Target Beam Position Monitor (TBPM) based on SEM

User's Manual

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1. Introduction

The *Target Beam Position Monitor* (*TBPM*) determines the electron-beam position right in front of the target in *Hall C* at *Jefferson Lab*. To prevent the polarized target from depolarizing due to local heating the electron-beam is rastered over the whole target (several cm^2). The *TBPM* allows a measurement of the beam position for each trigger; as a consequence the interaction point between the electron-beam and the polarized target is known for each event.

2. SEM Pick-up

The measurement principle of the *TBPM* is based on a *Secondary Electron Monitor* (*SEM*) with a horizontal- and vertical-array of several thin metal stripes and two thin anode foils. Each plane has 34 stainless steel stripes with a width of 1mm and a thickness of 8µm (6.3mg/cm^2). The ends of the stripes are glued on a cut out *Printed Circuit Board* (*PCB*). In order to cover the entire area with stripes, the even-numbered and odd-numbered stripes are distributed onto two separate planes, one on the top and the other on the bottom of the *PCB* (see *Figure 1*). The two planes are spaced by 1.6mm in beam direction, for both x and y. For each direction 28 of these stainless steel stripes are readout, corresponding to a coverage of ±14mm in both x and y.

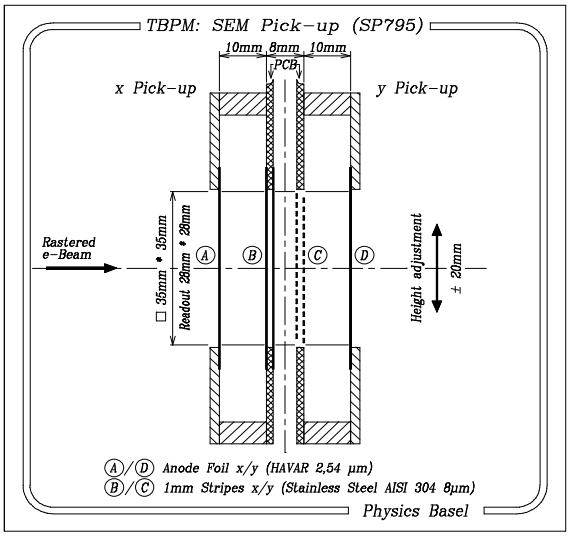


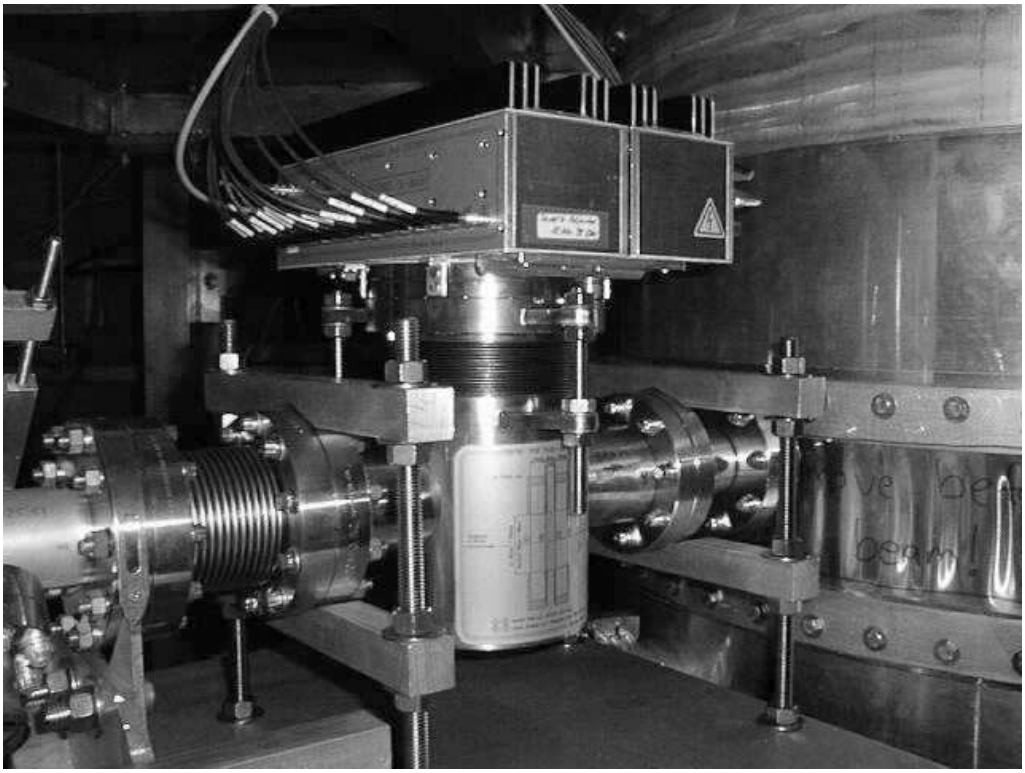
Figure 1: Vertical cross-section trough the inner part of the SEM Pick-up. The horizontal (x) and vertical (y) pick-up are face to face to each other.

