Maschine, Diagnose und Instrumentierung

MDI INTERNAL REPORT NR. 2006 – 1
26 SEPTEMBER 2006

VISIT OF ESRF

EXAMINATION OF THE BUNCH CURRENT AND BUNCH PATTERN DEPENDENCE OF THE LIBERA BPM ELECTRONICS

By K. Balewski, I. Krupchenkov, K. Wittenburg (DESY)

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BY K. BALEWSKI, I. KRUPCHENKOV, K. WITTENBURG (DESY)

INTRODUCTION

The visit of ESRF was intended to study the dependence of the LIBERA BPM System on different bunch patterns. Inhomogeneous bunch patters will create sidebands at the RF harmonics which can lay inside the bandwidth of the filter in the input of the LIBERA. Therefore one can expect some influence on the beam position on the filling pattern of the machine. This is certainly true also for the planned LIBERA BPM System for PETRAIII (sidebands are much closer to the harmonics due to the large circumference of PETRAIII) and should therefore be examined. ESRF offers a large variation of different standard bunch patterns and –many thanks- also offers us some beam time to study these effects with their LIBERA module.

Two colleagues from I-Tech (B. Baricevic and A. Bardorfer) were also present. They helped us a lot during the data sampling, as well as they upgraded the module to the latest version of the LIBERA software release 1.20 (and patch release 1.21) successfully within less than 1 hour. They also fixed a hardware bug in the Ethernet connection circuit of the LIBERA successfully prior the experiments (important only for long Ethernet cable connections).

SETUP

Eric Plouvier (ESRF) had setup an ESRF button type pickup for the experiments. Two buttons of 10 mm radius were combined (Mini Circuit Laboratory ZX10-2-20 (0.2 to 2GHz power splitter/combiner; http://www.minicircuits.com/ZX10-2-20.pdf)) in a way to achieve a position independent signal with enough power on one line (see Fig. 1-3). This line (cable type RG 223, about 25 m length) was connected to a 4 way splitter (type MCL ZBSC-413, http://www.minicircuits.com/dg03-134.pdf) to get 4 equivalent and beam position independent signals. Four additional cables (same type) of 25 m length were connected between the splitter and the 4 LIBERA inputs to avoid interfering reflections between the splitter and the module. The signals were recorded with a fast 20 GS (4 GHz) Scope (LE CROY WR6200A) (see Fig. 4-6). A reflection due to the signal combiner was still present (Fig. 6). All these pictures were sampled at a beam current of 30 mA in 4 bunches equally spaced.

During the first measurements the 4 lines were separately attenuated to generate a constant beam offset in the LIBERA inputs.

Input A = 0 dB
Input B = 1 dB
Input C = 2 dB
Input D = 1 dB

Later the attenuators were removed to simulate a centred beam.

An additional RF-attenuator was installed in front of the splitter to simulate different beam currents. The attenuation was adjustable between 0 – 10 dB attenuation by a switch. The bandwidth of the system was limited by the splitter to about 800 MHz (see data sheet and measured by E. Plouvier). All cables and attenuators were tightly fixed to the electronic rack to avoid movements of the setup during measurements. However, even carefully handling of the attenuator switch might result in small disruptions and, due to the very high sensitivity of the readout, to beam position displacements up to about 1 μm. Unfortunately this was unavoidable with the present setup.

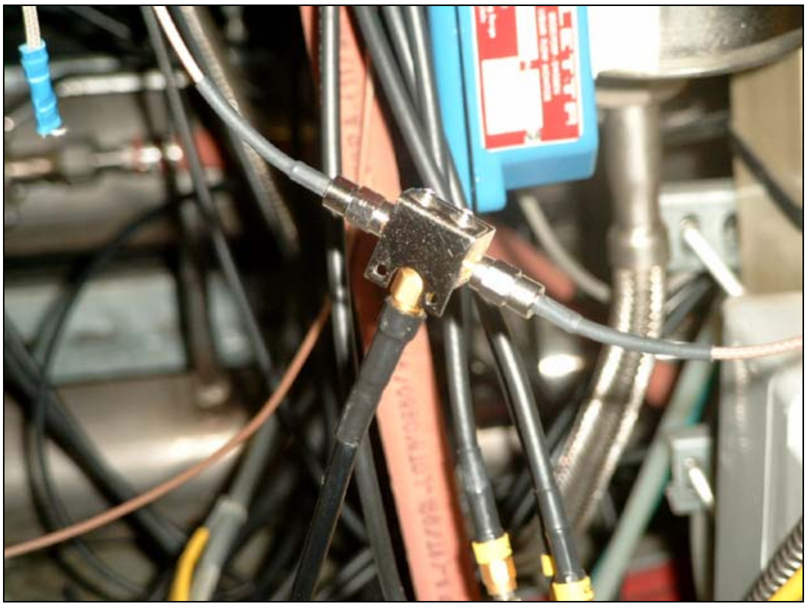


Fig. 1 Signal combiner

Fig. 2: BPM during the disconnection process.

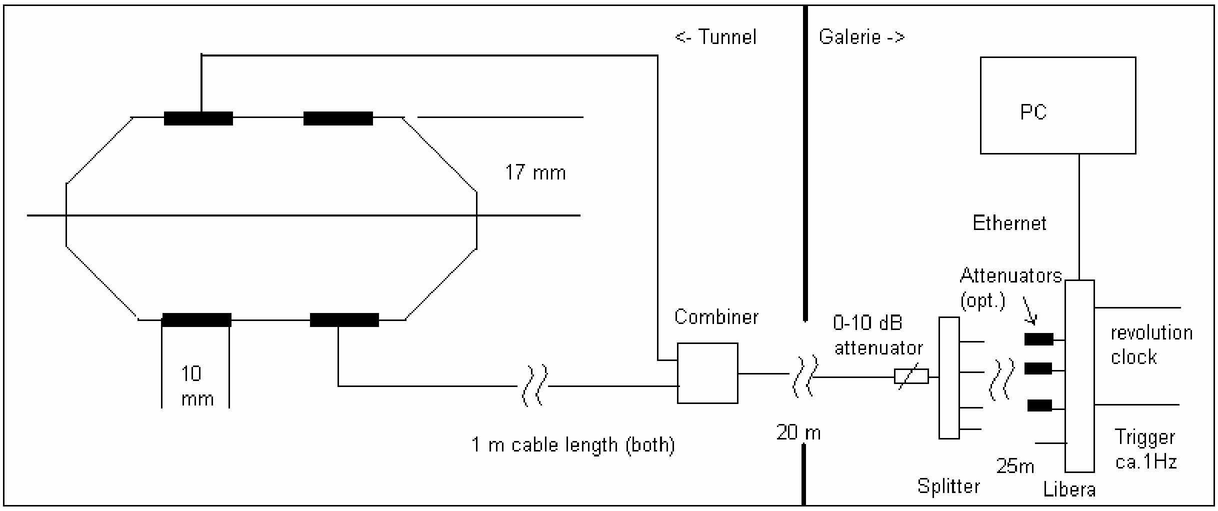


Fig. 3 Sketch of the Cable connections

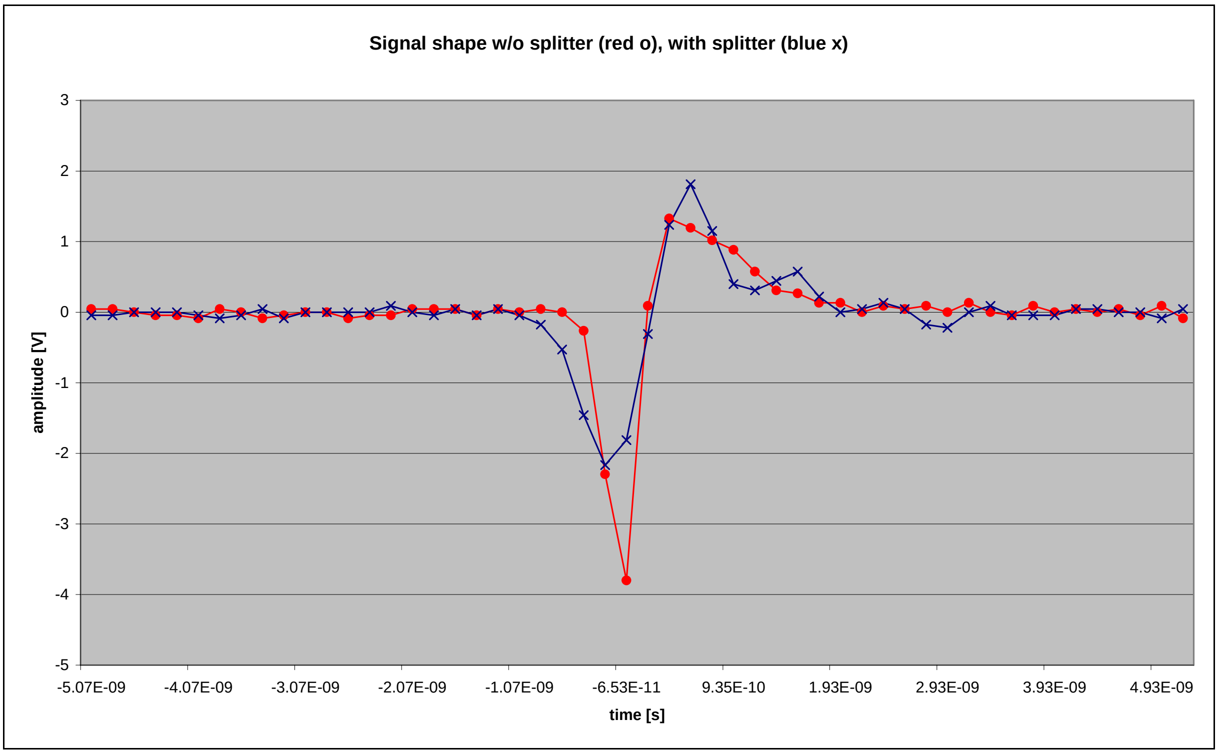


Fig. 4 Signal shapes with and without splitter (1 m cable after splitter)

