4.8 GHz than at 1 GHz, indicating a resonant response at 4.8 GHz. As seen in Fig. 2 presenting output voltage and S11 as a function of frequency for two pairs of detectors, "resonant detectors" have worse match.

All detectors were hand-made as "components-in-air" circuits on an SMA connector put into a small Al 20×12×11 mm enclosure. Absence of printed circuit board allowed minimising parasitic capacitances while careful soldering resulted in remarkable detector match.

BEAM MEASUREMENTS

The cleanest Schottky spectra observed with the S-BBQ system were for ions beams for which the regular Schottky system operates also very well. An example of S-BBQ spectra is shown in Fig. 3, compared to the corresponding spectra from the regular BBQ system. The measurement was done during ramping 170 ion bunches. At that time the S-BBQ system had only one channel for vertical (V) plane of beam 1 (B1). Zoom on the first two Schottky sidebands is shown in Fig. 4.

After successful observation of Schottky spectra with the S-BBQ system at the end of the 2011 LHC run the necessary cables were pulled during the Christmas technical stop to install a second S-BBQ channel for horizontal (H) plane of beam 2 (B2).

Measurements with the two S-BBQ channels were performed in 2012 with proton beams. An example of obtained results is shown in Fig. 5-8, concerning periods of injection (Fig. 5), ramp and flat top (Fig. 6), beginning of collisions (Fig. 7, so called "stable beams") and collisions about one hour later (Fig. 8).

It can be seen that proton spectra change significantly during the LHC cycle, in particular during the energy

Table 1: Performance of the built diode detectors. max V_R: maximal reverse voltage; Vo: DC voltage at the detector output with 10 dBm (2 V_{pp}) at the input; S11: reflection measured with the input of 10 dBm.

Detector diode	max V_R [V]	4.8 GHz Vo [V]	4.8 GHz S11 [dB]	1 GHz Vo [V]	1 GHz S11 [dB]
BAS283	70	0.723	-6.8	0.740	-20.8
HSMS286	4	1.486	-9.3	0.871	-27.5
2x HSMS286	8	1.031	-17.4	0.771	-31.4
HSMS282	15	1.642	-2.9	0.865	-18.4
HSMS286+280	70	1.662	-10.8	0.781	-23.0
2x HSMS280	140	0.749	-6.6	0.750	-21.0

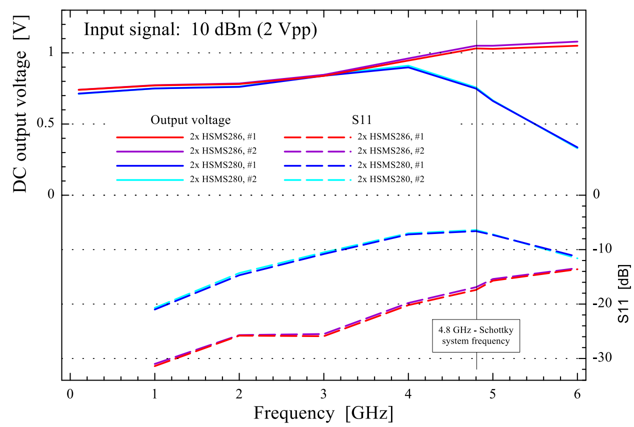

Figure 2: Symmetry of detector output voltages and S11.

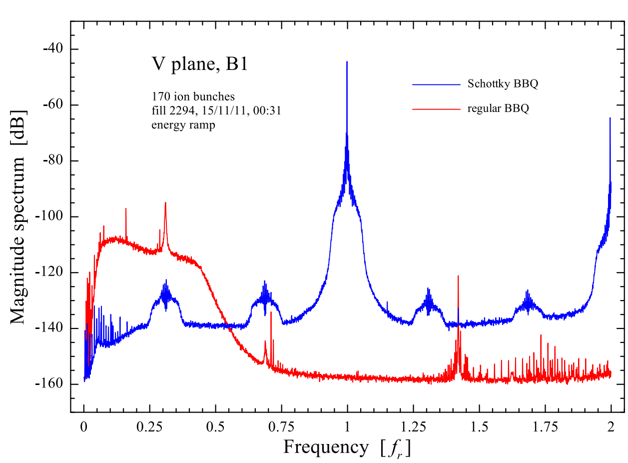

Figure 3: Spectra from S-BBQ and regular BBQ systems.

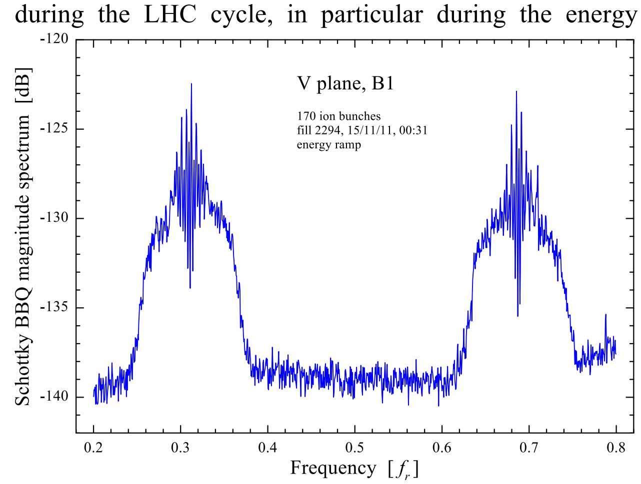

Figure 4: Zoom on the S-BBQ spectra from the left plot.

