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THE CLOSED ORBIT MEASUREMENT SYSTEM FOR THE CERN ANTIPROTON DECELERATOR

M. Le Gras, L. Søby, D.J. Williams

Abstract

The closed-orbit measurement system for the new Antiproton Decelerator (AD) employs 59 electrostatic pick-ups (PU). The intensity range from 2x10^{10} down to 10^{7} particles poses challenging demands on the dynamic range and noise of the head amplifier. A low noise-amplifier has been developed, having an equivalent input noise of 0.6nV/√Hz, allowing beam positions to be measured to ± 0.5 mm with 5x10^{6} particles. Two different gains take care of the large dynamic range. After amplification and multiplexing, the PU signals are fed to a network analyser, where each measurement point corresponds to one PU. The network analyser is phase locked to the RF of the AD, thus acting as a "tracking filter" instrument. An orbit measurement takes from 0.2 to 12 s depending on the IF-bandwidth of the network analyser, selected according to the beam intensity, and the precision required. At the end of the network analyser sweep the data are read via a GPIB interface and treated by a real-time task running in a VME based Power PC.

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The closed-orbit measurement system for the new Antiproton Decelerator (AD) employs 59 electrostatic pick-ups (PU). The intensity range from 2×10^{10} down to 10^7 particles poses challenging demands on the dynamic range and noise of the head amplifier. A low noise-amplifier has been developed, having an equivalent input noise of $0.6\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$, allowing beam positions to be measured to ± 0.5 mm with 5×10^6 particles. Two different gains take care of the large dynamic range. After amplification and multiplexing, the PU signals are fed to a network analyser, where each measurement point corresponds to one PU. The network analyser is phase locked to the RF of the AD, thus acting as a "tracking filter" instrument. An orbit measurement takes from 0.2 to 12 s depending on the IF-bandwidth of the network analyser, selected according to the beam intensity, and the precision required. At the end of the network analyser sweep the data are read via a GPIB interface and treated by a real-time task running in a VME based Power PC.

1 INTRODUCTION

The AD is a new machine, replacing the previous low-energy antiproton facility, which consisted of AC, AA and LEAR. In the AD, antiprotons of 3.5 GeV/c are injected and decelerated down to 100 MeV/c, to be ejected to the experimental area in the centre of the machine. During deceleration, on intermediate plateaus, stochastic cooling and electron cooling is performed. On each intermediate energy level the orbit must be measured, and if necessary, corrected.

2 BEAM AND SIGNAL PARAMETERS

The PUs in the AD are made of metal sheet, accurately cut and mounted in metal tubes fitted inside the vacuum chamber. One annular electrode provides the intensity signal (Σ). The difference signal (Δ) is derived from 2 semi-sinusoidal electrodes. The Δ/Σ–ratio together with the PU sensitivity gives an intensity independent beam position. The signal levels on the electrostatic PU electrodes are calculated using Eq. 1 below:

$$\hat{V} = \frac{Ne}{C}\frac{l}{S}\frac{\pi}{2}B_{\mathrm{f}} \quad [\mathrm{V}] \qquad (1)$$

where N is the number of particles, C the electrode capacitance, e the elementary charge, l the electrical length of the PUs, S the AD circumference, πB_{f} / 2 the ratio of peak to average line density. B_{f} = 1 yields a signal level of 4.2 μVp per electrode at $1\mathrm{x}10^7$ particles and a differential PU sensitivity of 0.1μVp / mm. In a 20 MHz system with an equivalent amplifier input noise of $2\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$, the signal-to-noise (S/N) ratio is approximately 0.01 for 1 mm of beam position, or in other words a resolution of ~100 mm ! It is clear that a reduction of bandwidth and input noise is necessary. On the other hand, one wants to observe the bunches of high intensity beams of 10^{10} particles on an oscilloscope, which demands a large bandwidth. In the AD the revolution frequency varies from 1.6 to 0.17 MHz and the minimum bunch length is in the order of 100 ns. For good bunch observation a system bandwidth of 10 kHz-20 MHz is thus necessary.