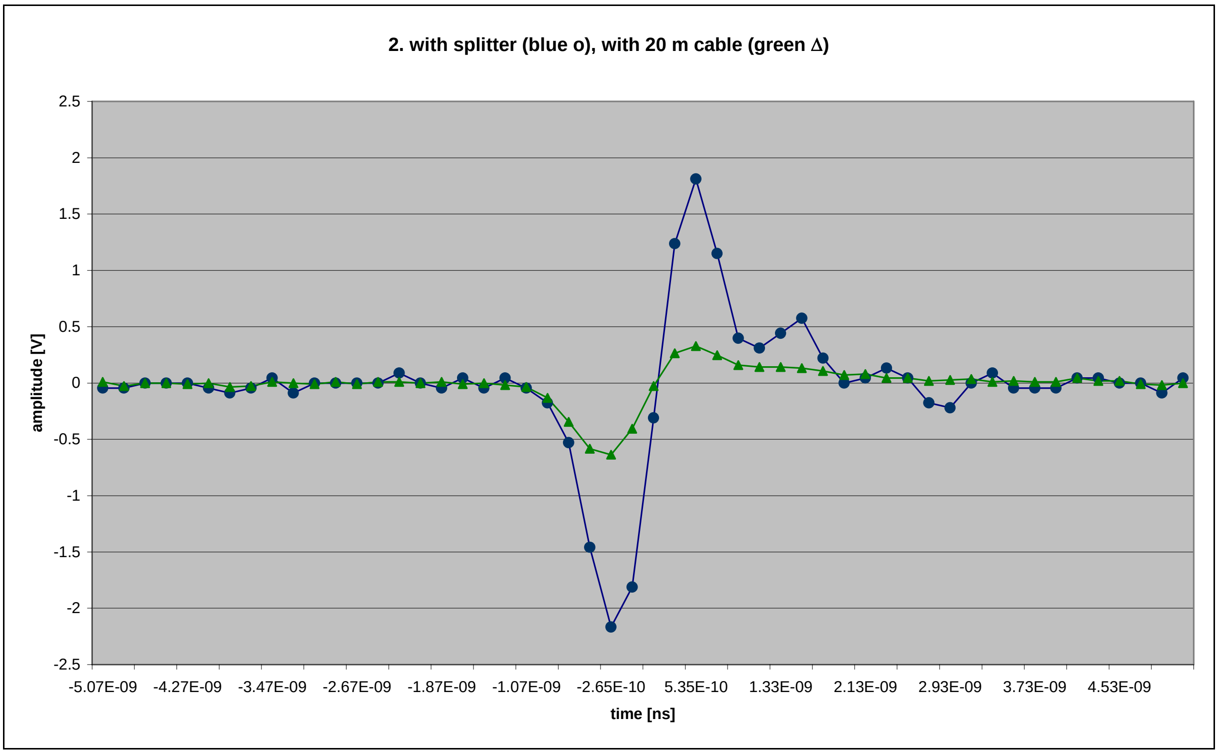


Fig. 5 Signal shapes after splitter

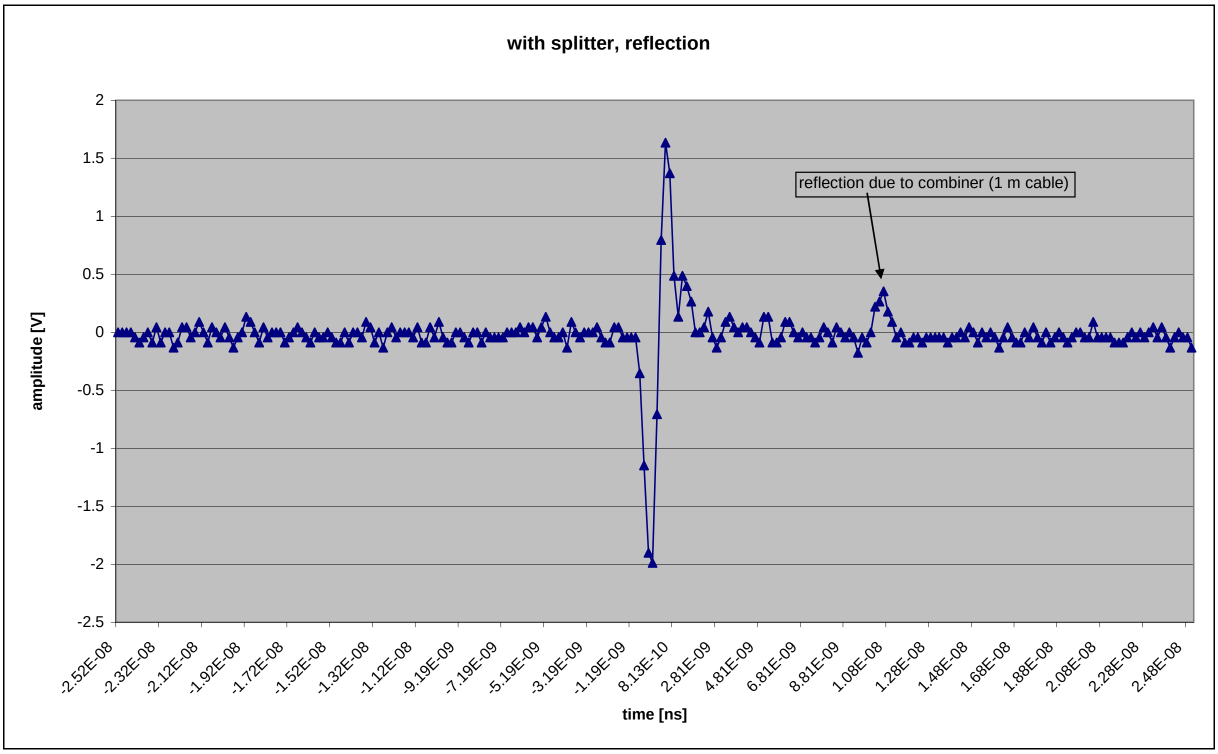


Fig. 6: Reflections due to the signal combiner. The distance of the reflection is equivalent to 1 m cable between the button and the combiner.

EXPERIMENTS

All experiments were done using the slow Ethernet output of LIBERA for the data sampling. The sampling rate was approx. 10 Hz for one x; y position value. During the discussion about the revolution clock (provided by E. Plouvier) we conclude that controlled detuning of the Machine Clock, which synchronizes Libera with revolution frequency, will be helpful to achieve the best resolution (see Ref. 1). Tests with the present setup have verified this and a detuning of 10 kHz was chosen for all following measurements. The reason for this behaviour should be discussed during the visit of I-Tech in Sept/Oct. 2006. More measurements should be done in the laboratory in the near future to confirm and to understand it.

To avoid a mixing of beam current dependence and bunch pattern dependence, the following measurements were done with an input AGC setting of -34 dBm ± 1dBm (otherwise noticed). This was adjusted by a careful choice of the adequate beam current and a simultaneous observation of the AGC setting of the module. The beam position numbers were calculated for a monitor constant of kx = ky =10 mm.

1) TEST OF ACQUISITION

The first experiment was done to prove the equivalence of the data sampling using I. Kruptchenkov's program and the Mathlab-program from I-Tech. 15 mA in 4 Bunches was filled and the two Laptops were connected to the LIBERA module one after the other. During the data sampling the attenuator was switched from 0 to 10 dB and back to 0 dB. This simulates a stepwise decay/increase of the beam current and proves the current dependence of LIBERA. Note that during all these measurement the present LIBERA module was not optimised for a current dependence, mainly the AGC settings can be optimised to minimise the dependence (see chap. 2)).

Both recording methods worked immediately and the data were successfully stored on the Laptop. Later the Mathlab data format (binary) was converted by the I-Tech colleagues into ASCI files. Fig 7 a, b shows the I-tech samples while Fig. 8 a, b shows the samples from Igor. I-Tech told us that LIBERA has some kind of learning curve of the AGC; therefore one can expect a slight discrepancy between the first and later measurements. However, the Y value was reproduced very well while in X one has a few microns difference of the minimum and maximum values between the two records.

More observations: a) The spikes in the samples are result of the switching process. The attenuator might disconnect the signal during switching, so that the position measurement at that moment gave an arbitrary result. b) The noise of the position value increases with higher attenuation as expected from LIBERA, however the amount of noise is always very low. The standard deviations σ were σ_x(0 dB) = 0.07 µm, σ_y(0 dB) = 0.079 µm, σ_x(10 dB) = 0.153 µm, σ_x(10 dB) = 0.165 µm. Fig. 9 shows a Gaussian fit to the noise distribution at 10 dB of the I-Tech data. c) After switching of the attenuator the AGC of the LIBERA needed a few seconds to find the optimum settings, resulting in a step of the position without switching. This even happened sometimes a second time some 10 seconds after switching (see Fig. 8b the second 3 dB step).

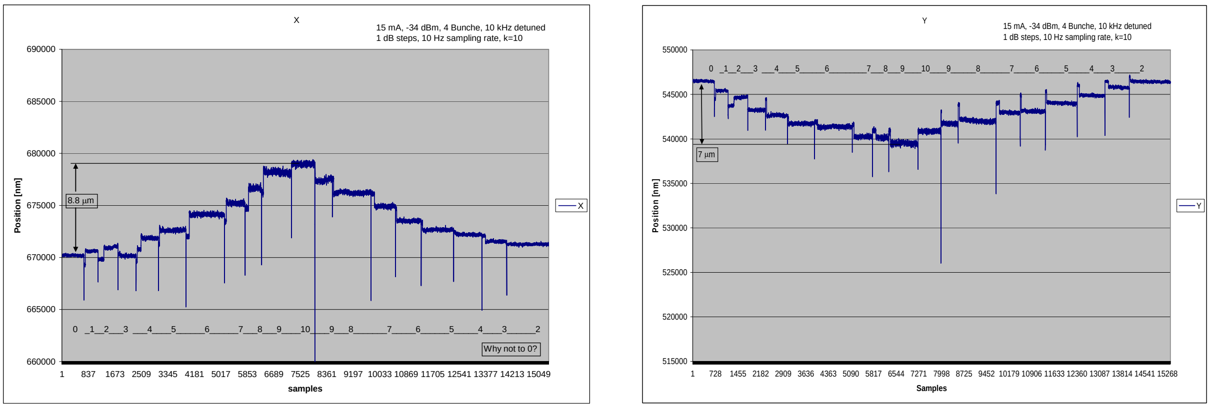


Fig. 7: Measured Position vs. attenuator setting a): x-position, b): y position. I-Tech records.