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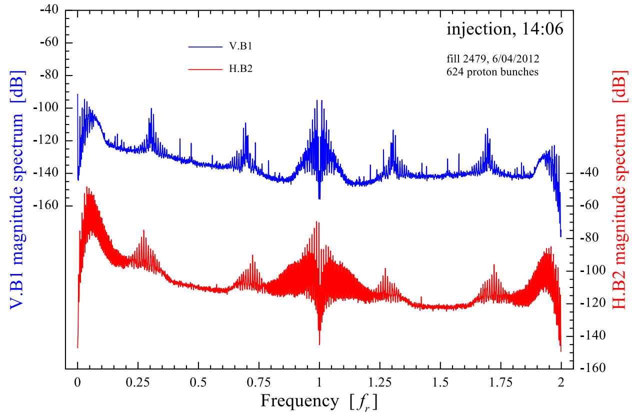

Figure 3: S-BBQ V.B1 and H.B2 spectra at injection.

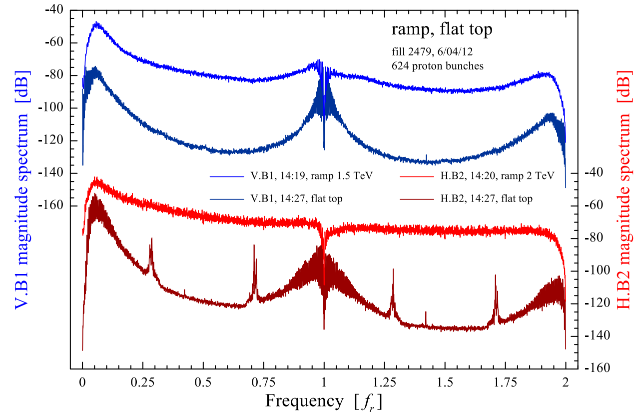

Figure 4: S-BBQ spectra during ramp and squeeze.

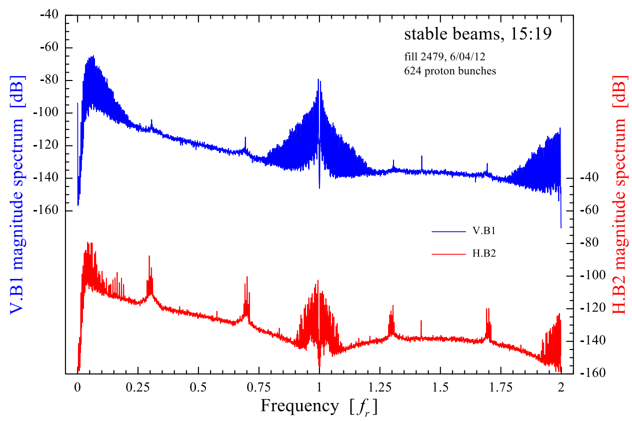

Figure 5: S-BBQ spectra at the collision beginning.

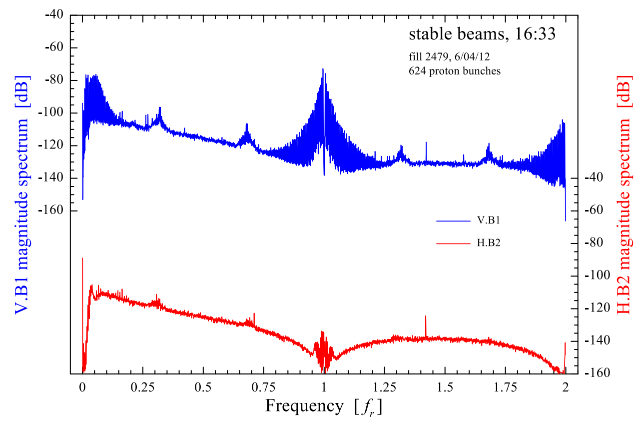

Figure 6: S-BBQ spectra during collisions.

ramp, when the spectra noise floor rises by some 40 dB, i.e. about two orders of magnitude. It takes a few minutes after the ramp till the noise floor decreases sufficiently enough to reveal again Schottky bands, see Fig. 5 and 6.

CONCLUSIONS

The LHC is equipped with a Schottky system, whose spectra get perturbed during energy ramp of proton beams. To verify whether this phenomenon is related to the instrument or rather to the LHC beam itself, a simple experimental set-up was built to provide an alternative processing to the signals from the Schottky pick-ups. The used hardware, referred to as S-BBQ, was based on a copy of the LHC BBQ tune system modified to operate at 4.8 GHz and to observe four Schottky sidebands.

The experimental S-BBQ system allowed observation of beam spectra for both, ion and proton beams. During the energy ramp of proton bunches the S-BBQ spectrum rises and Schottky sidebands disappear, similarly to what has been observed with the regular Schottky system.

To the author's knowledge the reported operation of a transverse Schottky pick-up with diode detectors has not been demonstrated before. However, it must be stressed that the LHC Schottky pick-ups operate with an important amount of coherent signals, providing the necessary carrier for diode detectors. It has been observed that when the LHC beams have been colliding for hours, the S-BBQ Schottky sidebands decrease, often disappearing completely, which is believed to be caused by the gradual decrease of the coherent signals at 4.8 GHz while operating the LHC at top energy. If ever such an experimental setup is considered for regular operation at top energy, this phenomenon should be addressed, e.g. by using adequate amplifiers before the diode detectors.

While this paper reports on successful observation of transverse Schottky spectra with direct diode detection, it does not answer the question whether such spectra can be used to measure other quantities than betatron tunes, such as chromaticity or emittance. Qualifying a Schottky diode system for such diagnostics requires further studies.

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