Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 120 (2015) 1229 – 1232
Procedia Engineering
www.elsevier.com/locate/procedia

EUROSENSORS 2015

Low-Noise Charge Preamplifier for Electrostatic Beam Position Monitoring Sensor at the ELENA Experiment

Marco Baù[a,*], Marco Ferrari[a], Vittorio Ferrari[a]
Lars Søby[b], Ricardo Marco-Hernandez[b], Flemming Pedersen[b]

[a]*University of Brescia, Via Branze 38, Brescia 25123, Italy*
[b]*CERN, Genève, Switzerland*

Abstract

The Extra Low ENergy Antiproton ring (ELENA) is a synchrotron under construction at CERN aimed to decelerate the antiprotons from the existing Antiproton Decelerator (AD) to an energy of 100 keV. The orbit measurement of the beam is accomplished by 20 electrostatic Beam Position Monitoring (BPM) sensors to measure complete orbits every 20 ms with a resolution of 0.1 mm for intensities in the range of 1-3×10^7 charges. For the conditioning of the pick-up signals from the BPMs a low-noise charge amplifier has been purposely designed and is under testing. The circuit must feature a bandwidth of 40 MHz and an equivalent input voltage noise spectral density of 0.4 nV/ √ Hz for a sensor capacitance C_S of about 26 pF. After amplification, the sum and difference signals are analogically derived and sent over 50 m cables to further blocks for digitalization and processing.

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: Beam Position Monitoring, Charge Amplifier, Low-Noise Circuit

1. Introduction

The Extra Low ENergy Antiproton ELENA ring is a new synchrotron with a circumference of 30.4 m that will be commissioned at CERN in 2016. The ELENA orbit measurement system will be based on 20 circular electrostatic

* Corresponding author. Tel.: +39-030-371-5896; fax: +39-030-380014.
E-mail address: marco.bau@unibs.it

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015
doi:10.1016/j.proeng.2015.08.836

Beam Position Monitoring (BPM) sensors mounted inside quadrupoles and dipoles. Each pick-up element consists of a stainless steel body containing two diagonal cut BPM sensors inserted into a vacuum tank, 100 mm in diameter. The electrodes have inner diameter and length of 66 mm and 120 mm, respectively with a capacitance of about 15 pF. The orbit measurement is expected to have a time resolution of about 20 ms and a spatial resolution of 0.1 mm with an accuracy of 0.3/0.5 mm [1]. The antiprotons will have energy of 100 keV and intensities in the range of 1-3×10^7 charges. Fig. 1 shows the schematic diagram of the pick-up sensors and front-end electronics. The two BPM sensors allow the measurement of the position in two orthogonal planes. The charged beam induces on the pick-up electrodes a charge which is measured by a pair of charge preamplifiers (CA1 and CA2). The readout signals v_1 and v_2 from the preamplifiers are analogically combined to derive the sum (v_1+v_2) and difference (v_1-v_2) signals. After amplification of the signals by low noise amplifiers located very near to the BPMs, the difference and sum signals will be transported by ~50m cables to the rack where they will be digitized and processed.

In a second phase it is foreseen to use the same BPM sum signals for longitudinal Schottky measurements of un-bunched beams and intensity measurements for bunched beams.

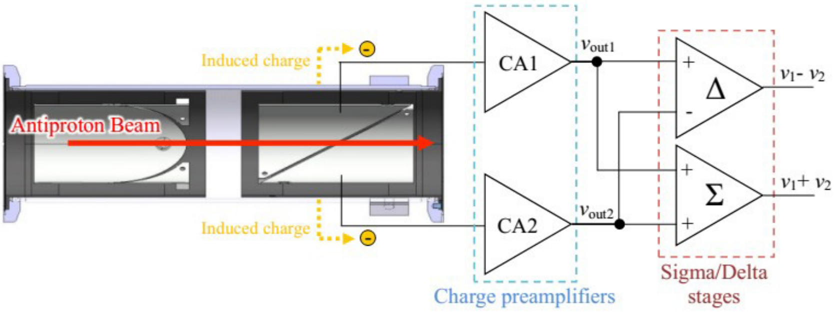

Fig. 1. Cross section view of the ELENA BPM pick-ups with a view of the two diagonal-cut sensors and the measurement principle for each pick-up.