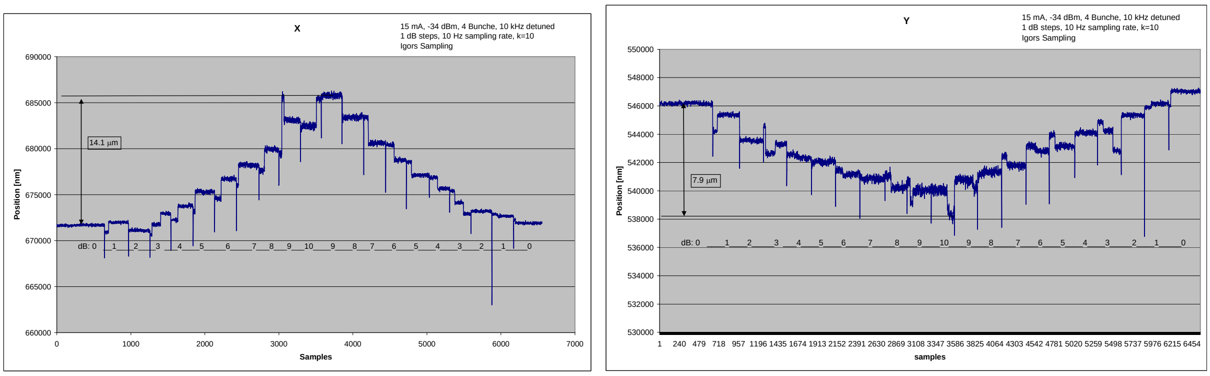


Fig. 8: Measured Position vs. attenuator setting a): x-position, b): y position. Igor's records.

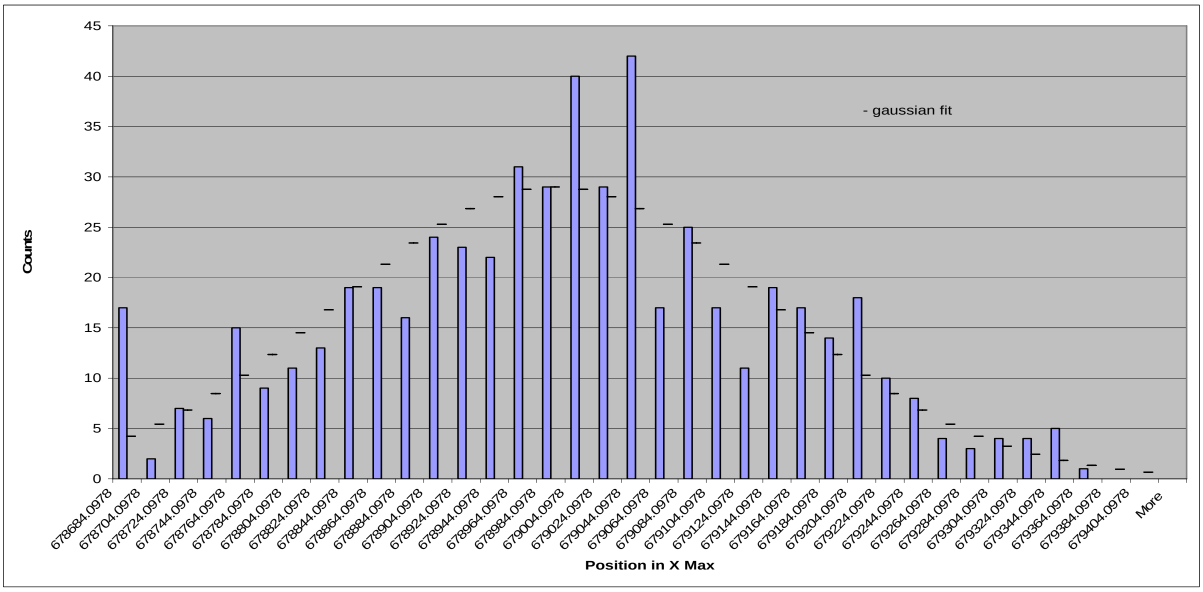


Fig. 9: Noise distribution and Gaussian fit.

2) BUNCH CURRENT DEPENDENCE (BCD)

Although the bunch current dependence (BCD) tests were not our primary goal, the measurements gave us a better understanding of the behaviour of LIBERA. Therefore some BCD tests were recorded with different bunch patterns (see Table 2). All measurements were done with an input power of -34 ± 1 dBm but with different beam currents related to the same input power. The measurement procedure was the same as in 1), but only the I-Tech Laptop and program was used for recording the samples. Table 1 gives the mean values measured whereas (x ; y) min is the measured position in x and y at the beginning at

0 dB, Diff (x ; y) $_{min\ max}$ the difference between the x and y positions at 0 dB and the maximum offset (sometimes at the second 9 dB step), and Diff (x ; y) $_{0\text{-}0\ dB}$ is the difference between the first and second 0 dB (x ; y) position.

The measurements with 4 bunches are summarized from the previous test. The other BCD measurements were done without the attenuators in the lines B to D to generate a more symmetric beam offset. The remaining offset was due to the unbalanced splitter, which was proven by rotating the inputs A -> D, B ->A, C ->B, D ->C. This generates a beam offset of opposite signs while the amount switched between X and Y. Note that this was a quite large change in the setup, all connected cables had to be moved which might have generated some additional offsets.

The last BCD measurement (16 bunches) was done with a new Automatic Gain Control (AGC) table, provided by I-Tech. It was a fast test to show that the current dependence can be minimized by a more matched setting of the AGC. A region can be specified were the dependence is minimal. For the current test the I-Tech colleagues installed a better table (by comparison with an available table of DIAMOND settings), but note that it probably can be still improved.

Bunches	Beam current [mA] ± 1 mA	(x ; y) min at 0 dB [μm]	Diff (x ; y) at 0 and 0 dB [μm]	Diff (x ; y) at min and max [μm]	Noise σ (x ; y) at 0 dB [μm]
4 (I-Tech)	15	670 ; 546.5		8.78 ; -7.0	0.07 ; 0.079
4 (Igor)	15	671.6 ; 546.2	0.24 ; 0.86	14.1 ; -7.9	0.083 ; 0.079
Offset attenuators removed					
4	15	23.51 ; -90.17	-0.024 ; 0.016	1.34 ; -17.85	0.066 ; 0.071
992	130	22.99 ; -86.7	-0.058 ; -0.945	1.55 ; -16.57	0.015 ; 0.02
16	54	23.76 ; -86.08	-0.049 ; - 1.18	2.70 ; -18.12	0.022 ; 0.026
Rotated inputs					
16	54	85.68 ; -11.35	0.227 ; -0.093	6.44 ; -19.82	0.025 ; 0.036
New AGC table installed					
16	54	90.64 ; -29.88	-0.001 ; -0.167	2.15 ; -0.588	Hand written mean values

Table 1: BCD measurements

3) BUNCH PATTERN DEPENDENCE (BPD)

Different beam position measurements were done for various bunch patterns. The patterns used for this experiment are shown in Tab. 2. The corresponding current- and frequency- spectra are shown in the figures A1 – A6 in the appendix. The bunch to bunch current variation is expected to be less than 5% (Ref. E. Plouvier, private communication)

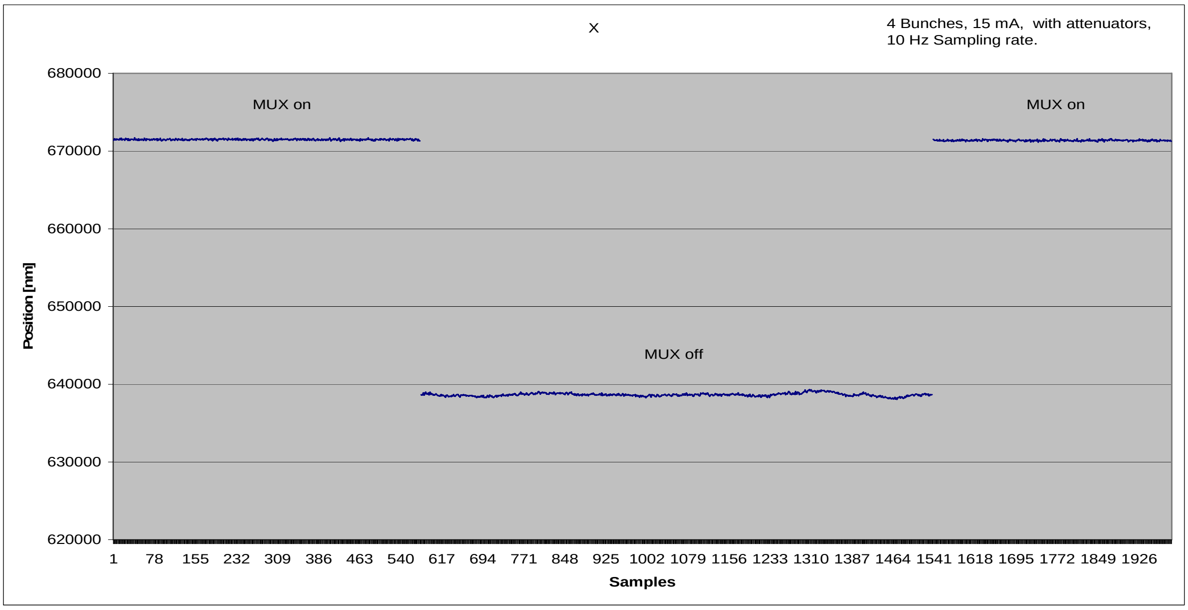
Bunch pattern	Description	Figure number
1	1 single bunch in the machine,	Fig. A1
4	4 bunches of same intensity uniformly distributed around the machine	Fig. A2
16	16 bunches of same intensity uniformly distributed around the machine	Fig. A3
992	992 bunches of same intensity uniformly distributed around the machine. This pattern represents a very homogeneous filling.	Fig. A4
868	Uniform filling of bunches of same intensity with a gap of 124 bunches	Fig. A5
868 + 1	Uniform filling with a gap of 124 bunches plus 1 bunch in the middle of the gap with three times the intensity of the others. This pattern represents a strong perturbation and a very inhomogeneous filling.	Fig. A6

Tab. 2: Used bunch patterns during the experiments in ESRF

While one might expect a larger BPD with an unused LIBERA multiplexer (MUX), recordings were done with the MUX running as well as with a defined setting of the multiplexer ("off"). Three successive records were sampled, 1) with running MUX, than 2) without MUX but defined setting which should be the same for all measurements without MUX, and 3) again with running MUX. Each recording was stopped after about 30 sec before applying the new setting to the LIBERA module. Fig. 10 shows the first record with 15 mA in 4 bunches which were equally spaced around ESRF. The effect of the MUX is clearly visible, in the absolute beam position as well as in the noise pattern. The differences Δ of the mean value in respect to the first mean value (Position MUX on) are shown in table 2.