The two anode foils on both sides of the stripe-arrays are used to collect the secondary electrons. They are made of 2.54µm (2.1mg/ cm^2) HAVAR foil. A typical static *anode voltage* of +100V is applied (E=100V/cm) and an *anode voltage* over +500V may not exceed.

Remember that the stripes and anode foils are permanently in the electron beam. To protect them from thermal damage a maximum unrastered beam current of 200nA is allowed. For a beam current up to 1µA a minimum raster-diameter of 2mm in has to be used. Above a beam current of 1µA the raster-diameter has to be increased by 2mm for each µA.

A bellows allows to move the inner part in the vertical direction within ±20mm (see *Photograph 1*). This vertical adjustment is foreseen to align the pick-up with the center of the target, which isn't always on a straight line due to the effect of the polarized target B-field. The *TBPM* is surveyed and installed, such that the center of stripe-arrays corresponds to the center of the beam pipe.

Before moving the *TBPM* to the position needed with the B-field on, measure and write down the three distances imposed by the three spacers (threaded rods).



Photograph 1: The TBPM installed in front of the GEN-target. One can see the vacuum housing of the SEM pick-up and the two Gated Integrator Boxes on the top. The cables are connected to the Analog Concentrating Unit in the target rack above.

The overall length of the pick-up is 270mm and the total weight with the two *Gated Integrator Boxes* on the top is about 15kg. The beam inlet of the pick-up is a $4^{5/8}$" rotating CF-flange and the outlet a $4^{1/2}$" rotating CF-flange.

3. Gated Integrator Box

The very small secondary electron currents on the x- and y-stripes are integrated over a certain time in the so called *Gated Integrator Boxes*. The two integration times of the x- and y-channel are controlled via two separate *Gate* signals; positive TTL signals with 50Ω termination.

Due to the necessary high charge sensitivity the *Gated Integrator Box* has to be as close as possible to the SEM pick-up and therefore the *Gated Integrator Box* is placed directly on the top of the SEM pick-up (see *Photograph 1*). The two *Gated Integrator Boxes* are directly connected to the vacuum feedthrough and they can be removed by unscrewing the eight screws on the circumference of the top flange. The x- and y-axis have their own well isolated *Gated Integrator Box* containing the 14 *Gated Low Noise Differential Integrator* modules (*GLNDI-modules*) in slide-in technique. The *GLNDI*-module can be easily changed by removing the top-cover of the *Gated Integrator Box*. For optimal performance, the static and dynamic offset of the replaced *GLNDI*-module should be adjusted in the actual slot position.

Due to the differential input each *GLNDI*-module is able to processes two stripes. It measures the charge difference during the integration time on two stripes equally spaced from the center (see *Figure 2*). This layout results in a high common noise reduction and a low vibration sensitivity. The *GLNDI*-module converts the charge difference to a bipolar current output, capable to drive a 50Ω impedance. For testing and debugging purposes an oscilloscope with a 50Ω input can be connected to the *GLNDI*-module output. A positive output current corresponds to a positive beam position and a negative output current to a negative beam position with respect to the center (see *Figure 5*). The conversion between the charge difference and the output current is given by:

25fC (156'000 electrons) ≈ 10mA (500mV @ 50Ω)

The *GLNDI*-modules have a typical output current noise of $1mA_{RMS}$ ($50mV_{RMS}$@ 50Ω) after an integration time of 125µs. The *GLNDI*-modules are saturated at a output current of about ±100mA, which corresponds to 250fC. The saturation of a *GLNDI*-module doesn't affect the determination of the beam position. The two times 14 current outputs of the x- and y-axis are fed to the *Analog Concentrating Unit* for further processing. The *Analog Concentrating Unit* also supplies the two *Gate* signals for the x- and y- *GLNDI*-modules (see *Figure 3*).

