PHASE MEASUREMENTS FOR GANIL AND LANL

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Abstract

Libera Brilliance has proved successful in the field of beam diagnostics. High performance, system reliability and its high level of integration into accelerator control systems makes Libera a very accurate, robust and powerful measuring system. Although Libera Brilliance has been developed mainly for applications involving frequency domain processing, the flexibility makes it a good time domain measuring system for single pass applications. Moreover, there are other applications dealing with pulses, where a modified version of Libera Brilliance can be used. This is the case of beam phase and position measurements in accelerators, like Spiral2 (Ganil) and LANSCE (Los Alamos), dealing with heavy particles (protons, deuterons and heavy ions). The phase information extracted by the measurement in such systems is used to control the acceleration process of such heavy particles. This paper shows the approach adopted in processing the signals produced by such bunch trains. A modified Libera Brilliance unit, configured for the LANSCE bunch trains, has been tested by means of extensive laboratory measurements. Performance has been evaluated by applying different digital signal processing.

INTRODUCTION

Libera Brilliance is a very accurate beam position measuring system. Although its performance was improved for applications in circular electron machines, the Libera Brilliance processing structure is flexible enough to fulfil the requirements of applications requiring an accurate signal measurement in time domain too.

The scope of the phase measurement is to control the acceleration processes of heavy particles. Two applications with similar requirements for the beam position and phase measuring system were taken as reference.

The first application is the LANSCE linac, where bunches of H^+ and H^- are accelerated. The bunches in the fundamental scheme have a repetition frequency of 201.25 MHz and are grouped in 0.625 ms long “macropulses” at the repetition rate of 30 Hz that results in a duty factor of 1.875%.

The second application is the Spiral2 linac (Ganil), where the deuteron or ion bunches are accelerated with bunching frequency of 88.0505 MHz, and are organized in “macropulses” with minimum duration of 100 us and repetition rate between 1 and 10 Hz. The minimum duty factor is in this case 0.01 %.

Table 1 compares the mentioned parameters for the two applications. The very low duty factors indicate that the signals produced by such beam signals need a time domain processing scheme, since the power is spread between the “macropulse” repetition rate harmonics.

Table 1: Macroplulse structure comparison

	LANSCE linac	Spiral 2 linac
Bunch rep. rate	201.25 MHz	88.0505 MHz
Macropulse length	0.625 ms	>0.1 ms
Macropulse rep. rate	30 Hz	1÷10 Hz
Duty factor	1.875 %	>0.01 %

The particles with the specified time structures cross stripline BPM pickups and excite bipolar pulses on four coaxial lines. The bunch repetition rate defines the main frequency component. Since the BPM pickup is time-invariant, the beam longitudinal shifts with respect to the RF reference are linearly transformed into a phase deviation of the main frequency component from the RF reference and therefore a phase measurement of the fundamental frequency can be used to adjust the set points of the LLRF system that controls the acceleration process.

MEASURING SYSTEM REQUIREMENTS

An amplitude and phase measurement is performed on the main bunch frequency component, at the bunch repetition rate. The phase is measured with respect to an RF reference signal, provided by the accelerator timing system, at the same frequency of the bunch repetition rate. Table 2 shows the main requirements relevant to the measurement.

Table 2: Measurement requirements and additional parameters

Parameter	LANSCE linac	Spiral 2 linac
Bunch rep. rate	201.25 MHz	88.0505 MHz
Input power range	50 dB	40 dB
Position repeatability	100 um	±10/±100 um
Phase repeatability	0.25 deg	±0.5 deg
Pickup position sensitivity	1.26 dB/mm	2.5 dB/mm

The signal level varies inside the specified input range depending on the particles’ charge. The pickup position sensitivity is a geometrical parameter defined by the pickup dimensions. The phase repeatability is expressed in degrees at the bunch repetition rate. In both the cases the signal levels are inside the range from -60 dBm to -10 dBm.