<table>
<tr><td>Bunch-pattern</td><td>Beam current [mA] ± 1 mA</td><td>Position MUX on (x ; y) [μm]</td><td>Δ MUX on-off (x ; y) [μm]</td><td>Δ MUX on-on (x ; y) [μm]</td><td>Noise MUX on (σ_x ; σ_y) [μm]</td><td>Noise MUX off (σ_x ; σ_y) [μm]]</td></tr>
<tr><td>4</td><td>15</td><td>671.5 ; 545.4</td><td>-32.8 ; -175.0</td><td>-0.11 ; -0.24</td><td>0.075 ; 0.082</td><td>0.200 ; 0.230</td></tr>
<tr><td>16</td><td>53</td><td>674.9 ; 549.6</td><td>-24.7 ; -162.3</td><td>0.099 ; 0.003</td><td>0.043 ; 0.033</td><td>0.140 ; 0.173</td></tr>
<tr><td>1</td><td>3.5</td><td>661.5 ; 537.9</td><td>-36.2 ; -184.2</td><td>-2.05 ; -1.42</td><td>0.375 ; 0.326</td><td>0.354 ; 0.371</td></tr>
<tr><td colspan="7">Removed attenuators => simulating a more centred beam position</td></tr>
<tr><td>1</td><td>3.5</td><td>23.24 ; -88.99</td><td>-3.23 ; -147.1</td><td>-0.024 ; 0.101</td><td>0.567 ; 0.315</td><td>0.3 ; 0.34</td></tr>
<tr><td>16</td><td>65
- 5 dB</td><td>23.48 ; -91.83</td><td>-5.98 ; -13.32</td><td>0.048 ; 0.048</td><td>0.032 ; 0.035</td><td>0.081 ; 0.167</td></tr>
<tr><td>16</td><td>-32 dBm
long record</td><td>23.37 ; -89.02</td><td></td><td></td><td>0.024 ; 0.031</td><td></td></tr>
<tr><td>4</td><td>15</td><td>23.43 ; -89.83</td><td>-4.66 ; -13.93</td><td>0.129 ; -0.001</td><td>0.082 ; 0.089</td><td>0.172 ; 0.157</td></tr>
<tr><td colspan="7">Next day about noon</td></tr>
<tr><td>4</td><td></td><td>24.1 ; -89.27</td><td>-5.15 ; -13.63</td><td>-0.304 ; 3.595
2 steps in off</td><td>0.082 ; 0.097</td><td>2 steps</td></tr>
<tr><td>992</td><td>130</td><td>23.01 ; -87.74</td><td>5.78 ; -14.74</td><td>-0.021 ; 1.09</td><td>0.016 ; 0.019</td><td>0.10 ; 0.079</td></tr>
<tr><td>662</td><td>120
- 6dB
(-29 dBm)</td><td>22.87 ; -89.66</td><td>-8.21 ; -16.1</td><td>-0.047 ; 0.124</td><td>0.051 ; 0.048</td><td>0.089 ; 0.088</td></tr>
<tr><td>868</td><td>200
– 6 dB
(-27 dBm)</td><td>22.87 ; -87.19</td><td>-0.34 ; -152.6</td><td>-0.01 ; -0.008</td><td>0.020 ; 0.02</td><td>0.097 ; 0.062</td></tr>
<tr><td>868 + 1</td><td>200
– 6 dB
(-27 dBm)</td><td>22.88 ; -87.36</td><td>-0.75 ; -148.4</td><td>0.014 ; 0.032</td><td>0.019 ; 0.021</td><td>0.090 ; 0.084</td></tr>
<tr><td>16</td><td>54</td><td>23.8 ; -87.40</td><td>-7.87 ; -130.5</td><td>-0.015 ; 1.376</td><td>0.020 ; 0.029</td><td>0.115 ; 0.085</td></tr>
<tr><td colspan="7">Inputs rotated</td></tr>
<tr><td>16</td><td>53</td><td>85.8 ; -11.37</td><td></td><td></td><td>0.023 ; 0.032</td><td></td></tr>
<tr><td colspan="7">Test for E. Plouvier</td></tr>
<tr><td>868 + 1
AGC off</td><td>200
-27 dBm</td><td>23.25 ; 81.77</td><td>-35.0 ; -146.5</td><td>0.041 ; 0.103</td><td>0.039 ; 0.055</td><td>0.164 ; 0.114</td></tr>
</table>

Tab. 2: Bunch pattern dependence



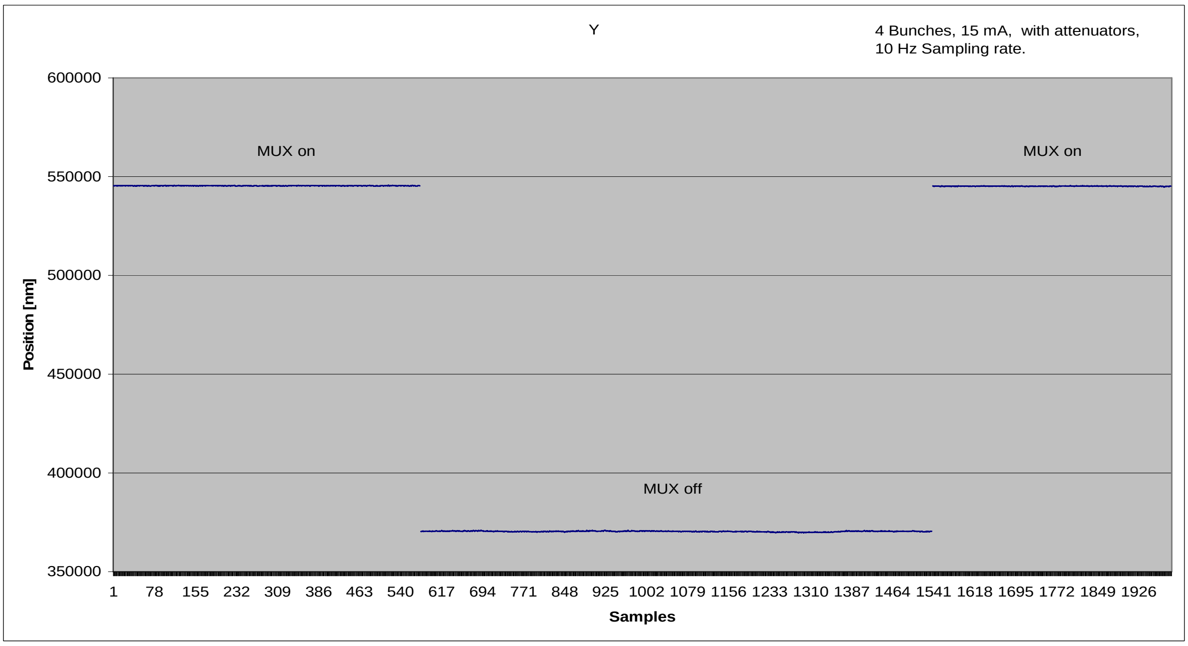


Fig. 10a, b: Three successive records with MUX on/off/on

3. DISCUSSION OF THE RESULTS

BCD: Table 1 shows a dependence of the measured beam position on the beam current (0 – 10 dB attenuation) of up to nearly 20 µm. But with a more adequate setting of the AGC one can reduce the dependence under the same conditions to about 2 µm. What we did not tested was the BCD with the AGC off, which has still to be done in the laboratory. With an adequate AGC setting one will be able to run LIBERA at PETRAIII even with the AGC on, but during top-up one can expect a stable beam current and might therefore switch the AGC off. This will avoid position jumps due to an AGC switching. The noise of the whole system (including EMV from running accelerator, cables, …) was always well below 0.1 µm, which is in agreement with the data sheet (0.3 µm at -20 dBm input power at 1 kHz). The reproducibility after one 0-10-0 dB cycle is typical well below 1 µm; however two events reached the 1 µm level. There might be two reasons for that: 1) A hysteresis in the AGC which led to different settings at 0 dB. This will certainly be reduced with an adequate AGC table. 2) The mechanical setup of this experiment was not tightly fixed. We observed a jump in the beam position of up to 1 μm when touching one of the cables. Unfortunately it is not excluded that this had happened during the experiments.

BPD: Table 2 shows the bunch pattern dependence (BPD). Neglecting the last two rows with different input power and with rotated connections the maximum dependence is Δx = 1.2 μm and Δy = 4.6 μm. A correlation of the maximum or minimum values with the bunch patterns cannot be found, the differences might be a result of the uncertainty of the setup (although both minimum values are with 868 bunches). Note that any touch of the setup can generate up to 1 μm offset. The reproducibility of the results at different days but equal settings was always better than 1 μm and is therefore within the general uncertainty. The reproducibility within the three successive recordings is typically less than 1 μm (Δ MUX on-on). The first record of the second day with 4 bunches shows in both planes much larger differences. This is a result of two jumps in the samples of the "MUX off" record (see Fig. 11). These jumps might be a result of touching the setup, or an automatic switching if the AGC, but we cannot prove it clearly.

