Design and fabrication of a preamplifier to be used with a MWPC at the ILSF

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2017 JINST 12 T04008

(http://iopscience.iop.org/1748-0221/12/04/T04008)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 80.191.200.82
This content was downloaded on 17/05/2017 at 11:44

Please note that terms and conditions apply.

You may also be interested in:

Basic design of a multi wire proportional counter using Garfield++ for ILSF
M. Ghahremani Gol, S. Ashrafi and J. Rahighi

Tracking chamber made of 15-mm mylar drift tubes
A. Kozhin, A. Borisov, N. Bozhko et al.

New drift chamber for the KEDR detector
I Yu Basok, V E Blinov, A V Bykov et al.

Monte Carlo and analytical calculations for characterization of gas bremsstrahlung in ILSF insertion devices
E. Salimi, J. Rahighi, D. Sardari et al.

A Piggyback resistive Micromegas
D Attié, A Chaus, P Colas et al.

Signal propagation in long wire chambers
P Bock, J Engelfried, T Friedrich et al.

TCPD, a TGEM based hybrid UV photon detector
G Hamar and D Varga

The Multi-Blade Boron-10-based neutron detector for high intensity neutron reflectometry at ESS
F. Piscitelli, F. Messi, M. Anastasopoulos et al.

Long-term study of backgrounds in the DRIFT-II directional dark matter experiment
J Brack, E Daw, A Dorofeev et al.
Design and fabrication of a preamplifier to be used with a MWPC at the ILSF

M. Ghahremani Gol, S. Ashrafi, J. Rahighi and R.H. Menk

Physics Faculty, Tabriz University, P.O. Box 51666-16471, Tabriz, Iran

Iranian Light Source Facility (ILSF), Institute for Research in Fundamental Sciences (IPM), P.O. Box 19395-5746, Tehran, Iran

School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), P.O. Box 19395-5531, Tehran, Iran

ELETTRA, Sincrotrone Trieste, P.O. Box S.S. 14, km 163.5, Basovizza, Trieste, 34012 Italy

E-mail: m.ghahremani@tabrizu.ac.ir

ABSTRACT: The Iranian Light Source Facility (ILSF) is a new 3 GeV third generation synchrotron radiation facility in Middle East, which at the time being is in its design stage. For day one operation of the ILSF a custom made two-dimensional multiwire position sensitive detector with delay line readout will be used in small/wide angle scattering and diffraction experiments with synchrotron radiation. For many years such X-ray detectors have played an important role in these synchrotron radiation experiments and owing to their robustness they are still in use in many places. Paired with state of the art read-out electronics they are serious low cost competitors to other solutions based on solid-state hybrid pixel detectors. To achieve minimum dead time and high global count rates these detectors will require preamplifiers with certain characteristics, which involve low noise, good signal/noise ratio (better than 20 dB), high gain, short rise time (lower than 10 ns) and pulse duration shorter than 120 ns. In this paper, we present the design and first results of the evaluation of a voltage preamplifier developed at ILSF within a collaboration agreement between ILSF, Iran and the Italian Synchrotron Radiation Facility (Elettra), Italy. The application of this preamplifier in an in-house multiwire detector is discussed and results are presented.

KEYWORDS: Detector design and construction technologies and materials; Instrumentation for synchrotron radiation accelerators; Wire chambers (MWPC, Thin-gap chambers, drift chambers, drift tubes, proportional chambers etc); X-ray detectors

1Corresponding author.
1 Introduction

The Iranian Light Source Facility (ILSF) will be the first Iranian synchrotron light laboratory. It is presently in its design stage and will be built in the city of Qazvin located 150 km west of Tehran. It is conceived as a national synchrotron light source to provide a powerful source of X-ray for the users and to cover requirements of experimental science in several fields [1]. The present draft design is a 3 GeV, 3rd generation light source with a circumference of about 500 m and a horizontal emittance of a storage ring of 275 pm-rad providing light for research in the spectral range from infra-red (IR) to the hard X-rays region beyond 10 keV [2]. Foreseen as day one beamlines are a protein crystallography line, small and wide angle x-ray scattering (SAXS/WAXS) beamlines for material science, UV/VUV/SXR, photoelectron spectroscopy and photon absorption spectroscopy, IR spectroscopy and EXAFS [3]. Each beamline will be equipped with dedicated detector systems.

