BEAM DIAGNOSTICS FOR CHARGE AND POSITION MEASUREMENTS IN ELI-NP GBS

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Abstract

The advanced source of Gamma-ray photons to be built in Bucharest (Romania), as part of the ELI-NP European Research Infrastructure, will generate photons by Compton back-scattering in the collision between a multi-bunch electron beam and a high intensity recirculated laser pulse. An S-Band photoinjector and the following C-band Linac at a maximum energy of 720MeV, under construction by an European consortium (EurogammaS) led by INFN, will operate at 100Hz repetition rate with trains of 32 electron bunches, separated by 16ns and a 250pC nominal charge. The different BPMs and current transformers used to measure transverse beam position and charge along the LINAC are described. Design criteria, production status and bench test results of the charge and position pickups are reported in the paper, together with the related data acquisition systems.

INTRODUCTION

The ELI-NP GBS (Extreme Light Infrastructure-Nuclear Physics Gamma Beam Source) is a high intensity and monochromatic gamma source under construction at IFIN-HH in Magurele (Romania). The photons will be generated by Compton back-scattering at the interaction between a high quality electron beam and a high power recirculated laser. Two interaction regions are foreseen: one with electrons accelerated up to 280 MeV (low Energy LINAC), the other with electrons up to 720 MeV (high Energy LINAC). The LINAC will deliver a high phase space density electron beam, whose main parameters are listed in Table 1 and depicted in Figure 1 [1].

Table 1: Main Characteristics of the GBS Electron Beam

Parameter	Value
Maximum Energy	720 MeV
Macro Pulse rep. rate	100 Hz
Number of bunches per Macro Pulse	up to 32
Bunch Spacing	16.1 ns
Bunch Length (σ_t)	0.91 ps
Bunch Charge	25 pC – 250 pC

Various diagnostics devices have been foreseen to be installed in the LINAC, in order to measure the properties of both the macropulses and the single bunches. Both intercepting and non-intercepting type of measurements will be implemented. The devices used for the intercepting type of measurements are Optical Transition Radiation (OTR) screens. A total of 23 stations will be installed along the LINAC: 12 on the Low Energy LINAC, 11 on the High Energy LINAC. They will be used to measure the Beam Position (Centroid) and the Spot Size of the beam. They will also be used to measure the beam energy and its spread, the bunch length and the Twiss parameters, in conjunction with a dipole, an RF deflector and quadrupoles respectively.

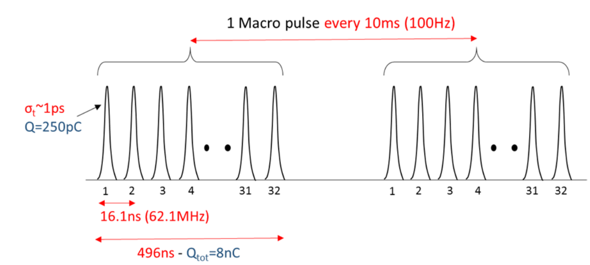

Figure 1: GBS Electron Beam representation.

The devices used for non-intercepting measurements are Beam Charge Monitors (BCM) and Beam Position Monitors (BPM).

The former ones are based on the Integrating Current Transformers (ICT) [2], which will be installed in 4 different positions (3 in the low energy LINAC, 1 in the high Energy LINAC).

Concerning the Beam Position Monitors, two different types will be installed: Stripline Beam Position monitors are the most common. 29 of them will be installed, specifically 13 in the Low Energy LINAC, 16 in the High Energy LINAC. Moreover, near the interaction points (both at low energy and high energy), a total of 4 Cavity Beam Position Monitors will be installed (see Fig.2).

BEAM CHARGE MONITORS

Beam charge monitors (BCM) will be installed in four positions: the first one will be located right before the first S-band accelerating structure; the second one will be located at the end of all the accelerating structures of the Low Energy LINAC, before the so-called “dogleg”; the third and the fourth will be installed before the low energy and the high energy interaction points. These four locations will allow studying the losses of charge of the beam at the key-points of the LINAC.

BCMs will have the capability to measure the charge of every single bunch, within the macro pulse. The ICT [2] (see Fig.3) could be seen as a band-pass filter and the passage of the beam bunches could be considered as the input signal.

