ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

GENÈVE, SUISSE
GENEVA, SWITZERLAND

Group Code.:	AB-BI/JMB	Original : English
EDMS No.:	711432	

AB Department Project

DO28=PS.13

Invitation to Tender
IT-3384/AB
Technical Specification for a new trajectory measurement system for the CERN Proton Synchrotron

Abstract

This Technical Specification concerns the design, construction and commissioning of a new trajectory measurement system for the CERN Proton Synchrotron. The system consists of 120 analogue signal acquisition channels, followed by digital signal processing to derive the positions of the particle bunches undergoing acceleration in the synchrotron.

Deliveries are foreseen over nine months from placement of the Contract.

May 2006

Table of Contents

Terms and Definitions

Term	Definition
CDD	CERN Drawing Directory
EDMS	Engineering Data Management System
QAP	Quality Assurance Plan

Annex 1 - Information and Documentation Management

Annex 2 - Manufacturing and Inspection of Equipment

1. INTRODUCTION

1.1 Introduction to CERN

The European Organisation for Nuclear Research (CERN) is an intergovernmental organisation with 20 Member States*. It has its seat in Geneva but straddles the Swiss-French border. Its objective is to provide for collaboration among European States in the field of high energy particle physics research and to this end it designs, constructs and runs the necessary particle accelerators and the associated experimental areas.

At present more than 5000 physicists from research institutes world-wide use the CERN installations for their experiments.

1.2 Subject of the Specification

This document specifies the means and methods to obtain the trajectories of particle bunches as they are being accelerated in the PS machine.

2. SCOPE OF THE TENDER

2.1 Scope of the Supply

The aim of this tender is to obtain price quotations from Bidders identified by the Market Survey MS-3384/AB. The successful Bidder shall design, supply and commission the necessary hardware, software and firmware to provide a new trajectory measurement system for the CERN PS. He will implement the algorithms described hereafter, and provide the necessary software, firmware and manpower support to enable CERN to do so.

CERN retains the intellectual property rights to the algorithms, but the successful bidder shall be free to use them in its products.

The PS trajectory measurement system is based on forty electrostatic pick-ups, each delivering three signals. The equipment therefore must acquire 120 analogue signal channels, in forty groups of three. Ten extra groups, or thirty channels, are needed as cold spares.

2.2 Items not included in the Supply

The pick-ups and the associated pre-amplifiers with their control system and cabling are existing equipment and are not part of the material to be supplied. All necessary signals are brought together in a few equipment racks in a building at the centre of the accelerator. Likewise, the necessary timing reference signals for operation will be provided by CERN.

Software to interface to the CERN accelerator control system and to display the resulting measurements on operator consoles is not part of the supply either.

* CERN Member States are: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.

3. GENERAL CONDITIONS FOR TENDERING AND CONTRACTING

Please refer to the commercial bidding documents for more complete information.

Tenders will only be considered from firms having been selected as qualified Bidders by CERN, as a result of the Market Survey MS-3384/AB. CERN reserves the right to disqualify any Bidder whose reply to this Market Survey is found to have been incorrect.

3.1 Tender procedure

3.1.1 Pre-tender discussions

All interested bidders are strongly encouraged to contact CERN and discuss details of this Technical Specification before submitting a tender. In particular, CERN wishes to ensure that no doubt exists as to the interpretation of this Technical Specification.

3.1.2 Alternative solutions

If the Bidder finds that any part of this Technical Specification is difficult, or costly to meet, he is free to propose an alternative solution, provided that the deviations from this Technical Specification, together with the reasons and advantages, are clearly indicated in the tender. Such alternative solutions shall always be made in addition to a conforming bid, which must comply fully with this Technical Specification.

CERN reserves the right to accept or reject the proposed alternative solutions without justification.

3.1.3 Preliminary programme

The Bidder shall propose a preliminary design and a manufacturing schedule with the tender, based on the specified CERN provisional delivery schedule. The preliminary design shall be sufficiently detailed to demonstrate that the system performance objectives can be met. CERN reserves the right to reject the tender if the preliminary design is deemed not to comply with the technical requirements.