3 THE HEAD AMPLIFIER

It was therefore decided to build a head amplifier of the following specification:

	Intensity range: $1x10^7-5x10^8\,\overline{P}$	**Intensity range:** $5x10^8-10^{10}\,P$
Input imp.	5 MΩ // 49 pF	5 MΩ // 18 pF
Gain	47 dB	20 dB
Bandwidth	10 kHz-20 MHz	10 kHz-50 MHz
Input noise	$0.6\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$	$6\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$
CMRR	>66 dB	>66 dB
Max. Output	1.5 Vp in 50 Ω	1.5 Vp in 50 Ω

Table 1: Head amplifier specification

To achieve the very low noise performance required of the head amplifier in the high gain mode, a technique using paralleled Junction Field Effect Transistors (JFETs) [1] was used. A simplified diagram of an input stage is shown in Fig. 1.

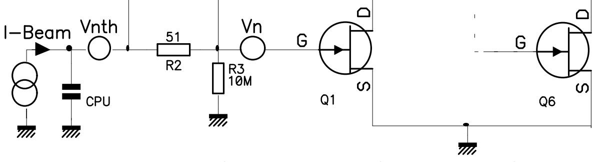

Figure 1: Simplified diagram of head amplifier

The total equivalent input noise is dominated by the voltage noise of the JFETs and the thermal voltage noise of *R2* // ω*L1*. The voltage noise of the JFETs [2] is given by:

$$V_n = \sqrt{8kT \;/\; N\,3gm} \qquad [\mathrm{V}\;/\sqrt{\mathrm{Hz}}\,] \tag{2}$$

where g_m is the transconductance [A/V], *N* the number of JFETs in parallel, *k* [J/°K] Boltzman's constant and *T* [°K] the absolute temperature. The thermal voltage noise of the input filter is given by:

$$V_{nth} = \sqrt{4kT\left|R_2 \;//\; \omega L_1\right|} \qquad [\mathrm{V}\;/\sqrt{\mathrm{Hz}}\,] \tag{3}$$

In the case of a capacitive source, the current noises of the JFETs and *R3* can, in our frequency range, be considered as bypassed by the PU capacitance, and are therefore ignored. The total equivalent input noise is solely determined by the voltage noises and becomes;

$$V_{n,in} = \sqrt{V_n^{\;2} + V_{nth}^{\;2}} \qquad [\mathrm{V}/\sqrt{\mathrm{Hz}}\,] \tag{5}$$

It is possible to select the value of L_1, such that V_n mainly determines the input noise, in the frequency range of interest. Since V_n decreases with $\sqrt{N}$ and the signal decreases linearly with *N*, due to the increase in input capacitance, there exists a value for *N* for which the S/N ratio is optimum. A plot of the theoretical S/N ratio for *N* paralleled JFETs is shown in Fig. 2. In practice, due to dissipation and amplifier oscillations, this number could not exceed *N*=6. As seen on this plot, it is possible to gain another 17% in S/N-ratio by having a total of 16 JFETs in parallel, but for a differential input stage this would add 3W dissipation and require extra cooling. A differential amplifier with 2 x 6 JFETs in parallel has been developed, with an equivalent differential input noise of $0.6\mathrm{nV}/\sqrt{\mathrm{Hz}}$.

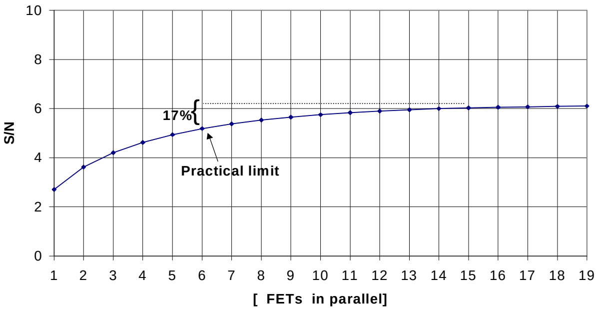

Figure 2: S/N-ratio with 10^7 particles, 1 mm, 1 kHz BW

4 THE TRACKING FILTER

Even though a very low noise amplifier is used, with the full bandwidth the signal to noise ratio is still <<1. In such a system it is very difficult to resolve the PU-signals using averaging. It was therefore decided to pass the PU signals trough narrow bandwidth filters i.e. 1 kHz, in order to reduce the noise level. The minimum S/N ratio in 1 kHz bandwidth is then ~ 5.

Using a commercial network analyser to measure the Δ/Σ –ratio, bandwidth is restricted by the different IF-filters. It also gives the possibility to phase lock on to an external reference signal, and in this way, beam positions are measured at a wide range of bunch frequencies. In our case the network analyser locks onto the RF of the AD.