DEVELOPED MEASURING SYSTEM

Brief description of Libera Brilliance processing structures

Libera Brilliance unit is composed of an analog and a digital processing system. The analog part processes the RF signals produced by the BPM pickups. The gain of each RF chain is adjusted by means of an active AGC system, while the signal bandwidth is limited by means of band pass filters removing the unwanted frequency components. Furthermore the analog crossbar switch, at the beginning of each RF chain, gently exchanges the paths of the four input signals through the RF board resulting in a very precise calibration system that preserves short term performance and guarantees submicron long term stability. The signals are then sampled by means of four 16 bit ADCs. The sampling clock is generated by a VCXO locked to the external reference by means of a software PLL loop. The external reference is provided by the accelerator timing system at the revolution frequency. The PLL can be programmed in order to have an offset tune respect the provided reference.

The digital processing is implemented inside an FPGA and includes the digital signal conditioning, the filtering, the digital down conversion, several decimation stages and subsystems for full integration of the data streams into the accelerator feedback and control systems.

Adopted measuring technique with modified Libera Brilliance system

The phase and amplitude measurement is based on the quadrature sampling technique. Table 3 shows some choices for the sampling clock for the LANSCE linac and Spiral2 linac cases.

The quadrature sampling technique, also known as IQ sampling, has the property that it implicitly extracts from the samples of a sine signal the in-phase and in-quadrature components like an IQ demodulation process does. Depending on the choices of the phase step and the time axis origin, the ADCs are streaming out a sequence of input signals expressed with I and Q components. (E.g. in the case of a phase step of 630 deg. the ADC will produce the sequence I, –Q, –I, Q, I, -Q, –I, Q …etc…). Figure 1 shows the block diagram of the analog processing chains.

Table 3: Sampling clock frequency choices for quadrature sampling in the case of LANSCE linac and Spiral2 linac

Phase step	**Sampling frequency (LANSCE f_{rf}=201.25 MHz)**	**Sampling frequency (Spiral2 f_{rf}=88.0505 MHz)**
90 deg	805 MHz	352.202 MHz
270 deg	268.3 MHz	117.40 MHz
450 deg	161 MHz	70.44 MHz
630 deg	115 MHz	50.31 MHz
810 deg	89.4 MHz	39.13 MHz

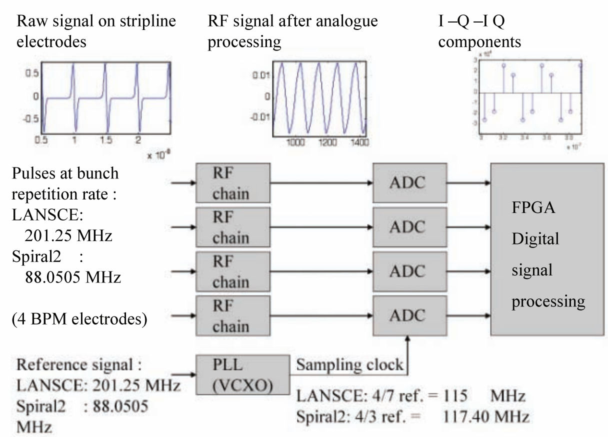

Figure 1: Block diagram of analogue signal processing and quadrature sampling scheme.

In order to measure the mentioned signals in the specified signal ranges (see table 1) the Libera Brilliance RF chain gain and bandwidth have been adapted. Moreover the VCXO used to generate the sampling clock has been closed in a much tighter PLL loop implemented inside a low jitter clock distribution circuit. The scope of the PLL circuit is the generation of the sampling clock from the reference frequency. In the case of the LANSCE linac a 630 deg phase step was chosen, since this maximizes the amount of information taken by the ADC. In this case the 115 MHz sampling clock is produced by multiplying the RF reference signal at 201.25 MHz by 4/7. This frequency multiplication is accomplished by the PLL circuit. The signal produced by the PLL at 115 MHz is phase locked to the reference signal; therefore the BPM signal is sampled in quadrature.

In the case of Spiral2, where the bunches have a repetition rate of 88.0505 MHz, the phase step of 270 degrees has been chosen and therefore the PLL is locked with a ratio of 4/3 resulting in a sampling clock of 117.40 MHz.