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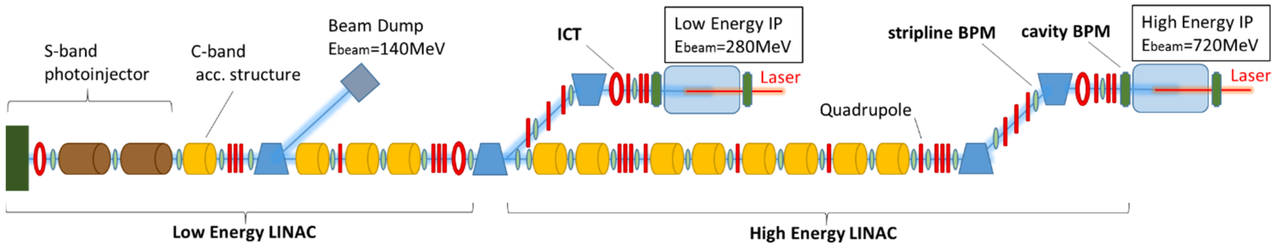

Figure 2: Simplified layout of ELI GBS. Both dump lines after the interaction points and some accelerator components are not depicted (i.e. corrector magnets).

The low and high cutoff frequency are in the order of few kHz and hundreds of MHz respectively (see Table 2).

Table 2: Main Parameters of the ICTs for GBS. In parenthesis the measured values in laboratory.

Parameter	ICT Type I	ICT Type II
Sensitivity in a 50Ω load	5 Vs/C *(4.96 Vs/C)*	10 Vs/C
Beam charge to output charge ratio in 50Ω load	~10:1	~5:1
Output pulse duration (6σ)	5 ns *(5.6 ns)*	5 ns
Output signal droop	3.59 %/µs *(3.57%/ µs)*	N/A
f_{low} / f_{high}	5.3kHz/191MHz *(4.5kHz/180MHz)*	9.7kHz / 112MHz

The frequency content associated to the beam bunch is significantly higher (hundreds of GHz) than the high cutoff frequency. As a result, rise and fall time are both slowed down and a bunch of ~1ps will induce an output signal with a duration significantly higher. Nevertheless, even if the original shape of the signal is lost, the charge of the output signal is proportional to the charge of the bunch. Therefore, by integrating the ICT output and calculating the charge associated to it, it is possible to measure the beam charge (see Eq. (1)).

$$Q_{bunch} = \frac{1}{S} * \int_0^{16ns} V_{out}(t)dt \qquad (1)$$

In Equation (1), $V_{out}(t)$ is the output voltage read by a measuring device (with R_{in}=50Ω); S is the sensitivity of the ICT in Vs/C (taking account of the reading device resistance of 50Ω); 16ns is the time interval between bunches and represents the maximum time allowed to integrate the output signal associated to a single bunch.

The ICT output signal generated by a single beam bunch has a nominal duration of 5ns, which not exceeds the interval between bunches (16ns), to allow bunch by bunch measurements.

The signal is digitized with ADC model M9210A from Agilent, whose main parameters are shown in Table 3.

We plan to use four ADC in single channel mode, in order to achieve the maximum sampling rate. The M9210A will be installed in two Input Output Controllers (IOC). The latter is a cPCI crate embedded system, LINUX based, with a dedicated control software written in EPICS. The acquisition of a full train of bunches will be synchronized with the timing signal (100Hz), handled by the IOC. The software will then record the samples from the ADC up to 512ns, dividing them in 32 windows of 16ns each and will calculate the charge for each window, by applying a calibration factor and offset compensation chosen by the user.

The nominal values of the ICTs main parameters are shown in Table 2. The main difference between type I and II is a factor of two on the sensitivity of the device. Moreover, the Type-I is resistant to temperature up to 150°C, to allow baking procedures. The Type-2 ICT has also a calibration coil integrated into it. This could be used for testing and for calibrating the device on a regular basis, by sending to it an electrical signal with a waveform generator.

Table 3: Main parameters of the ADC (Agilent M9210A) for the BCM

Parameter	ADC – M9210A
Resolution	10 bit
Sampling rate (single ch.)	4 GS/s
Analog Bandwidth	1.4 GHz
Input Range	50mV$_{p-p}$ / 5V$_{p-p}$ (programmable)

ICT Characterization

Since there will be limited possibilities to set up an electronic laboratory in site, our goal is to prevent any possible problem on diagnostic devices, in order to not slow down the commissioning activities. Thus, we performed a full characterization of the Type-I ICT already acquired, with a test bench set up at the INFN-LNF. Furthermore, the test bench components are portable and could also be used on site during the commissioning phase, as a diagnostic tool for the ICTs.