5 THE SYSTEM

A block diagram of the orbit measurement system is shown in Fig. 3. The 59 PU-signals are amplified using the low-noise amplifiers located very close (0.7 m) to the PUs. Transmission to the control room (~100 m) is differential, and after the reception amplifiers the signals are fed to the network analyser via multiplexers (MPX).

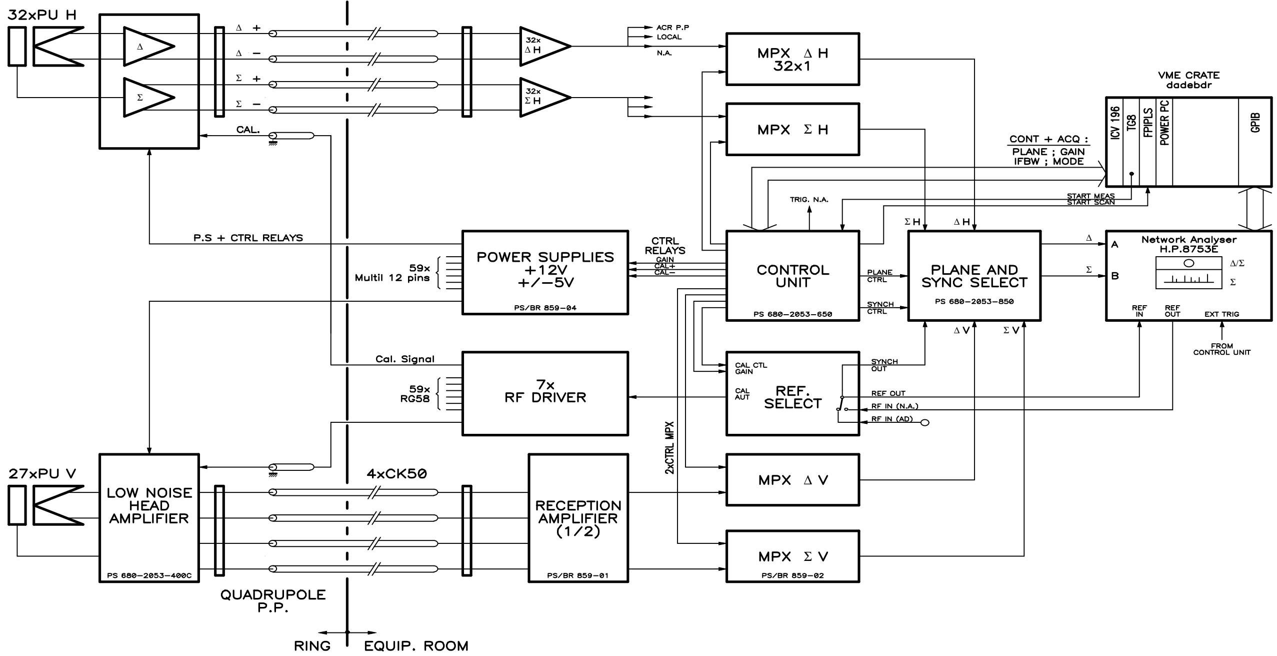

Figure 3: AD Closed-Orbit measurement system

When the Control Unit receives an external trigger, it starts the sweep of the network analyser at the same time as the MPXs. It was foreseen to trigger the network analyser on a point-by-point basis, but unfortunately this was not possible in the external reference mode. Instead the trigger starts a complete sweep (101 points) on the network analyser and at the same time the Control Unit increments the MPXs with exactly the same Δt as between the points on the network analyser. Each point on the network analyser corresponds to 1 PU.

The Plane and “Sync” Select unit selects the plane in which to measure. It also supplies a synchronous signal, which is switched to the network analyser after the scan of the MPXs has finished. This gives the possibility to verify that both the network analyser and MPXs are advancing at the same speed. When the software reads the data, the amplitude of the synchronous pulse is also checked.

It is possible to calibrate the electronics. In this mode the network analyser source sends a 1 MHz, CW signal via the RF-drivers to the input of each amplifier. The Δ/Σ-ratio from the amplifiers is then measured and stored for position calculations.

The Control Unit gives the possibility to choose between 4 different IF-bandwidths, which should be set accordingly on the network analyser, i.e. 1 kHz, 300 Hz, 100 Hz, and 10 Hz. In this way optimisation with respect to intensity, precision and duration, is obtained. With an IF-bandwidth of 300 Hz a complete orbit measurement takes approximately 600 ms.