The noise of the measurements decreased with the number of bunches from σ = 0.56 μm for 1 bunch down to 0.019 μm for 992 bunches. This will fulfil our requirements for PETRAIII for the slow orbit stabilization. The much larger variation of the position with "MUX off" and the larger noise show the importance of this feature of LIBERA. We try to make sure, that the MUX settings were always the same for all measurements, however, starting with the measurement at 868 bunches, one can observe a much larger difference Δ between "MUX on" and "MUX off". This might be explained by a different MUX setting than the previous measurements, but the exact settings were not recorded. Nevertheless, no influence on the "MUX on" values can be observed.

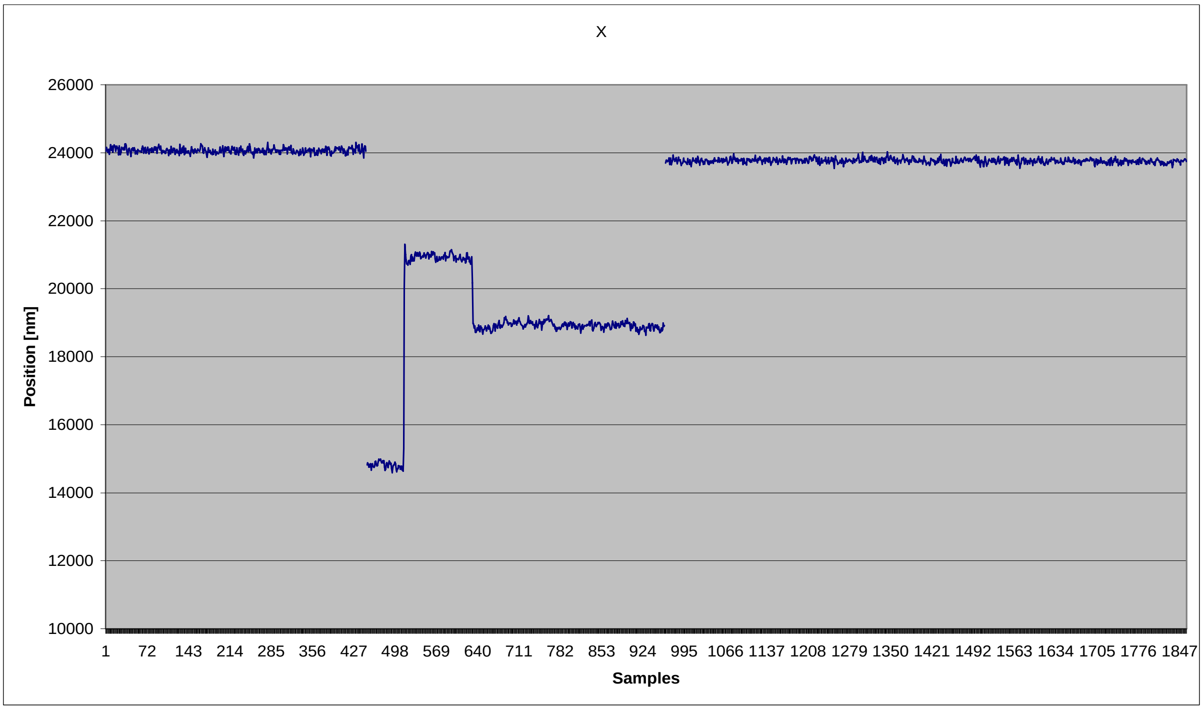


Fig. 11: Record of the x-position with 4 bunches on the second day. Note the jumps in the part were the MUX was off.

4) SOME MORE OBSERVATIONS AND GENERAL COMMENTS

As already noticed, a slight touch of the cables may have led to jumps in the position value. This was proved online by watching the readout values, but no dedicated experiment was recorded. However, in the data one can find these kinds of jumps but we can correlate it no more with touches. Fig. 12 shows such a jump of 0.135 μm. An other reason might be an automatic switching of the AGC. Since we do not know the reason of such jumps, one should check in the laboratory if such jumps really happened, happened arbitrary or if one can find correlations.

Fig. 12 shows also some kind of slow oscillations, which are also visible in other samples. The setup was done in a way to avoid influenced from real beam oscillations, but this might be an residual effect of real beam oscillations or effects from LIBERA itself (1/f noise?). Note that the amplitude of these oscillations is very small (≈ 0.01 μm).

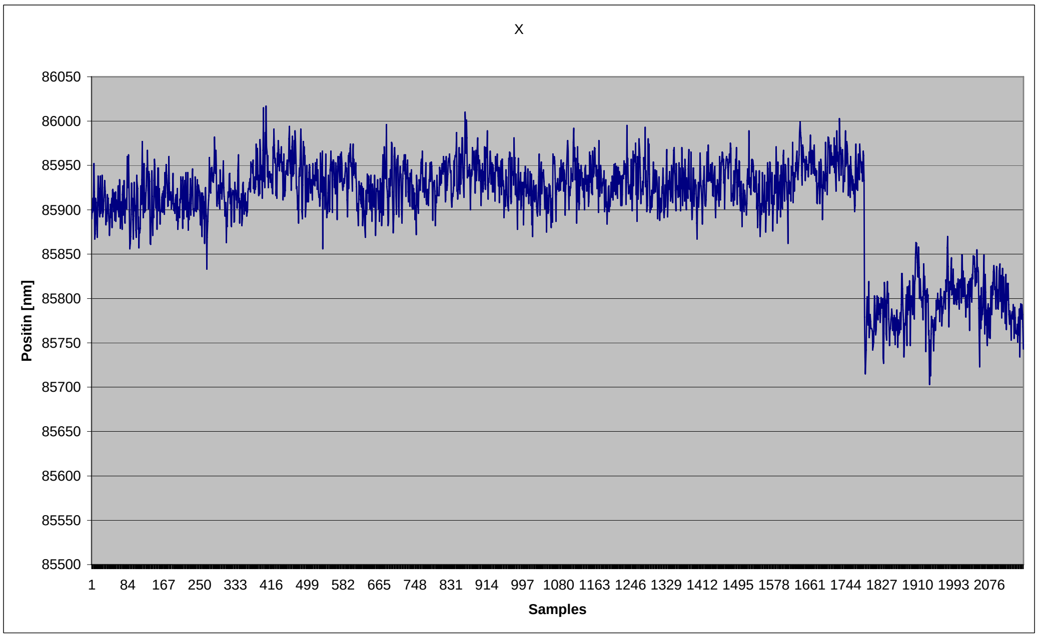


Fig. 12: Jump of x-position

In general the visit had shown the smooth behaviour of LIBERA. The upgrade of the software was done without any problems as well as the readout and the control of the module. Any treatment of the module was done by the I-Tech experts, but without any visible problems. Their program to control the module seemed to work very well (by Ethernet connection), so that one can expect for PETRAIII also an uncomplicated start-up of the whole system (if there are no other hidden problems). This is related to the low orbit control but so far not to the fast data readout (10 kHz); this readout is still under development by MSK.

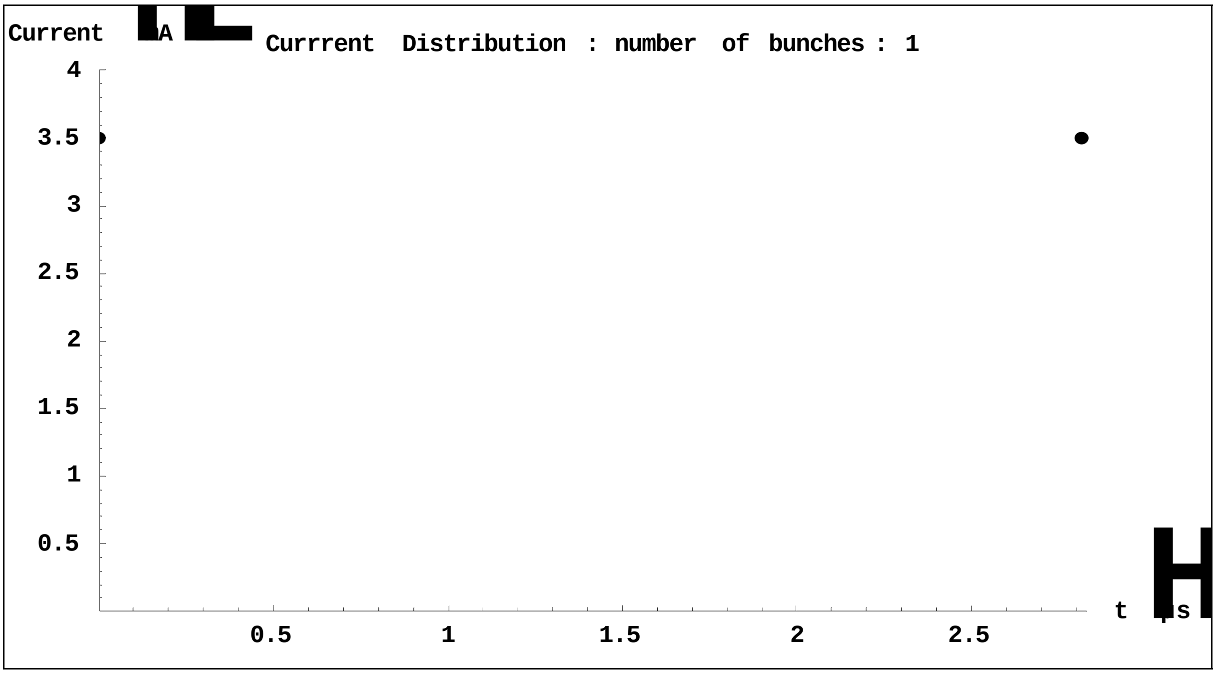
ACKNOWLEDGEMENTS

We like to thank E. Plouviez from ESRF for his fantastic help during the measurements. He provided us a friendly welcome and a well organized visit as well as a lot of technical equipment. We like to thank the shift crews of ESRF who provided us immediately with any strange kind of beam we like to have. The help of the I-Tech colleagues to ensure a smooth data recording is greatly acknowledged.