The power consumption of each of the two *Gated Integrator Boxes* is about 12W (+15V: 450mA; -15V: 300mA); cooling bodies are mounted on the top of the *Gated Integrator Boxes*.

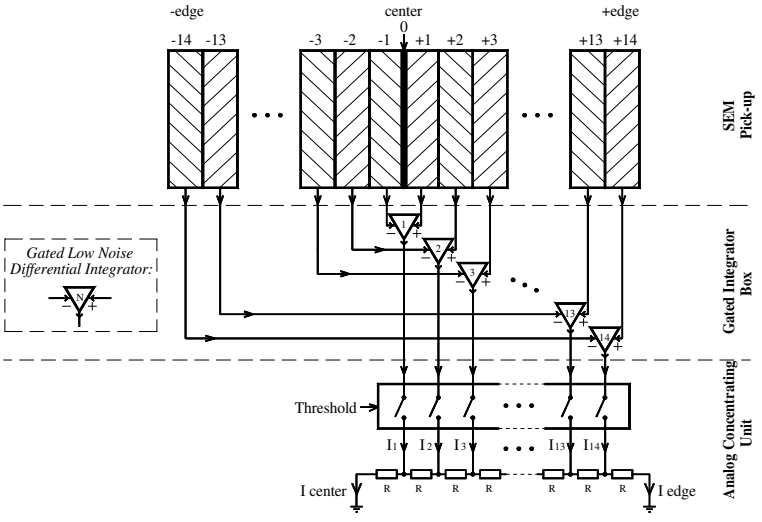


Figure 2: The principle function diagram of the TBPM. On the top the stainless steel stripes of the SEM pick-up; in the middle the GLNDI-modules and on the bottom the ACU. Both directions (x and y) have the same layout.