For the foreseen diffraction beamlines at ILSF a position-sensitive X-ray detector based on a large area multi-wire gas proportional chamber (MWPC) with delay line readout has been designed and produced [4], which allows time resolved experiments in the sub millisecond time. In MWPCs, free charge carriers are produced by impinging X-rays within the conversion gas and are separated by an externally electric field. The number of initial charge carriers is then multiplied by a gain factor that may exceed $10^5$. However, the electric signal generated by this much higher number of charge carriers is still too small to allow for direct observation of the electric signal.

In this work, the design and fabrication procedures of an in house preamplifier, which matched all these requirements is described. In addition, we also report on the preamplifier characterization utilizing pulse generators and results on measurements of the pulse height for the x-ray source. The x-ray source was the Ag fluorescence target of a variable $^{241}$Am source.
2 ILSF MWPC

Following a classical configuration and as described in our previous work [4], the ILSF MWPC consists of three planar electrodes where two orthogonal cathode planes bracketing an anode plane at the center. The distance between the anode and cathode planes is 3 mm. The anode plane (10 × 10 cm²) comprises 20 gold plated tungsten wires (thus at a pitch of 2 mm) with diameter of 25 µm. Both cathode planes feature the same spatial dimensions. While the upper cathode plane consists of 20 wires (pitch of 2 mm, diameter of 25 µm) the lower is fabricated utilizing strips printed on printed circuit boards. A sandwich of these three planes are accommodated into a suitable aluminum housing that encloses a gas mixture mostly Ar 90% CO 10% which enables us to operate the MWPC at lower anode voltage. A conducting 25 µm thick aluminized Mylar foil serves as entrance window and seals the housing. Applying negative potential at the conducting entrance window and a positive potential (+1900 V) at the anode plane results in an external electric field, which direct negative charge carriers towards the anode plane and positive charge carries towards the window. When the photon interacts with the gas mainly through the photoelectric effect, the generated ions are therefor drained into the window while electrons drift towards the anode wires. In the vicinity of the anode wires, the electric field increases rapidly. In this region secondary electrons are generated by impact ionization of the primary X-ray generated electrons, which leads to an exponential increase of the number of carriers (gas gain) and results in an avalanche. Since the avalanche is well localized position encoding in one plane is applicably [5]. In the system described here the induced charge on the two cathode planes is used to determining the position of the avalanche and subsequently of the incident radiation. The signal from cathode plane is coupled into an external delay line comprising a network of inductance-capacitance (LC) and the position of avalanche and subsequently the incident radiation is deduced measuring the time difference between the signals at each ends of the delay lines [6]. For the position encoding in a plane two orthogonal delay lines and time to digital converters (TDC) are used.

Primary tests have been carried out using a 241 Am source demonstrating the position encoding capability of this detector [4]. The delay between the start and stop signal are in the order of 15 ns and also the characteristic impedance is 50 Ω. The relationship between timing jitter and total delay time can be found like: \( \Delta T = T \left( \frac{\Delta l}{L} \right) \), where L is the physical length of the delay line (10 cm) and \( \Delta l \) is theoretical resolution of a detector. Therefor for a delay time of 15 ns and a desired resolution of 150 µm it requires a time jitter of 0.225 ns, which can be easily obtained with present electronics. The raw signal amplitude of detector is in the order of 10 mV. Since the electric signal level is small, it requires a preamplifier, which matches the characteristics of the detector. The signal from a MWPC can be modeled as a high impedance current source and therefore a low input impedance preamplifier will maximize the input signal. Experimental set up and the output signals of the detector and preamplifier are depicted in figure 1.

3 Circuit design and simulation

Basically, the primary function of a preamplifier is to extract the signal from the detector without significantly decreasing the intrinsic signal-to-noise ratio. To reduce the input capacity, thus the serial noise and pick up of electromagnetic radiation from external sources, it is necessary to locate
Figure 1. Experimental set up. Shown on the oscilloscope are the start signal from one delay line of the detector (red trace) without amplification and the output signal of the preamplifier (green trace).

the preamplifier as close as possible to the detector. Different pulse processing techniques are typically employed, depending on whether the arrival time or the amplitude (energy) of the detected event must be measured.