3.1.4 Subcontractors

The Bidder shall declare in his Tender any subcontractors whose services he intends to use in the event of a Contract. Refer to the commercial documents for more details. If awarded the Contract, the Bidder shall restrict himself both to the subcontractors and the amount mentioned in the Tender. If, for some reason, he wants to change any subcontractor, or the scope of subcontracted work, or the amount subcontracted, he must obtain CERN's prior agreement in writing.

3.1.5 Technical Questionnaire

The Technical Questionnaire attached to this Technical Specification shall be completely filled in and returned with the Tender Form, otherwise the tender will not be considered as complete and will be discarded.

3.1.6 Presentation of Tender

The Bidder may be required to make a formal presentation of his tender at CERN at his own expense. He shall be ready to do so within a week of notification.

3.1.7 Country of Origin

Please refer to the commercial bidding documents for specific conditions concerning the country of origin of the equipment or services to be supplied.

3.2 Contract Execution

3.2.1 Responsibility for Design, Components and Performance

The Contractor shall be responsible for the correct performance of all items supplied, irrespective of whether they have been chosen by the Contractor or suggested by CERN. CERN's approval of the design and components choice does not release the Contractor from his responsibilities in this respect.

CERN assumes responsibility for the performance of items and sub-systems supplied by CERN.

CERN reserves the right to make minor modifications to the specification before placing the contract. These minor changes must not affect the contractual price that shall remain fixed.

3.2.2 Contract Follow-up

3.2.2.1 Contract Engineer

The Contractor shall assign an engineer to be responsible for the contract and its follow-up including all contacts with CERN throughout the duration of the contract.

3.2.2.2 Progress Report

The Contractor shall supply, within one month of notification of the order, a written programme detailing the manufacturing and testing schedules. The programme shall include preliminary dates for inspections and tests. A written progress report shall be sent to CERN every two months until delivery.

3.2.2.3 Design approval and production

The detailed design shall be submitted to CERN for approval within three months after notification of the contract. CERN will give its approval or refusal, in writing, within three weeks. Component ordering and equipment manufacture shall not start without CERN's written prior agreement.

The series production shall be preceded by the production of one pre-series unit. Production of the series shall not start before CERN has given its formal approval of the pre-series unit in writing. Unless CERN has agreed otherwise in writing, the series production shall be identical to the pre-series unit. CERN reserves the right to terminate the Contract if the pre-series unit does not fully comply with the technical requirements.

3.2.3 Deviations from the Specification

If, after the Contract is placed, the Contractor discovers that he has misinterpreted this Technical Specification, this will not be accepted as an excuse for deviation from it and the Contractor shall deliver equipment in conformity with this Technical Specification at no extra cost.

During execution of the Contract, all deviations proposed by the Contractor from this Technical Specification, the Tender, or any other subsequent contractual agreement, shall be submitted to CERN in writing. CERN reserves the right to reject or accept such proposals without justification.

CERN reserves the right to modify this Technical Specification during execution of the Contract. The consequences of such modifications shall be mutually agreed between CERN and the Contractor.

3.3 Factory access

CERN and its representatives shall have free access during normal working hours to the manufacturing or assembly sites, including any subcontractor's premises, during the Contract period. The place of manufacture, as stated in the Tender, may only be changed after written approval by CERN.

4. TECHNICAL REQUIREMENTS

4.1 General description

The purpose of the system is to measure the trajectories of particle bunches during acceleration in the CERN Proton Synchrotron (PS). Each bunch, of which there may be up to 21 at the time of writing, must be measured individually. The measurements of the forty pick-ups (PUs) distributed around the ring are collected and combined on demand from the operator console application programs to form several kinds of measurements:

- Trajectory measurements of a single selected bunch through all PUs over a small number (up to a few tens) of turns.
- The mean for each pick-up over a few hundred such turns, hereafter referred to as an 'orbit'. For a small number of selected pick-ups, this measurement may be requested at 1ms intervals in order to form a plot of the evolution of the mean position in these pick-ups over an acceleration cycle.
- The (weighted) mean of a selected bunch over all pick-ups over a few hundred turns, hereafter referred to as the 'Mean Radial Position', or MRP. This measurement may be requested at 1ms intervals to form a plot of the evolution of the MRP over an acceleration cycle.
- The instantaneous position of a selected bunch through two selected pick-ups over a large number of turns (~100k), hereafter referred to as a 'phase space plot', or PSP.