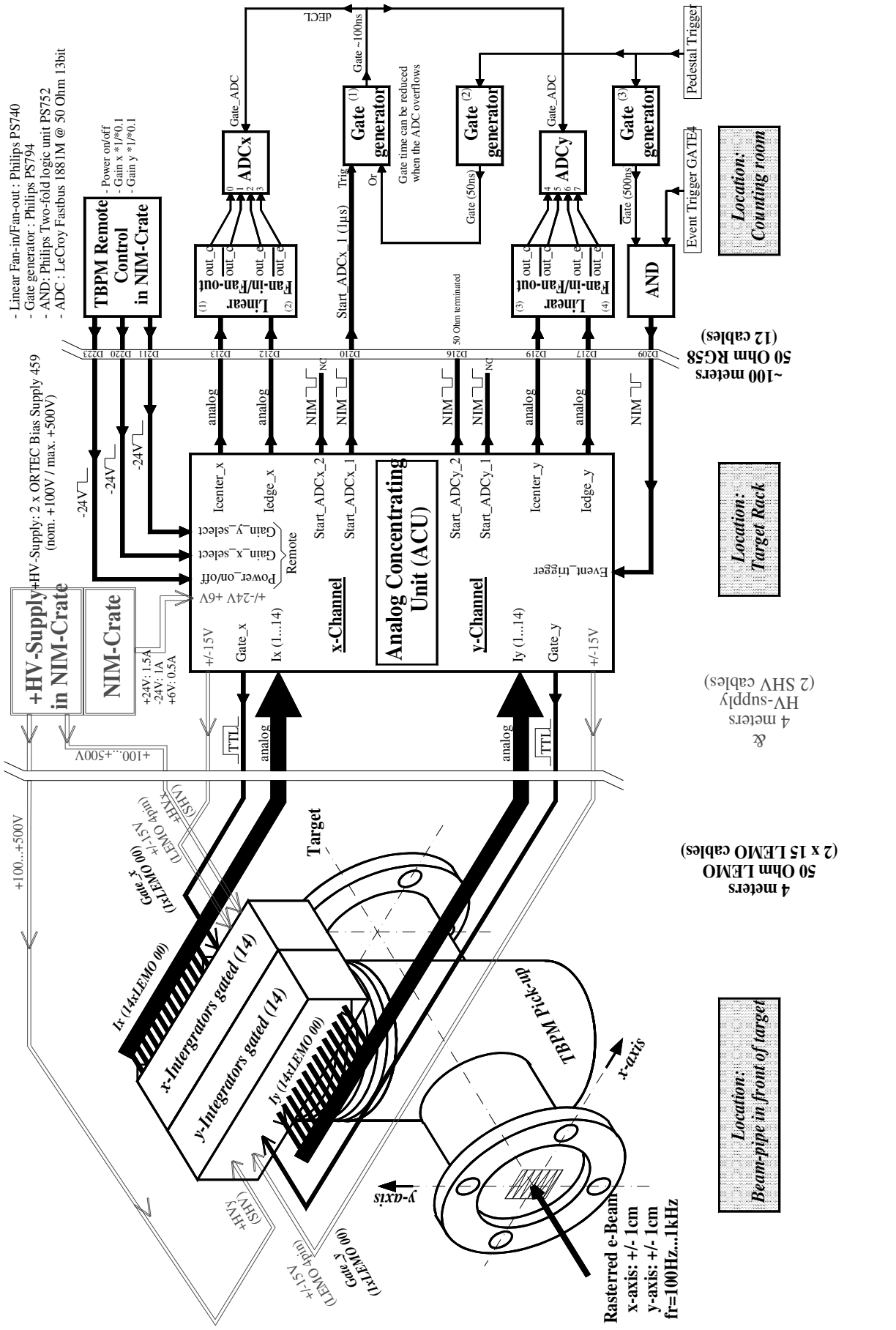


Figure 3: Signal and Power-Supply Interconnection Diagram from the SEM Pick-up via the Integrator Boxes and the ACU to the Fastbus ADC.

4. Analog Concentrating Unit

The *Analog Concentrating Unit* (*ACU*) consists of two almost identical parts for the x- and y-channel. Therefore the description and the *Figure 4* are for the x-channel only. The four major tasks of the *ACU* are (see also *Figure 4*):

- The **Threshold- and Display-Unit** receives the 14 current outputs of the *GLNDI-modules* and selects only the signals above the adjusted threshold for further processing. All channels reaching the threshold are indicated on a LED-bargraph (-14...+14), which is useful for a coarse beam position estimation. The threshold can be adjusted by a multiturn trimmer and measured with a DVM at the frontpanel of the *ACU*. The threshold range is between 10mV and 1V assuming a 50Ω termination of the current outputs of the *GLNDI-modules*. Simulation results showed an optimal threshold of four times the RMS-noise (4σ) of a *GLNDI-module*, which corresponds to a threshold of about 200mV. The threshold is symmetrical for positive and negative current outputs of the *GLNDI-modules.*

- The **Addition-Unit** concentrates the selected current outputs of the *GLNDI-modules* to the position depending *center*- and *edge*-signal. The position sensitive addition is done by a resistor-ladder with 14 current inputs connected to the corresponding current outputs of the *GLNDI-module* (see *Figure 2).* The two bipolar current signals from the ends of the resistor-ladder are the so called I_{center} - and I_{edge} -signals. To reduce ground-loop problems they are send to the counting room via differential current drivers. For optimal adaptation of the analog signals to the *ADC*-range two different gains (*1 / *0.1) can be selected either locally on the frontpanel of the *ACU* or remotely. A typical output signal measured with an oscilloscope (50Ω input) is in the region of ±10mV to ±150mV depending on the beam position. The analog signals are turned on 2µs (*ADC-delay*) before the *Start ADC* signal and turned off 1µs after the *Start ADC* signal. The *ADC-delay* is preselectable from 1µs to 15µs inside the *ACU.*