Network analyser and Control Unit are controlled via a VME based Power PC C-program, which every 1.2 s sends the required control parameters, and whenever a measurement has taken place, reads the data from the network analyser. The data read from the network analyser consists of the normalised data (Δ/Σ) and the Σ-data. The latter is used to verify the intensity range and to check the validity of the signals. After data treatment with the previously stored calibration data and the PU data, the beam positions are calculated and stored in memory for orbit displays.

6 RESULTS

In total 59 low noise amplifiers, having a differential input noise of $0.6\,\text{nV}/\sqrt{\text{Hz}}$, were installed in AD-ring close to the PUs. The orbit measurement system was tested during the running in of the AD in October-December 1998. Orbits were measured in the intensity range 2x10^{10} to 5x10^{6} particles. From 2x10^{10} to 5x10^{7}, the measurement does not change with intensity as shown on Fig. 4. Below this intensity, at certain PUs close to the accelerating cavity, the measurements deviate from the high intensity values. It was found that RF-signals from the cavity leak into the head amplifiers and interfere with the PU-signals. Shielding and grounding around the low-noise head amplifiers close to the cavity have to be improved. This should make it possible to measure orbits with down to 5x10^{6} particles without significant errors.

7 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] R. B. Hallgreen, "Paralleled transconductance ultra low-noise preamplifier", Rev. Sci. instrum.59(9), September 1988.

[2] Y. Netzer, "The Design of Low-Noise Amplifiers", Proc. of the IEEE, Vol. 69, 728 (1981)

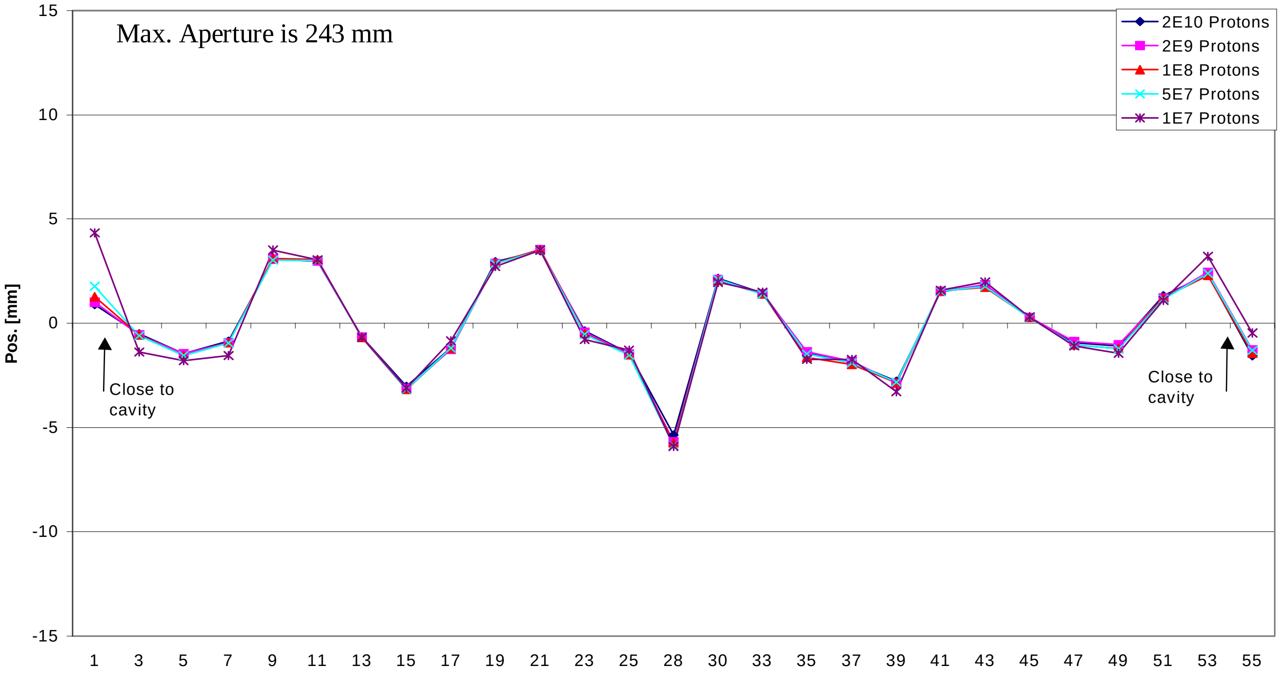

Figure 4: Vertical orbits measured at different intensities