REFERENCES

Ref. 1: PERFORMANCE VERIFICATION OF THE DIAMOND EBPM ELECTRONICS.
By G. Rehm, M. Abbott (RAL, Diamond),. Jun 2005. 3pp. Prepared for 7th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC 2005), Lyon, France, 6-8 Jun 2005. Published in *Lyon 2005, Beam diagnostics and instrumentation for particle accelerators* 99-101

All following figures were calculated for the ESRF RF-frequency of 352.2025 MHz. The box in the frequency spectrum indicates the bandwidth (about ± 7.5 MHz) of the filter in the input of the LIBERA module to demonstrate the distribution of the sidebands inside the bandwidth. The shape of the filter is unknown, but a rough estimation confirms the bandwidth. At the same input power we had measured:
992 bunches => beam current = 130 mA => one spectral line inside filter bandwidth (see fig. A4b)
16 bunches => beam current = 54 mA => 130/54 = 2.4 => filter includes 2.4 lines (Fig. A3b)
4 bunches => beam current = 15 mA => 130/15 = 8.6 => filter includes 8.6 lines (Fig. A2b)
1 bunch => beam current = 3.5 mA => 130/3.5 = 37 => filter includes 37 lines (Fig. A1b)
All numbers agree quite well with the figures.



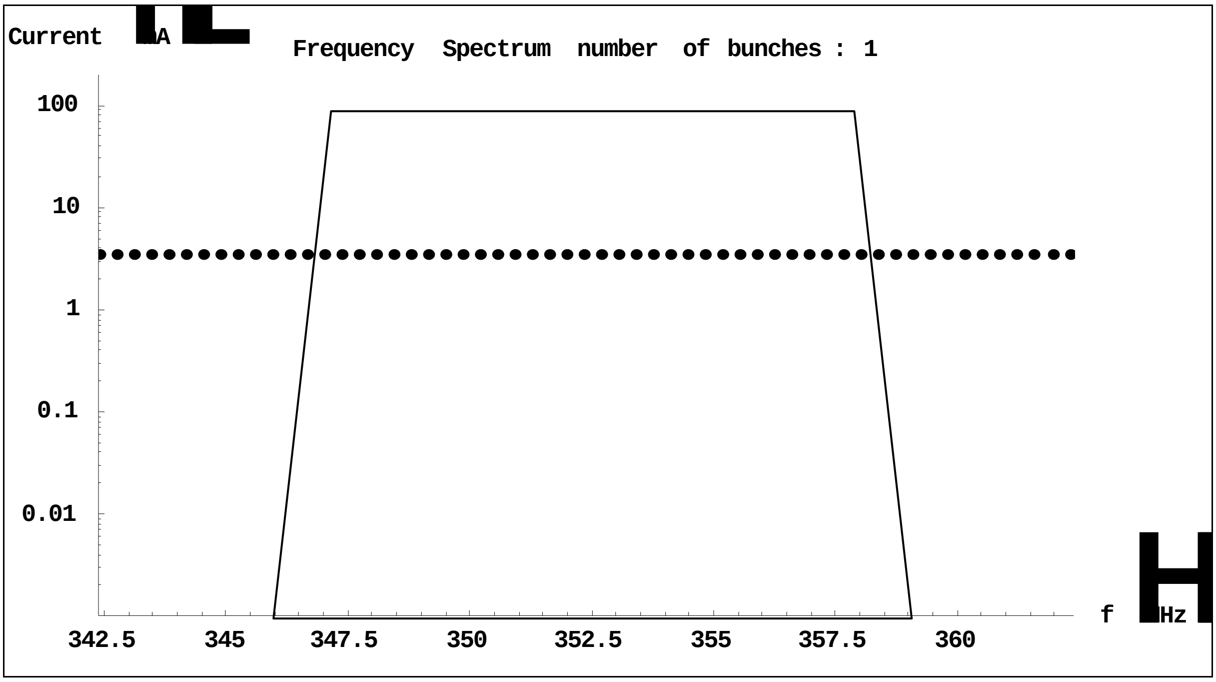
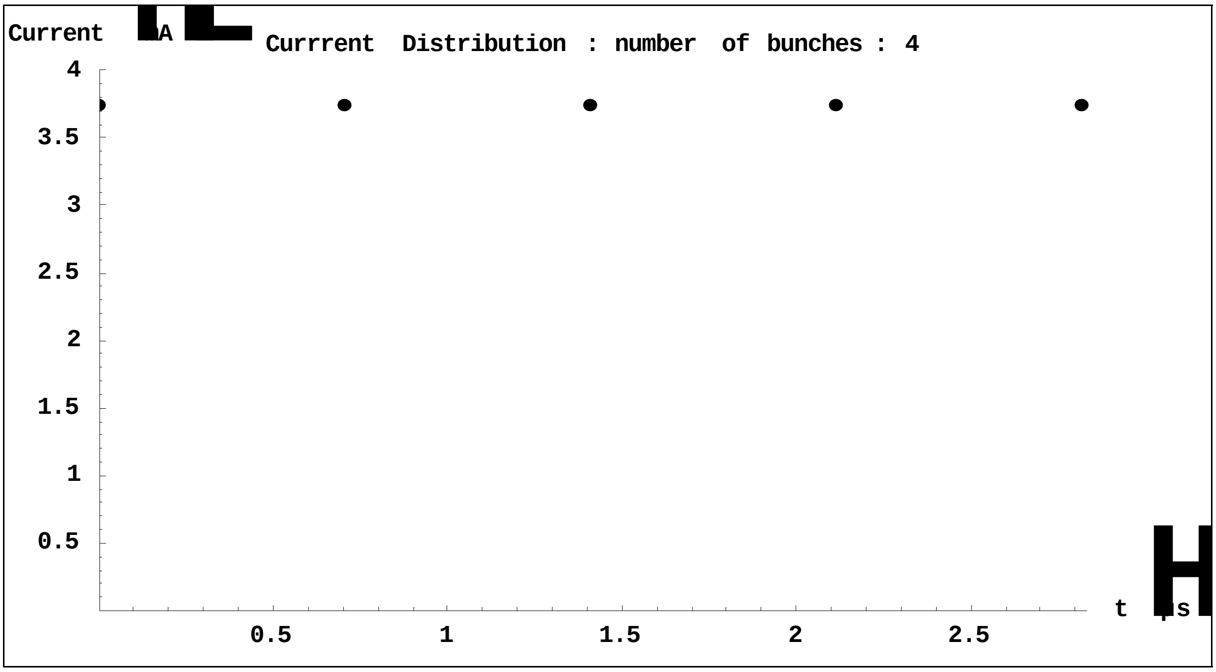


Fig. A1 a) Current- and b) frequency spectrum of a single bunch in ESRF.



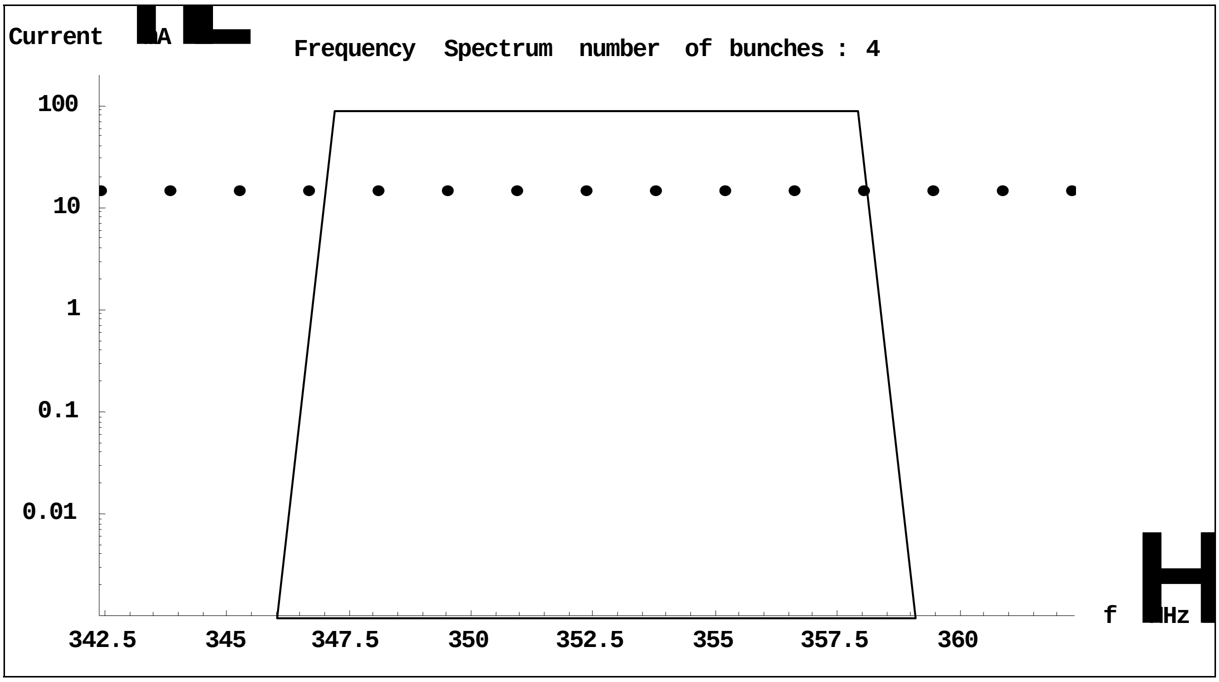
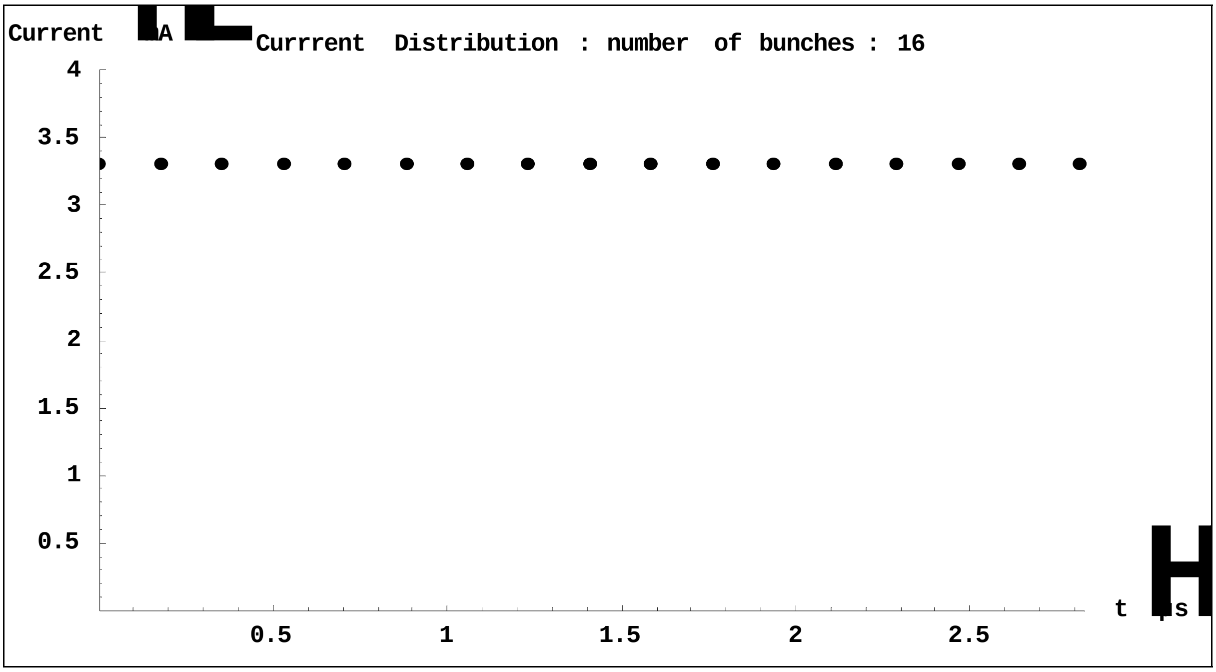