- The **Timing-Unit** receives the *event trigger* signal from the counting room and starts the measurement with the preselected *Gate time* and ends with the *Start ADC* signals. The width of the NIM *Start ADC* signals is 1µs and the falling edge indicates the *ADC* to convert the analog position signals. To reduce ground-loop problems the NIM signals are send to the counting room via differential current drivers. The *Gate time* is programmable by four HEX-switches on the frontpanel of the *ACU* with a resolution of 100ns. The minimum *Gate time* is limited by the *GLNDI-modules* to 15µs and the maximum *Gate time* is 6.55ms corresponding to a programmed HEX-value of FFFFh. A typical *Gate time* during normal operation is in the range from 20µs to 200µs. On the frontpanel of the *ACU* the mode ONE or TWO can be selected with a switch. Mode ONE means that only one measurement is performed and only the *Start ADC 1* signal is activated. Mode TWO means that two successive measurements are performed; the *Start ADC 1* signal is activated after the first measurement and the *Start ADC 2* signal after the second measurement. This mode is foreseen for beam track reconstruction. The minimum time between two measurements is given by the *RESET-time* of the *GLNDI-modules*. It is preselectable from 1µs to 15µs inside the *ACU*; the nominal value is 4µs. The *ACU* can be triggered either by an external *event trigger* or internal 100Hz clock generator. The trigger is common for both x- and y-channel. Three LEDs (Ready, Trigger, Gate) indicate the status of the Timing-Unit.

- The **Supply-Unit** generates the two independent and stable ±15V supply voltages for the two *Integrator Boxes*. Further it supplies the *ACU* electronics with ±15V and +5V. The *power on/off* can be selected either locally on the frontpanel or remotely. Three LEDs (+24V, -24V, +6V) show that the used NIM-supply voltages are available.