The test bench includes a waveform generator / pulse generator (the models used are Stanford DG535 and Picosecond mod.1000) which send signals to an “input” loop built in laboratory, coupled to the ICT (see Fig.3). The latter is made of a copper strip connected in series to five resistors in parallel, with a total resistance of ~50Ω. The design of the input spire allows to reduce its inductance, so as to minimize unwanted reflections [3].

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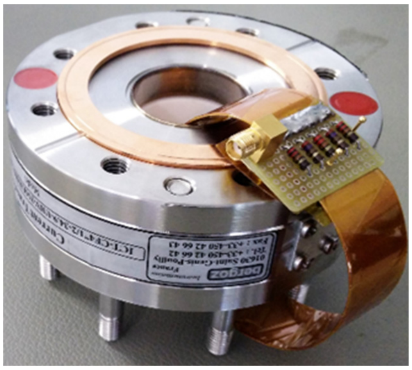

Figure 3: ICT Type-1 with the “input” loop coupled to it used to send electrical signals.

In order to acquire and digitize output signals we used a Picoscope 6404D with a LabVIEW VI. This ADC has a resolution of 8 bit, a maximum sampling rate of 5 GS/s, an analog BW of 500MS/s and an input range of 50mV$_{p\text{-}p}$ / 5V$_{p\text{-}p}$.

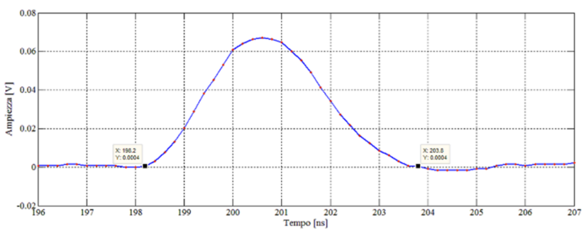

Figure 4: ICT Type-I output signal for an input pulse of 1ns, with an amplitude of 3.2V and a charge of 35pC.

We measured all the most important parameters of the ICT Type-1: they are roughly equal to the nominal ones (see Table 2). As such, no further analysis is necessary for our purposes.

We also investigated the effect of cables (connecting the ICT output to the reading electronics) of different lengths. We sent a sequence of pulses with a time interval of 16ns to the ICT and we measured the output signals for different cable lengths (type RG223): 1.5m, 50m, 100m. As it is possible to see in Figure 5, with this type of cable, a length of 50m could be considered the limit, in order to not have relevant overlap errors between bunches. In the case of GBS, the maximum cable path length could slightly exceed this limit. For this reason, we selected the FSJ1-50A 1/4” coaxial cable, which have lower attenuation effects than the RG-223.

We also studied the possible error in charge measurements introduced by the sampling frequency of the ADC. In order to do so, a pulse of fixed properties has been sent to the input loop and the integral of the output pulse (duration ~5.6ns) has been measured for different sampling rates.

As shown in Fig.6, the value of the integral of the output reach a specific value for sampling rates higher than 625MS/s. For lower values, the sampling rate introduces a systematic error in the measurements: in the case of the measurement proposed here, lower rates lead to higher value of the integral.

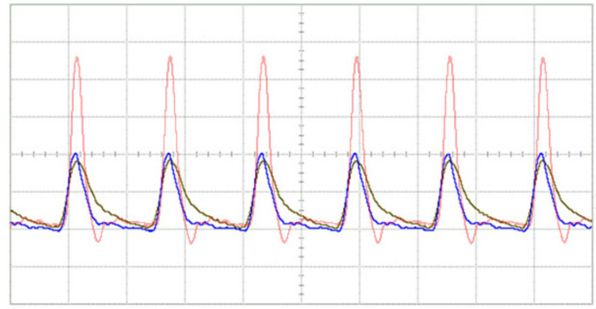

Figure 5: Output signals for different lengths of RG223 cable (red: 1.5m, blue: 50m, gold: 100m). Time scale: 10ns/div. Red and blue plots: 2mV/div. Gold plot: 1mV/div.

Nevertheless, this error is dependent on the synchronization of the signal and the ADC samples. As such, the error could also lead to lower values of the integral. The relative standard deviation calculated at 1250MS/s is ~1.4% and is maintained roughly equal up to 5000MS/s. This brings to the conclusion that the M9210A digitizer have a high enough sampling rate, even by using both channels (2000MS/s), opening to the possibility to use the dual channel option for future upgrades or as spares.