These representations are drawn from the set of accumulated data by a post-processing stage, the details of which remain to be defined, but that may take the form of a separate computer communicating with the acquisition system through a bus or private network. It communicates its processed results to the operator consoles via the accelerator control system network. The post-processing equipment is not part of the supply which is the subject of this tender.

4.2 Machine description

The PS is a circular machine with a diameter of 200m (*Fig 2*). The vacuum chamber is of elliptical cross-section, 140mm wide and 70mm high. One hundred combined-function magnets focus and bend the beam to guide it around the machine. One hundred straight sections in between the magnets contain auxiliary equipment, such as vacuum pumps, injection and ejection kickers, correction magnets and various kinds of instrumentation.

The machine sections are numbered from 0 to 99. A straight section carries the same number as the bending magnet following it (*Fig 1*). The forty pick-ups of the trajectory measurement system are installed in straight sections with numbers ending in 0, 3, 5 and 7. Each PU is identified by the straight section in which it resides, even though it is actually installed in the pumping manifold of the preceding bending magnet. The PU locations are shown as the dots on Fig 2. Each pick-up measures the horizontal and the vertical positions simultaneously.

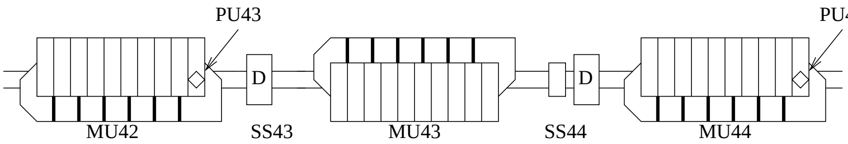

Fig 1: Some magnets and straight sections in the PS ring

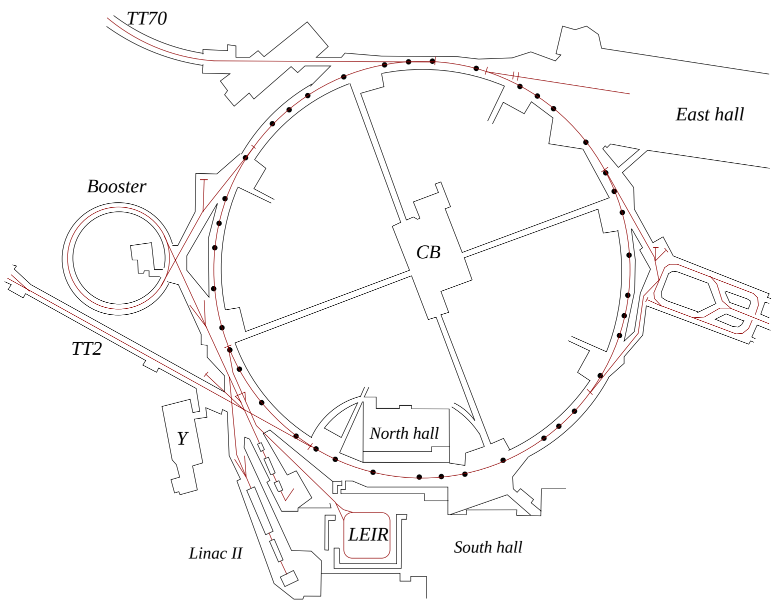

Fig 2: The PS complex

The accelerator operates in cycles, each lasting 1.2s. From one to sixteen bunches of particles are injected near the beginning of the cycle at 1.4 GeV. Radio frequency cavities accelerate the beam. Some acceleration operations may span up to three cycles. After acceleration to up to 26 GeV, the beam is ejected towards an experiment in a target area, or to the next accelerator in the chain. During acceleration, bunches of particles can be split into several bunchlets, or moved closer together or farther apart using what is colloquially known as 'RF gymnastics'. During the accelerating process, the revolution frequency F_{rev} of the beam varies from 437 to 477 kHz for p^+. The revolution frequency for ions can be much lower: down to 177 kHz at injection.