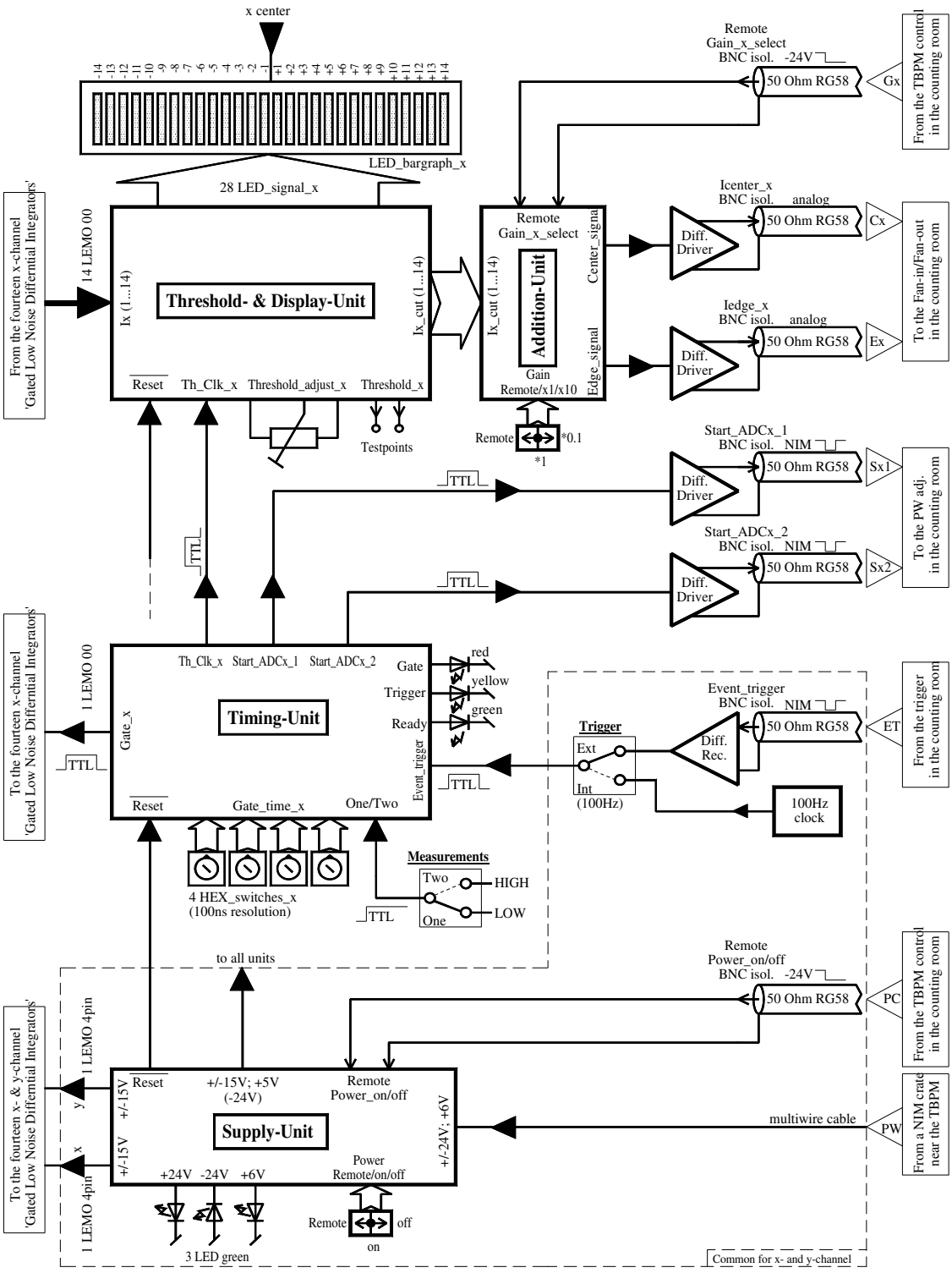


Figure 4: Block diagram of the Analog Concentrating Unit (ACU). Only the x-channel is shown, the y-channel is identical. The ACU is in a 19" housing and is supplied by a NIM-crate.

For testing purposes the *ACU* has two *Test Current* sources, one for the x-axis and one for the y-axis, with a selectable output current of ±10mA. The *Test Current* sources can be used to simulate a current coming from a *GLNDI-module*. It allows easy testing the *ACU* electronics from the current inputs to the position signals outputs. All inputs (I_1...I_{14}) can be tested sequentially with a positive and a negative *Test Current*.

To check the SEM pick-up, the *Gated Integrator Boxes* and the *ACU* there is a straightforward test -possibility: Connect all outputs of the *Gated Integrator Boxes* to the appropriate input of the *ACU*. Program a *Gate time* of 400µs (0FA0h) for both channels x and y. Select the *internal trigger* running with 100Hz. Then most of the time all LEDs of the bargraph should be "off", but due to the noise some channels may reach the threshold and the corresponding LED on the bargraph will flash randomly. Now change the *anode voltage* of the x-axis rapidly with the potentiometer on the frontpanel of the ORTEC Bias Supply 459 from +100V to about +300V and back to +100V. While rapidly increasing the *anode voltage* all even positive stripes (+2,+4,+6...,+14) and all odd negative stripes (-1,-3,-5...,-13) should reach the threshold and the corresponding LED on the bargraph should flash. While rapidly decreasing the *anode voltage* all odd positive stripes (+1,+3,+5...,+13) and all even negative stripes (-2,-4,-6...,-14) should reach the threshold and the corresponding LED on the bargraph should flash. Repeat the same procedure for the y-axis. After these tests make sure that all switches are set to their original value or position.

The charge induced by the varying *anode voltage* is slightly different for the stripes glued on the top or on the bottom of the PCB. Because each *GLNDI-module* measures the charge difference of one stripe on the top and one on the bottom of the PCB a signal is generated during a rapid change of the *anode voltage*. The sign of the induced charge difference depends whether the *anode voltage* is increased or decreased (see *Figure 2*).

The *ACU* has a 19"-case and is installed in the left target rack. It is supplied with +24V: 1.5A / -24V: 1A / +6V: 0.5A by the NIM crate direct below the *ACU*, where also the *anode voltage* bias supplies are located.

5. Remote Control

The *Remote Control* of the *TBPM* is used to select the appropriate *gain* and to turn the *power on* and *off* (see *Figure 3*). The gain is selectable for the x- and y-axis between *1 and *0.1 individually. At a low beam current (<50nA) and relatively short *integration times* the *gain* should set to *1. For a higher beam current (>50nA) and relatively long *integration times* the *gain* should set to *0.1. The two different *gains* allow a coarse adjustment of the analog signals (I_{center} and I_{edge}) such that they are within the *ADC* range. A fine tuning to an optimal *ADC* range is possible by adjusting the *ADC* gate-width.

The remote *power on/off* can be used to switch on and off the whole *TBPM* and this option could be useful if the system hangs.