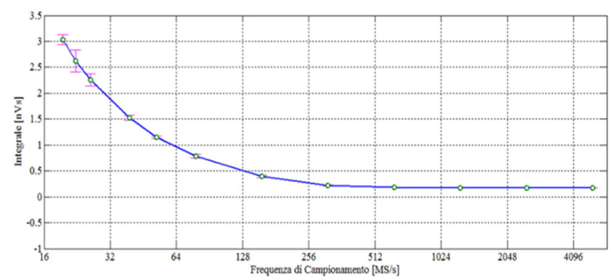

Figure 6: Value of the integral of the ICT output puls with a fixed input, for different sampling rates.

BEAM POSITION MONITORS

Stripline BPM

A total of 29 installed BPMs will be installed. They are the main devices used for ELI GBS to measure the average position of the macro pulse along the LINAC. Their design is the same for all of them (Fig.7), except for the one installed on the dump line after the low energy interaction point.

The pickup selected for use is generally referred to as stripline and is composed of four stainless steel electrodes of length l=140mm and width w=7.7mm, mounted with a π/2 rotational symmetry at a distance d=2mm from the vacuum chamber, to form a transmission line of characteristic impedance Zo=50Ω with the beam pipe. Their angular width is ~26 degrees and the acceptance is Ø34mm.

Time domain reflectometry measurements have been performed to select the final strip width to get the best impedance matching.

The amplitude of the frequency response presents a sinusoidal shape with maxima at odd multiples of c/4l (~535MHz), selected to be as close as possible to the operating frequency of the detection electronics and to present

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non zero response at the LINAC frequency of 2856 MHz allowing measurements of any satellite bunch.

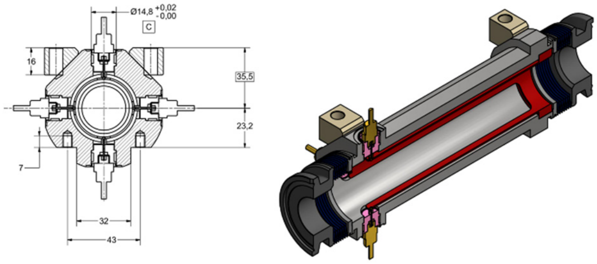

Figure 7:Main BPM model for ELI GBS.

In the Dump line BPM, the beam width and its possible position misalignment require a large BPM acceptance. Thus we have designed this BPM for an acceptance of Ø100mm and with a frequency response similar to the other BPMs. This assures that the output signals will have the same frequency content of the other BPMs, allowing to use the same acquisition system, based on LIBERA Single pass E system by Instrumentation Technologies. The latter is specifically designed as a BPM signal processing system and each of them will contain four modules. Each module will handle the signals coming from one BPM. Thus, a total of 8 LIBERA Single Pass E systems will be used in ELI GBS. By providing calibration factors, the latter gives the possibility to directly calculate the position of the beam, by means of polynomial equations.

The calibration factors, used in the polynomial equations, will be extrapolated from the measurements and calibration performed at ALBA laboratories [4] for each BPM and will be implemented directly in the LIBERA Single Pass E acquisition systems.

We also plan to calculate the charge of each macropulses by using the output signals of the BPM, in order to increase the number of the charge measurements (although only for the whole macro pulse) all along the LINAC.

Cavity BPM

In order to have higher precision beam position measurements (<1µm) and the possibility to measure it bunch by bunch, a total of four Cavity BPM are foreseen. They will be installed immediately before and after the two interaction points with the laser, where the precision on the beam position is more compelling. The cavity pick-up is the PSI BPM16 model, consisting of one cavity for charge measurements (used as a reference) and two position cavities with low quality factor (Q=42.4) [5].

The low Q allows to measure the charge and the position of the beam bunch by bunch. In fact, the output signals associated to the passage of a single bunch will decay faster (about 9ns) than the time interval between bunches (16ns).

The readout electronics will be specifically designed for the cavity BPM of ELI GBS by Instrumentation Technologies. Its development is in progress and the measurements done with a prototype developed during the first project phase confirmed the feasibility of the development and the performance of the RF front-end [6].

CONCLUSION

An overview of the devices involved in non-intercepting beam position and charge measurements of ELI GBS has been presented in this paper.

Since there will be limited possibilities to set up an electronic laboratory in site, our goal is to characterize all the devices and prevent any possible problem before the commissioning activities will start. Thus, we have set up a test bench at LNF to characterize ICTs. From our measurements, they will be capable to measure the charge bunch by bunch, within the project requirements.

Stripline BPMs, used for the macro pulse position and charge measurements, are at the final stage of testing and calibration at ALBA laboratories. We will then calculate and implement the calibration factors within the acquisition system.

Cavity BPMs, used for precise bunch by bunch position and charge measurements near the interaction points, have been acquired and the acquisition system is currently under development.

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