Fig. A2 a) Current- and b) frequency spectrum of 4 bunches in ESRF.



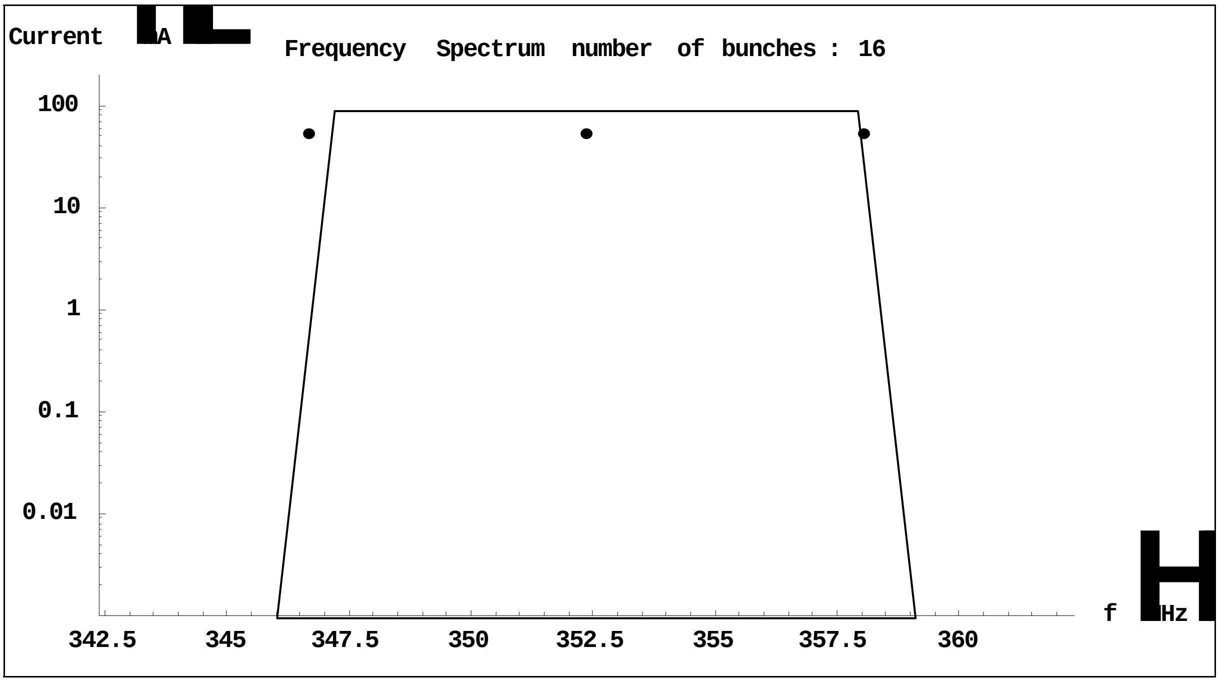
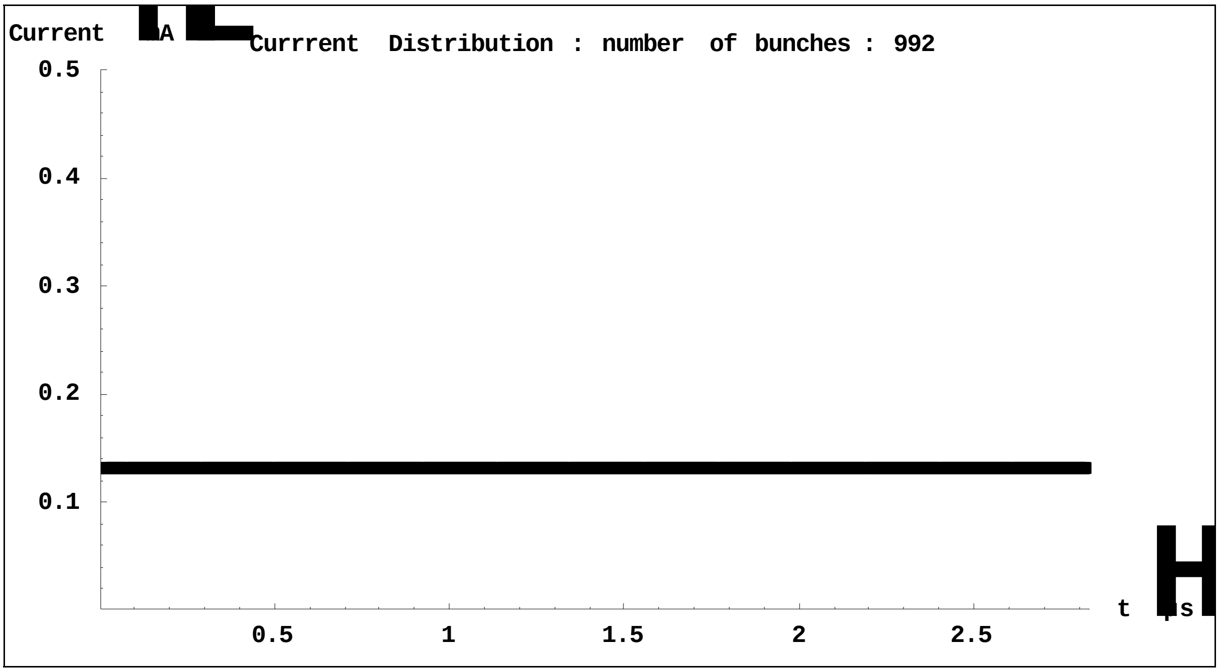


Fig. A3 a) Current- and b) frequency spectrum of 16 bunches in ESRF.