4.3 Pick-ups and signals

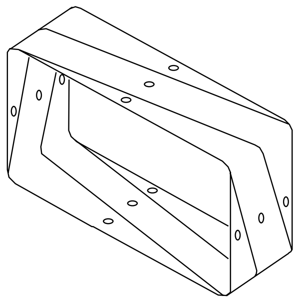

Fig 3: Pick-up electrodes

The PUs are composed of four electrode plates fixed inside the vacuum chamber (*Fig 3*). The PU aperture is 166 × 80 mm. The passage of a particle bunch induces image charges on the plates, resulting in a measurable voltage pulse. The signals are combined into a sum signal (Σ) and horizontal and vertical difference signals (Δ_x, Δ_y) using passive hybrid transformers. The signal levels are brought up to about 1 V_p by variable-gain amplifiers installed near each PU. The signal bandwidth is 150 kHz – 35 MHz. The upper cut-off frequency has an O(5) Bessel roll-off characteristic to preserve pulse shape. A computer in Central Building (CB) (see

Fig 2) remotely controls the amplifier gain, based on the expected beam intensity. The pick-ups, the pre-amplifiers and the associated control system are existing equipment, and not part of the supply subject of this tender.

The plot shows an example of a typical beam signal (*Fig 4*). The beam is an example of a p^+ beam that will be common in the LHC era. Four bunches are injected into the PS and kept circulating there at constant energy for 1 s while the injectors (Linac II + Booster) prepare a second batch of two bunches. The picture shows the instant this second batch arrives in the PS. The new bunches can be identified by their large negative displacement during the first turn, near sample 700.

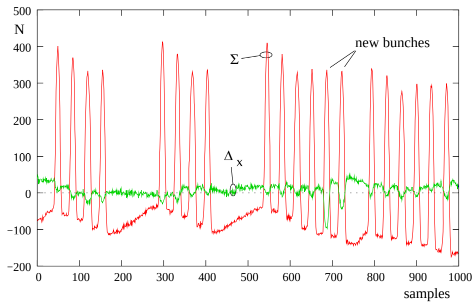

Fig 4: Beam signals at LHC 2nd injection

4.4 Acceleration

A normal acceleration cycle takes 1.2 s. During the first 100 ms, there is time for calibration and other housekeeping and setup operations. At 100 ms after the start (C100), the magnetic field is ramped up to its injection value. One or more bunches of particles are injected at C170. A timing signal marks the exact instant of injection. This signal is synchronised to $8 \cdot F_{rev}$, even if the machine harmonic (the number of accelerating RF periods per turn) is different from eight.

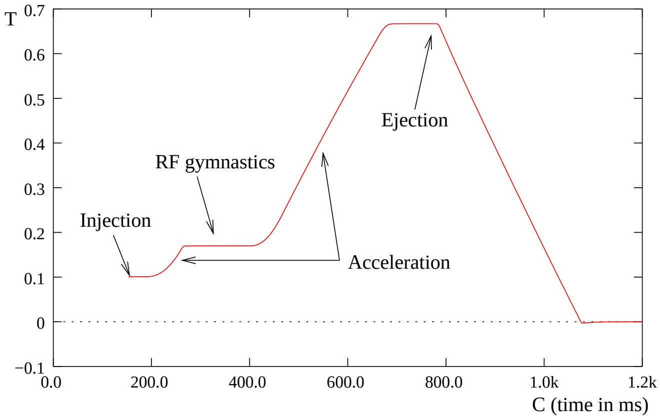

Fig 5: Example magnetic cycle (SFTPRO)

RF gymnastics may take place at any time. They are always done on a constant-energy (and therefore constant B-field) plateau, and take from 20 to 300ms, depending on the specific operation. At the beam's final energy, some operations may debunch the beam, or raise its harmonic number beyond the bandwidth of the PUs, in which case further trajectory measurements become impossible.