Several types of detectors such as photomultiplier tubes (PMT), scintillation detectors, microchannel plates and electron multipliers produce moderately large signals at their outputs, and this relaxes the restrictions on the noise contribution from the preamplifier. For such detectors wide-band amplifiers with low input impedance can be used directly at the detector output to generate short, fast-rising pulses for timing or counting purposes. Other detectors such as Si(Li), germanium (coaxial, LO-AX™, and planar), silicon charged-particle detectors, and gas proportional counters produce considerably smaller output signals, which renders preamplifiers mandatory and requires that the input stage of the preamplifier contribute little noise [7].

The formation of the signal in a MWPC depends on the arrangement of the electrodes and on the geometry such as wire planes spacing, pitch, wire diameter of the anode plane and cathode planes. Moreover, gas composition and gas pressure are influencing parameters. The behavior of the ILSF MWPC has been simulated in relation to these parameters. Simulations have been performed mainly utilizing the Garfield++ [8] code and Magboltz for the simulation of the transport properties of electrons in gas mixtures. Moreover, GMSH [9] has been used for creating geometries and meshing. Eventually the Elmer [10] software has been used to calculate the electrostatic fields using these meshes. Figure 2 depicts the result of the simulation for a 90% Argon and 10% CO₂ gas mixture at 2 bars. This signal sequence was then used to determine the preamplifier characteristics. Together with the requirements for low noise, high sensitivity and the exigency to utilize the output signal of the preamplifier either timing or energy spectroscopy a new voltage preamplifier has been designed.

The new preamplifier developed at ILSF is based on a Gali S66+ [11] commercial monolithic amplifier circuit, which has been configured to match the (simulated) delay line output signals of the MWPC. This monolithic amplifier circuit was chosen, since it provides a high gain typically from
16.4 dB–21.6 dB in a wide frequency range from DC to 3 GHz and a low noise figure of typically 2.4 dB at 2 GHz.

4 Set up of the test preamplifier and experimental results

A schematic of the circuit scheme is depicted in figure 3. This circuit comprises of two stages both being built around the GaliS66. Internally the Gali S66+ uses a Darlington configuration providing intrinsically high gain and the possibility to drive higher loads. The first stage delivers an initial signal amplification while the second stage provides an ulterior (inverting) amplification and sufficient output current to drive the output signal via long signal cables into a constant fraction discriminator with low input impedance (50 \( \Omega \)) that is matched to the our detector with 50 \( \Omega \) delay line (equations described in our previous work [4]). In addition a linear voltage regulator (LM317M [12]) has been included to provide more than 500 mA over an output voltage range of 1.25 V to 37 V and to decrease pick-up on the supply power lines.

Firstly, the dynamic characteristics of the preamplifier have been determined on the bench. The bandwidth was measured using a network analyzer (Agilent HP 8712ET RF). The lower −3 dB point was found to be 300 kHz with the upper −3 dB point at 1300 MHz. No gain peaking was observed at 40 dB. In addition, the bandwidth has been measured by injecting attenuated sine waves generated by a Tektronix AFG3252 pulse generator, to provide very low amplitude signals. By sweeping the sine wave frequency up to 250 MHz (the maximum provided by the used generator), the frequency-response characteristic was obtained which is shown in figure 4. As expected from the data sheet and from the results obtained with the network analyzer the frequency response follows a sigmoidal progression with a maximum gain of approximately 100 at the plateau up to the cut off frequency of 10^8 Hz within the error bars (5%).
Figure 3. Preamplifier scheme, $V_+ = V_{cc} = +12\,\text{V}$ and $V_- = -V_{cc}$.

Figure 4. Measured voltage gain versus input signal frequency.
Depicted in figure 5 is the response (blue trace) of ILSF preamplifier to fast input pulses (black trace), which has been measured by injecting a 10 mV high and 100 ns wide pulse from the pulse generator (Tektronix AFG3252 pulse generator). The rise time of the input pulse \( t_{\text{in}} \) can be quoted with 10 ns (10%-90%). With an output amplitude of 950 mV the gain in this specific case results in almost \(-40\) dB while the rise time of the output pulse \( t_{\text{rise}} \) is in the order of 12 ns (10%-90%). Of note is that the contribution of the preamplifier \( t_{\text{pre}} \) to the total rise time measured is in the order of \( t_{\text{pre}} = \sqrt{t_{\text{rise}}^2 - t_{\text{in}}^2} = \sqrt{12^2 - 10^2} = 6.6 \) ns.