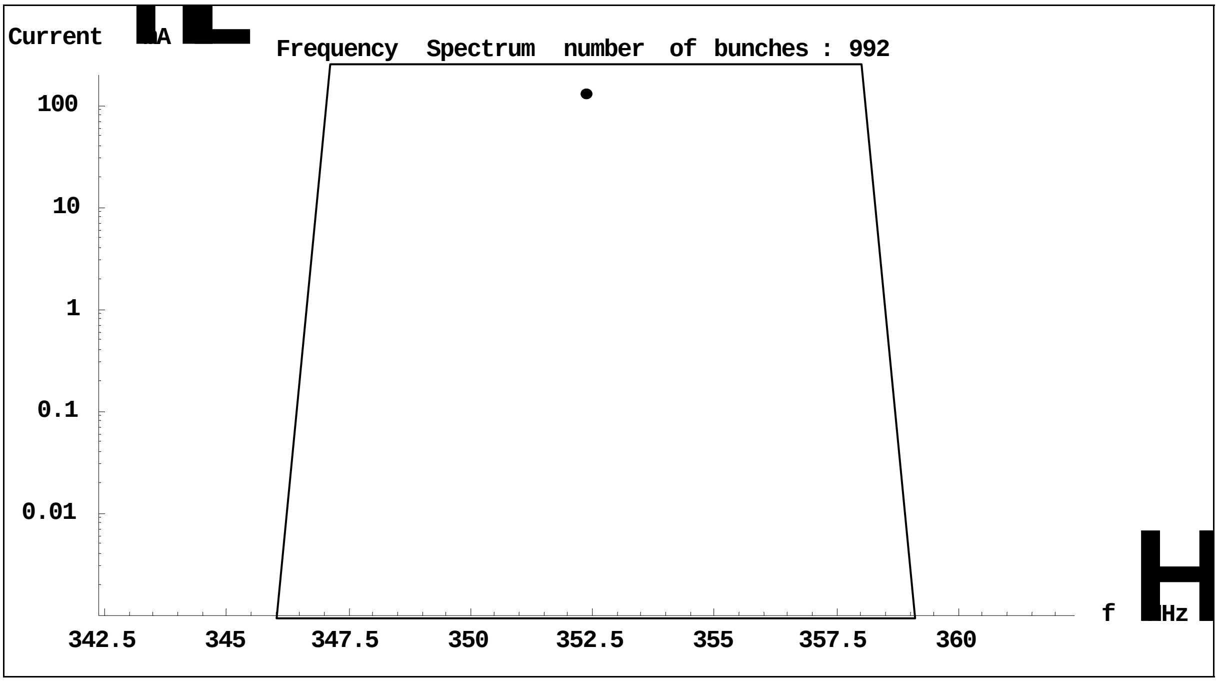
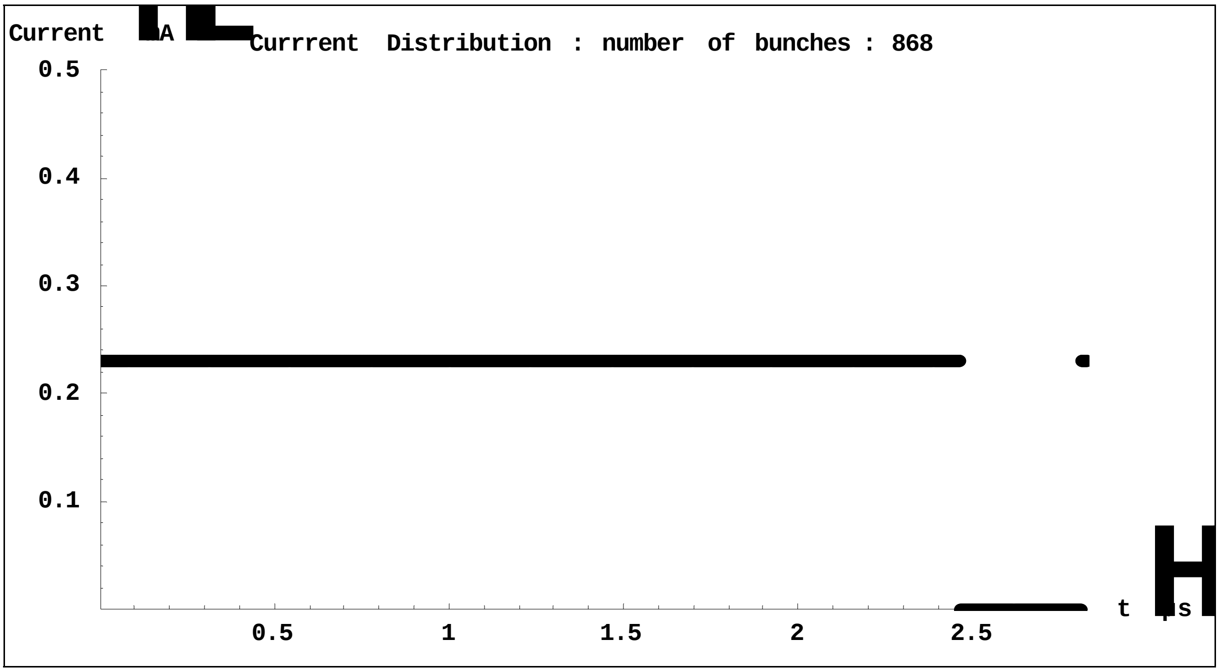


Fig. A4 a) Current- and b) frequency spectrum of 992 bunches in ESRF.



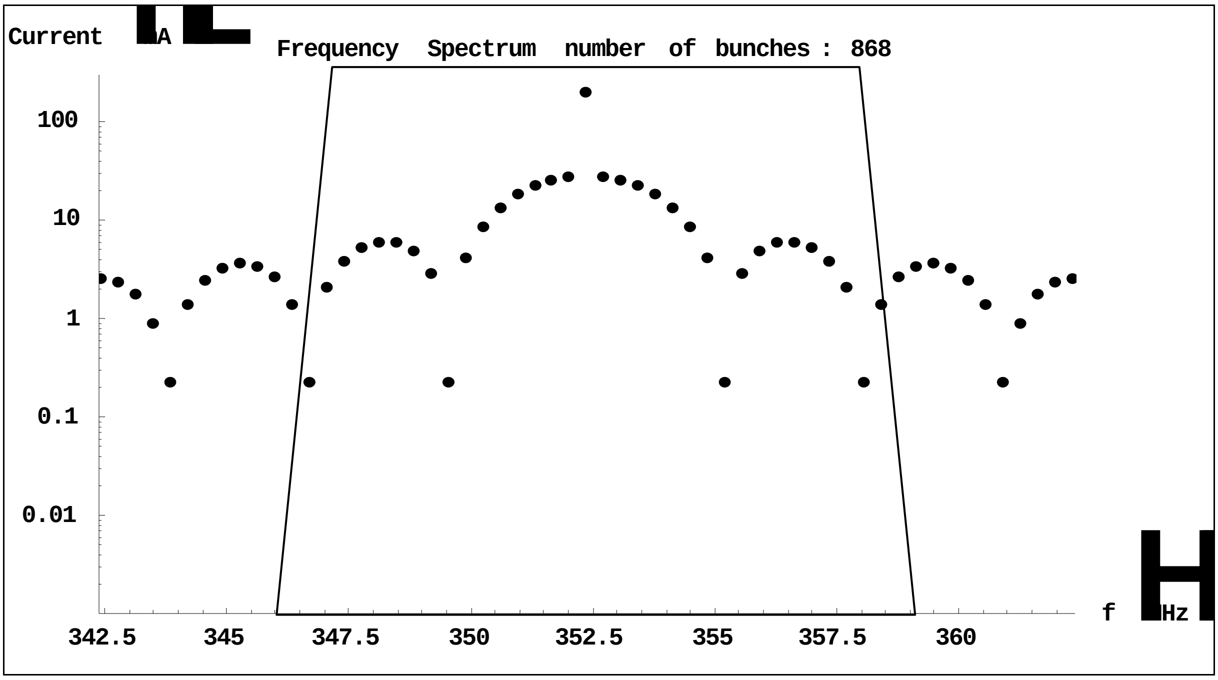


Fig. A5 a) Current- and b) frequency spectrum of 868 bunches with a gap in ESRF.

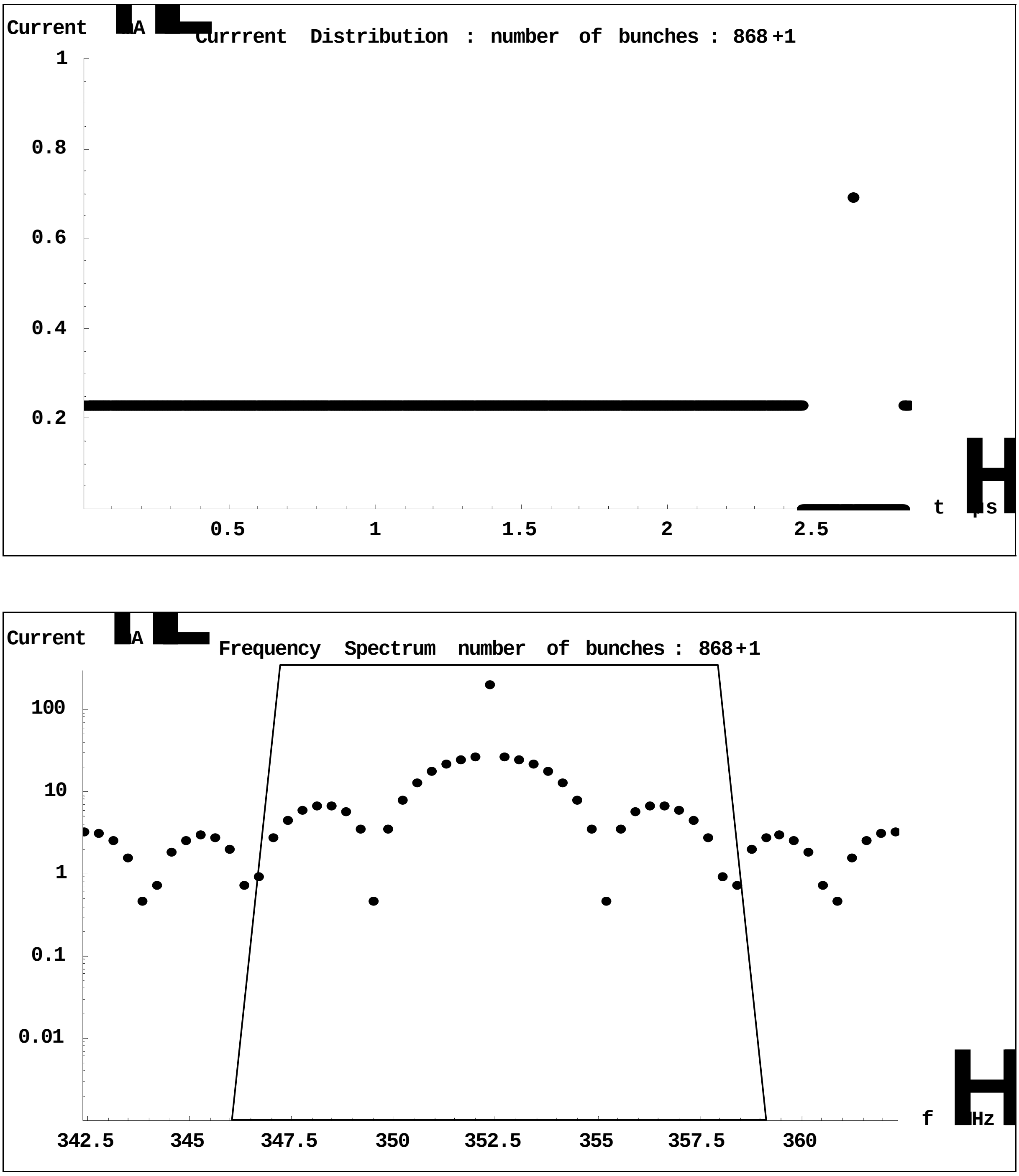


Fig. A6 a) Current- and b) frequency spectrum of 868 bunches + 1 larger bunch in ESRF.