The *Remote Control* signals have 0V/-24V levels and they are used to switch reed-relays. The *Remote Control* itself can be controlled by external NIM signals. The *Remote Control* is housed in single unit NIM module and needs only the -24V supply (200mA). It is installed in the electronics room two racks left of the HMS rack.

6. Trigger & ADC

The *event trigger*, which starts the *TBPM*, is connected to the signal *event trigger GATE4* (see *Figure 3*). A *pedestal trigger* can be used to measure the offsets of the analog electronics and the ADC-channels. The *event trigger* for the *TBPM* is suppressed while the *pedestal trigger* is active. During normal measurements the *Start ADC* signal from the *TBPM* generates an *ADC* gate of about 100ns. During *pedestal triggers* there are no *Start ADC* signals from the *TBPM* and therefore the *ADC* gates are released by the *pedestal triggers*.

The analog signals I_{center} and I_{edge} are bipolar current signals. The inputs of the *ADC* (LeCroy 1881M / 13bit) accept only negative signals and therefore a bipolar *Linear Fan-in/Fan-out* (Philips PS740) is used in front of the *ADC*. If the analog signals are positive, the *inverted ADC-channels* have the correct polarity and if the analog signals are negative, the *normal ADC-channels* have the correct polarity.

The selections of the suitable *ADC-channels*, the pedestal subtraction and the calculation of the beam position are made offline by software. The beam position is determined for the x- and y-axis with the following equation:

$$beam\ position\,[mm] = 7.5 \cdot sign(I_{edge} + I_{center}) \cdot \left[1 + \frac{I_{edge} - I_{center}}{I_{edge} + I_{center}}\right]$$

The result of the equation above is directly the beam position in *mm*. Definition of the *TBPM*-axes is shown in *Figure 5*:

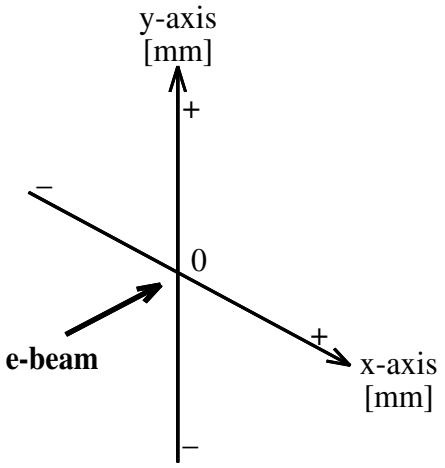


Figure 5: Definition of the TBPM-axes. The horizontal axis is the x-axis and the vertical axis is the y-axis. All values are in mm.

The trigger logic, the *Linear Fan-in/Fan-out* and the *ADC* is installed in the electronics room in the HMS-rack. The *ADC* is in slot 14 of the *HMS Fastbus* rack and the following signals are assigned to the *ADC*-channels:

ADC-channel #	*Signal name*
0	I_{center} x
1	inverted I_{center} x
2	I_{edge} x
3	inverted I_{edge} x
4	I_{center} y
5	inverted I_{center} y
6	I_{edge} y
7	inverted I_{edge} y

7. Cabling Map

PP = patch panel
CH = counting house

Signal Name	*Cable Name*	*PP-pivot #*	*PP-CH #*	*Direction*	*Level*	*Comment*
Event trigger	sem 1	1	D209	to *TBPM*	NIM	common x &y
Start ADCx 1	sem 2	2	D210	to *CH*	NIM	used for ADC
Start ADCx 2	sem 3	-	-	to *CH*	NIM	not used yet
I_{edge} x	sem 4	4	D212	to *CH*	analog	bipolar
I_{center} x	sem 5	5	D213	to *CH*	analog	bipolar
Start ADCy 1	sem 6	8	D216	to *CH*	NIM	50 Ohm term.
Start ADCy 2	sem 7	-	-	to *CH*	NIM	not used yet
I_{edge} y	sem 8	9	D217	to *CH*	analog	bipolar
I_{center} y	sem 9	11	D219	to *CH*	analog	bipolar
Remote Gain x	sem 10	12	D220	to *TBPM*	0V/-24V	control
Remote Gain y	sem 11	3	D211	to *TBPM*	0V/-24V	control
Remote Power on/off	sem 12	15	D223	to *TBPM*	0V/-24V	control