2. Preamplifier Circuit Description and Analysis

The charge preamplifier circuit is shown in Fig. 2a. The input stage is based on a NJFET/BJT folded cascode configuration. The two paralleled NJFETs (BF862) lower the noise voltage due to capacitance matching with the sensor, while the PNP (BFT92) allows to down-shift the DC level with respect to a NPN configuration [2-6].

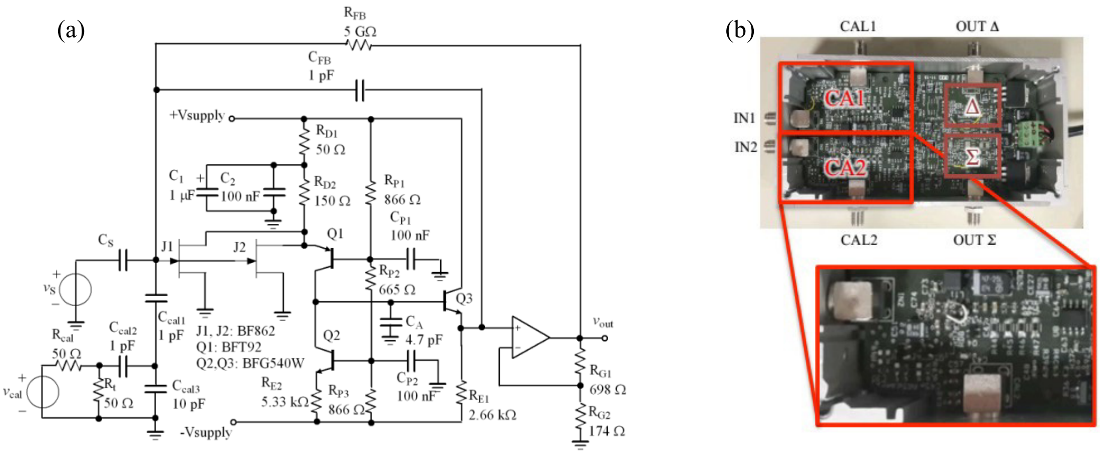

Fig. 2. (a) Circuit diagram of the charge preamplifier; (b) Picture of the prototype realized.

The cascode pair is driven by an active load based on the NPN BJT (BFG540W) to obtain a voltage open-loop gain of about G_1=-6000. The output emitter follower decouples from the following stage. The output from the emitter follower is capacitively fed back with a precision 1±0.05 pF capacitance C_{FB} to the JFET inputs. An additional feedback loop based on the AD811 current feedback amplifier with gain $G_2=(1+R_{G1}/R_{G2})=5$ is adopted to implement a “cold” resistance mechanism to reduce the thermal noise of the feedback resistor R_{FB} of 5 GΩ and to set the low corner frequency of the preamplifier at about 100 Hz [2-3]. The capacitance C_A sets the high corner frequency to 40 MHz. Modeling the signal from the BPMs with an equivalent voltage source v_S and considering the source capacitance comprising the cables and the pick-up electrodes modeled by C_S, the voltage transfer function between v_{out} and v_S in the bandwidth below the amplifier high corner frequency can be written as:

$$G_{CA} = \frac{v_{out}}{v_S} = -G_2 \frac{C_S}{C_{FB}} \frac{j\omega C_{FB} R_{FB} / G_2}{1 + j\omega C_{FB} R_{FB} / G_2} \tag{1}$$

For the typical value of C_S of about 26 pF, a mid-band voltage gain $G_{CA0} \approx -G_2 C_S / C_{FB}$ of 42.3 dB can be estimated from (1). The calibration of the preamplifier gain is achieved by injecting a charge through the calibration network in Fig.2a by means of the generator v_{cal}. For the voltage transfer function between v_{out} and v_{cal} (1) still applies, provided that C_S is replaced with the equivalent capacitance of the calibration network $C_{cal}=C_{cal1}(C_{cal2}+C_{cal3})/(C_{cal1}+C_{cal2}+C_{cal3})$. C_{cal}=0.92 pF with the values indicated in the schematics. In this case, a mid-band voltage gain $G_{CAL0} \approx$-14 dB is expected. Additionally from (1) it can be seen that the low corner frequency is set to $f_L=1/(2\pi C_{FB} R_{FB}/G_2)$. Fig. 2b shows a picture of the complete prototype realized comprising two charge preamplifiers and the sigma (Σ)-delta (Δ) stages.