Adopted digital signal processing

The digital signals produced by the ADCs are processed in the FPGA by means of digital signal processing. The quadrature sampling scheme converts the frequency component at the bunch repetition rate to $f_s/4$, where f_s is the chosen sampling clock frequency (see table 3). Figure 2 shows the processing blocks. The signals are first processed by three stages of programmable second order IIR bandpass filters tuned at exactly $f_s/4$. The transfer function of each IIR section is

$$F(z) = \frac{z}{z^2 - k} \qquad (1)$$

where k is a real parameter that can be used to adjust the filter bandwidth and has to be $-1<k<0$ for stability reasons.

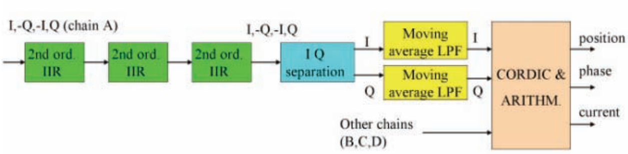

Figure 2: Block diagram of digital signal processing

Once the signals are filtered the separation of I and Q components is performed and there after the I and Q components are filtered by means of configurable moving average low pass filters. Afterwards amplitudes and phase are computed from the stream of filtered I and Q components by means of a cordic algorithm. The phase computation is based on the vector sum of signals on different electrodes, therefore I and Q signals are summed on the four channels. The position is computed with the standard delta over sum equation involving two electrodes with sensitivity coefficient specified in table 2.

MEASUREMENTS

One modified Libera Brilliance unit has been tested by means of extensive laboratory measurements. The PLL circuit has been programmed for the LANSCE linac 630 deg phase step (see table 3). The board was equipped with a VCXO with a center frequency of 115.404 MHz and a tuning range of ±90 ppm. The measurements were performed with a slight detune with respect to the designed 115 MHz sampling clock for the LANSCE linac. The reference signal for the PLL was therefore detuned by the same amount to preserve the PLL ratio 4/7. Consequently the bunch repetition frequency of the laboratory setup was fixed to 201.957 MHz. The adopted testing setup is depicted in figure 3.

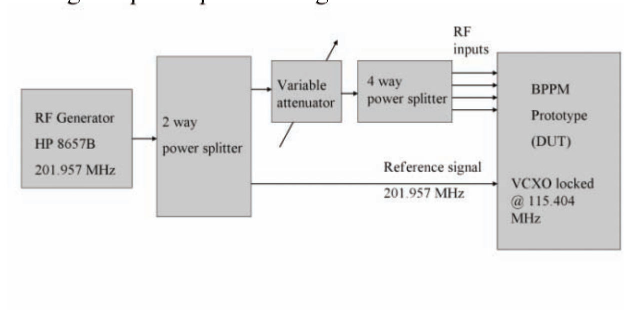

Figure 3: Block diagram of the measurement setup

An RF signal generator at 201.957 MHz is used to simulate the beam signal. This RF signal is passively split by means of a 2 way splitter. One branch of the split signal is attenuated by means of a variable attenuator and therefore equally distributed to the four RF inputs of the measuring system by means of a 4 way splitter that simulates a centred beam. The variable attenuator is used to simulate the charge excursion in the 50 dB dynamic range. The remaining branch from the 2 way splitter is used as the reference signal for the phase measurement.

Figures 4 and 5 show diagrams of the acquired samples and the relative phase measurement.

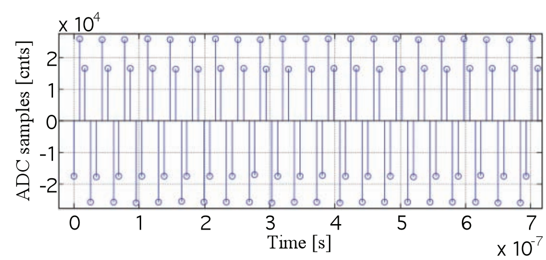

Figure 4: Acquired ADC samples

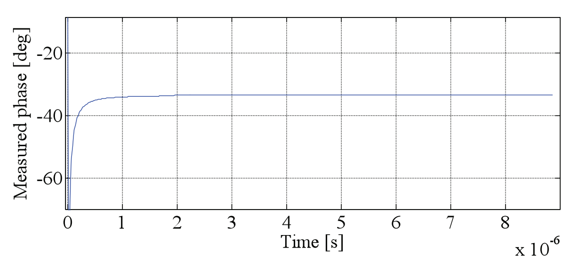

Figure 5: Typical phase measurement

Figure 4 shows the periodic pattern of I and Q components resulting from the quadrature sampling. Figure 5 shows the phase stream after the processing. After a short transient, introduced by the processing, the phase reaches a stable value.