With a measured noise floor of 10 mV (r.m.s.) of the output and a voltage amplitude of 950 mV the signal to noise ratio results in 95 thus 19 fold the Rose criteria [13] in this case.

![Figure 5. Response of the ILSF preamplifier to a low level input square wave generated by the pulse generator.](image)

Varying the input voltage from 0.2 mV to a maximum of 2.4 mV and measuring simultaneously the output voltage the dynamic range of the preamplifier has been determined. The corresponding signal sequence is depicted in figure 6. Within the error bars the output follows linearly the input voltage from 0.2 mV up to a cut-off input of 20 mV where an onset of saturation effects is observed. Applying the definition of the dynamic range in an arbitrary signal processing system as the ratio of the maximal and minimal signals that can be reliably and simultaneously measured [14] the dynamic range for the ILSF preamplifier can be quoted as to 111 or approximately 41 dB.

Utilizing the circuit shown in figure 7 the charge gain of the preamplifier was elucidated by applying the following equation [15]:

\[
G_q = \frac{q \times V_O}{C \times V_{\text{in}}}
\]

where \( q = 1.6 \times 10^{-19} \) C is the electron charge magnitude, \( V_O \) is the measured output voltage and \( V_{\text{in}} \) the input voltage, respectively, and \( C = 2 \) pF is the coupling capacity.
Figure 6. Linearity of the ILSF preamplifier.

Figure 7. Schematics of the circuit to determine the charge gain.

The results of the bench measurements, which thoroughly characterize the performance of the in house preamplifier are summarized in table 1 with respect to the following parameters:

Table 1. The main parameters of the voltage preamplifier for ILSF.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise voltage ($V_{P-P/2}$)</td>
<td>10 mV</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Exceeding 50 MHz</td>
</tr>
<tr>
<td>Gain</td>
<td>$&gt; 40 , \text{dB}$</td>
</tr>
<tr>
<td>Rise time</td>
<td>Below 10 ns</td>
</tr>
<tr>
<td>Charge gain into 50 Ω</td>
<td>0.16 $\mu$V per electron</td>
</tr>
<tr>
<td>Supply current quiescent +12 V</td>
<td>16 mA</td>
</tr>
<tr>
<td>$-12, \text{V}$</td>
<td>16 mA</td>
</tr>
<tr>
<td>Input impedance</td>
<td>50 Ω</td>
</tr>
<tr>
<td>Output impedance</td>
<td>50 Ω</td>
</tr>
</tbody>
</table>
In order to verify the overall performance of the preamplifier circuit, it has been tested with aforementioned ILSF MWPC operated with an Ar-CH₄ (90%, 10%) gas mixture at normal pressure. The X-ray source was the Ag fluorescence target of a variable ²⁴¹Am source. Depicted in figure 8 is the preamplifier output signal of the induced signal on the delay-line. In this case the gas gain was estimated as to ~ 5000 when taking into consideration the charge gain of 0.16 µV/e and a mean (I and II ground state) ionization energy of 22 eV to generate a free electron ion pair.

![Figure 8. ILSF preamplifier output.](image)

Compared to the performance of other custom made and commercial preamplifiers as summarized in M. Kocsis et al. [16] the ILSF in-house preamplifier present similar gains and noise figures. Regarding rise time, gain and pulse amplitude, the described preamplifier prove better performance and shows a faster return to the baseline value.

5 Conclusions

This paper describes the design and fabrication of a voltage preamplifier that is adequate for use with the MWPC developed at ILSF. Also presented are the main steps in the circuit design, including simulations and bench measurements that may be helpful in the development of other preamplifier circuits. The ILSF preamplifier provides fast, non-distorted output signals at high gain, which quickly return to the baseline. Other advantages are its simple layout, easy maintenance and the low cost per channel.
Acknowledgments

The authors would like to express their gratitude to Rudi SERGO\(^1\) and Paolo PITTANA\(^2\) from Elettra’s Detector and Instrumentation Group for their helpful discussions and comments. Also, we would like to sincerely thank M. Jafarzadeh, coordinator of the ILSF, for his valuable discussions on this project and continuous supports. Moreover, the authors are grateful to M. Barnaba from the Elettra Mechanics group for his help. This work is supported by ILSF.

References