3. Simulations and Experimental Results

Achieving low-noise performances compliant with the ELENA experiment requirements, i.e. an input-referred voltage noise density in the order of 0.4 nV/√Hz, has demanded for the use of paralleled JFET elements in the input stage of the preamplifier. Analytical calculations show that under the assumptions of identical paralleled JFETs operating with the same value of transconductance and when C_S>>C_{FB}, the optimal number of paralled JFETs for minimizing the peak-to-peak output voltage noise is $N_{opt}=C_S/C_J$, being C_J the input capacitance of the single JFET. The calculated value of N_{opt} corresponds to the condition of matching between the source capacitance and the input capacitance of the circuit.

Fig. 3a shows the calculated trends of the peak-to-peak output voltage noise and the signal-to-noise ratio (SNR) as a function of the number N of paralleled JFETs. In particular, with the values of the components of the circuit, it can be observed that N_{opt} is between 2 and 3, corresponding to the minimum of the output voltage noise and the maximum of the SNR. Considering the case of N=2, SPICE simulations of the noise behavior of the preamplifier

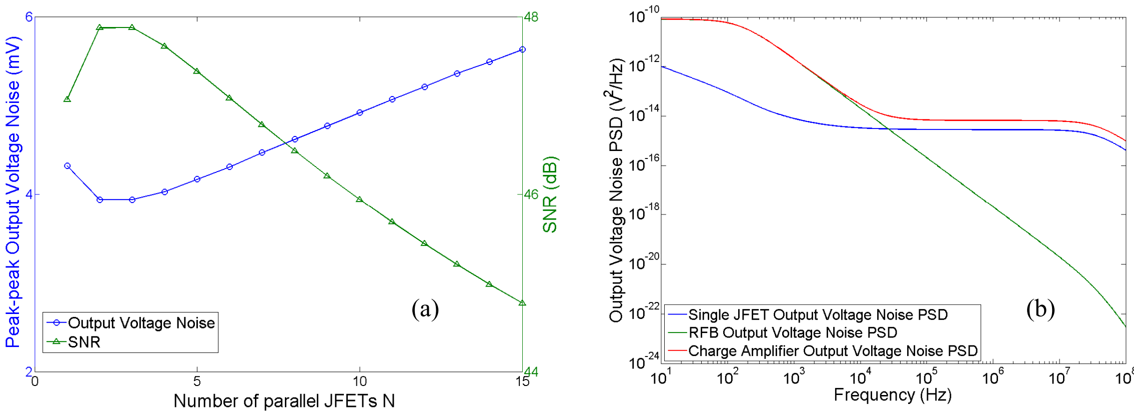

Fig. 3. (a) Peak-to-peak output voltage noise and SNR vs number of JFETs connected in parallel; (b) Simulation results of noise analysis.

have shown that the main contributions to the output power spectral density over the bandwidth of interest come from the feedback resistor and from the voltage noise of the JFETs. Fig. 3b shows the corresponding output voltage noise Power Spectral Density (PSD) indicating that up to about 10 kHz the output voltage noise is dominated by the noise of R_{FB}, while beyond 10 kHz the output voltage noise of the JFETs dominates.