Two different sets of filtering coefficients were adopted during the measurements:

- Filtering 1: 1 stage of IIR with coefficient k=-0.8 and moving average of 100 samples.
- Filtering 2: 3 stages of IIR with coefficient k=-0.9 and moving average over 500 samples.

The position and phase repeatability has been measured by means of the standard deviation computation on consecutive position and phase samples. The plots of the position and phase repeatability as function of the input power are shown in figure 6 and figure 7.

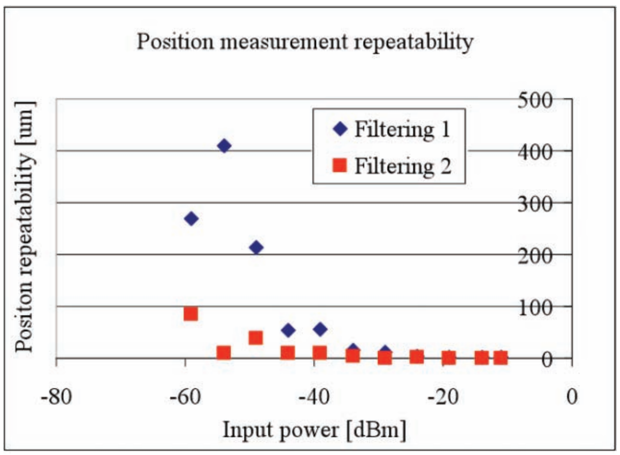

Figure 6: Position repeatability measurement vs. input power for two different settings of filtering coefficients.

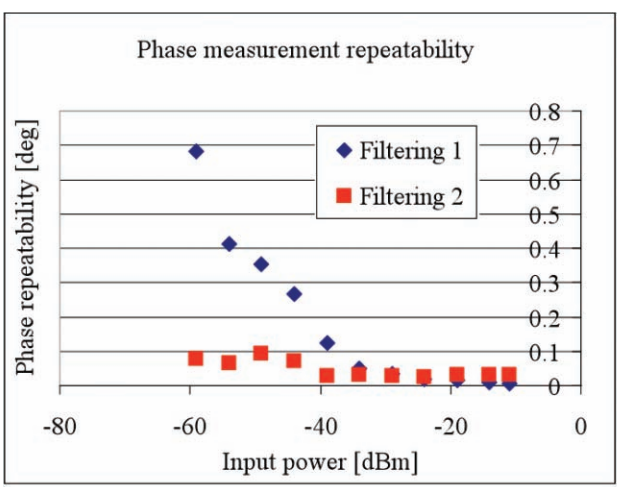

Figure 7: Phase repeatability measurement vs. input power for different sets of filtering coefficients.

At higher input levels, down to -40 dBm, the two different setting of the processing schemes give similar results in terms of repeatability. At lower input power levels, the signal is progressively deteriorated by noise and therefore the repeatability is affected. The second filtering scheme is more effective in terms of repeatability, since it is filtering out more noise. When the second filtering scheme is used, both position and phase repeatability are inside the LANSCE requirements (see table 2).

CONCLUSIONS

A modified version of Libera Brilliance has been successfully tested for time domain phase measurements inside an input power range of 50 dB. The quadrature sampling scheme has been successfully implemented inside Libera Brilliance by means of a hardware PLL. Digital signal processing has been applied to the quadrature sampled signal. Two different filtering schemes were evaluated for the data processing. The schemes give very similar results at higher input level. The second scheme is more effective in the lower input power range. It was shown how the flexibility of the processing schemes allows the user to configure the digital algorithms and therefore improve measuring performance.

REFERENCES

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[2] P. Ausset et al., Ganil, Orsay, France, private communication.