The first complete prototype of the circuit has been tested by measuring the frequency response by means of a HP4194A gain-phase analyzer. In particular Fig.4a shows the voltage transfer function of the output voltage v_{out} measured with respect to the calibration input v_{cal} of the charge amplifier CA1, when v_S=0 and C_S≈20 pF. As expected a mid-band gain of about -15.33 dB can be observed, while f_L and f_H are respectively found at 99 Hz and 39.7 MHz, very close to the theoretical predictions. Preliminary measurements to evaluate the noise performances have been taken by means of a spectrum analyzer HP E4404B in the range from 9 kHz to 100 MHz. A test capacitance of about 26 pF on the input channel connected to ground has been used. Fig. 4b compares the experimental data with the simulation results showing a good agreement for frequencies above 400 kHz. In the flat region from 400 kHz up to 40 MHz an output voltage noise PSD of about 6×10^{-15} V^2/Hz has been measured, which corresponds to a voltage noise density referred to the input of about 0.33 nV/√Hz, in agreement with the predicted performances. In the low frequency region a deviation from the theoretical expectations has been observed which demands for further investigations that are currently under way.

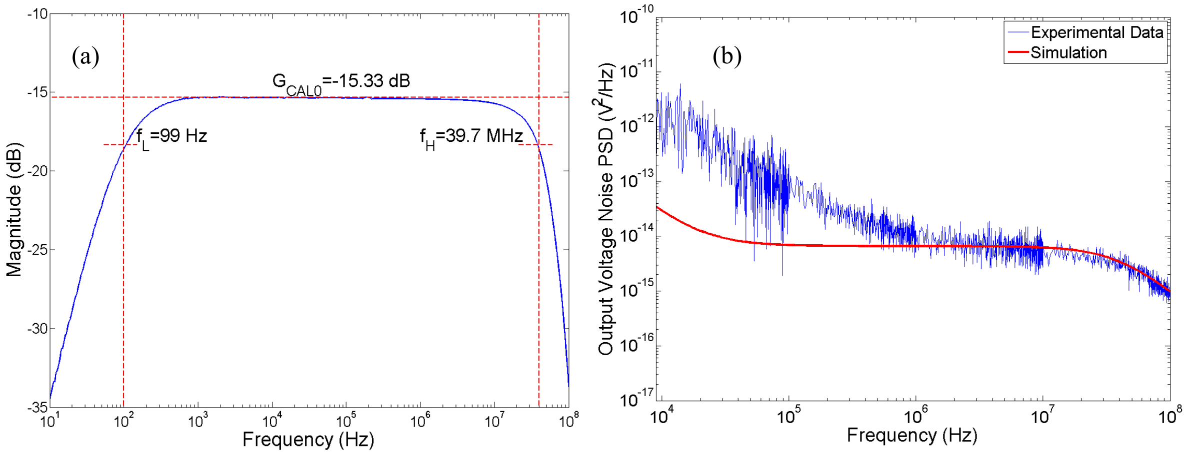

Fig. 4. (a) Frequency response measured for the charge preamplifier CA1 obtained by using calibration input CAL1; (b) Output voltage noise power spectral density measured at the output of the charge preamplifier.

Acknowledgements

Proff. D. Marioli and L. Venturelli at the University of Brescia are acknowledged for starting the project.

References

[1] L. Søby, M. E. Angoletta, R. Marco-Hernandez, J. Molendijk, F. Pedersen, J. S. Quesada, M. Baù, M. Ferrari, V. Ferrari, ELENA Orbit and Schottky Measurement System, Proc. IPAC 2015, May 3-8, 2015, Richmond, VA, USA, *in press*.
[2] A. Pullia, R. Bassini, C. Boiano, S. Brambilla, A "Cold" Discharge Mechanism for Low-Noise Fast Charge Amplifiers, IEEE Trans. Nucl. Sci. 48 (2001), 530-534.
[3] R. Bassini, C. Boiano A. Pullia, A Low-Noise Charge Amplifier with Fast Rise Time and Active Discharge Mechanism, IEEE Trans. Nucl. Sci. 49 (2002), 2436-2439.
[4] E. Gatti, P. F. Manfredi, Processing the signals from solid-state detectors in elementary-particle physics, La Rivista del Nuovo Cimento, 9 (1) (1986), 1-146.
[5] V. Radeka, Low-Noise Techniques in Detectors, Ann. Rev. Nucl. Part. Sci. 38 (1988), 217-277.
[6] Y. Netzer, The Design of Low-Noise Amplifiers, Proc. IEEE 69 (6) (1981), 728-741.