If the beam remains bunched up until ejection, the EJ signal marks the last possible instant at which a valid trajectory exists. It is possible to eject the beam over several turns, or to eject one bunch, while another stays in the machine to be subjected to further acceleration before being ejected in turn.

Beams are injected at a magnetic field of 102 mT. Acceleration can then take place up to a maximum field of 1.26 T. While p^+ undergo only a small variation of F_{rev} when accelerated from 1.4 to 26 GeV, Pb ions see their revolution frequency change by more than one octave (*Fig 6*).

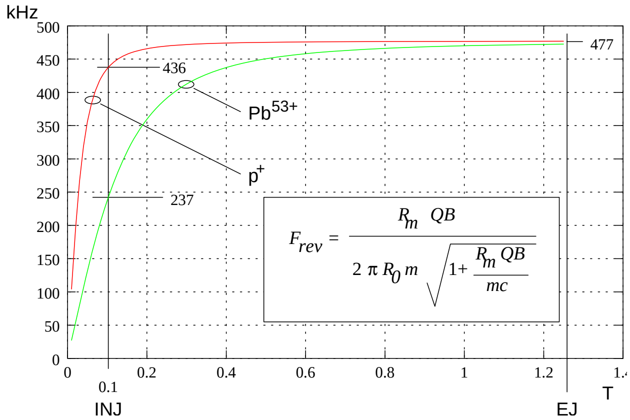

Fig 6: Revolution frequency vs. magnetic field

$$F_{rev} = \frac{R_m QB}{2\pi R_0 m \sqrt{1+\frac{R_m QB}{mc}}}$$

With reference to Fig 6, R_m=70.0789 m is the bending radius of the main magnet, R_0=100 m is the machine radius, Q [C] is the particle charge, m [kg] the particle mass and B [T] the magnetic flux density. The peak *dB/dt* is about 2.3 T/s, yielding a peak *dF/dt* of 1.6 MHz/s near the start of acceleration for protons.

4.5 Measurement method

The system to be supplied should be able to measure the position of the centre of charge of each bunch as it passes through each PU, during the time there is beam in the machine. The projected resolution of the measurement is 0.1 mm. The principle of position measurement is as follows: For each of the three signals Σ, Δ_x and Δ_y, the signal is integrated over the duration of one bunch. The x position can then be found by applying:

$$x = S_x \frac{\Delta_x}{\Sigma} + E_x \qquad (1)$$

where x is the horizontal bunch position, S_x is a proportionality constant and E_x is an additive error correction. The resulting value is the horizontal position of the *centre of charge* of the passing bunch. S_x and E_x are found as the result of a calibration procedure. The same calculation applies to the vertical axis.

In order to measure the position, we envisage a system where the 120 PU signals are digitised using 12-bit ADCs running at a rate of at least 125 MS/s. The measurement resolution target translates into a required effective number of bits (ENOB) of at least 10.5. The samples must be pre-processed on the fly into per-bunch integrals before being stored in memory. The pre-processing reduces the data storage rate per channel to the bunch frequency. The required memory size depends on the time the beam resides in the machine (up to 2 s), the number of bunches in the machine (up to 21) and the beam revolution frequency F_{rev} (up to 477 kHz). This yields 20 Msamples/channel, corresponding to 128 MB per PU. (Rounded up to the nearest power of two).

The pre-processing imposes the use of a synchronisation system that follows the particle bunches from injection, through possible RF gymnastics, until ejection. Due to the fact that the number of bunches can vary from cycle to cycle, and even within a single cycle, the synchronisation system must be quite sophisticated. Both synchronisation and integration process data at the sampling rate and are to be implemented in fast programmable digital logic, preferably in an FPGA, such that we will be able to adapt the algorithms in house in order to follow the evolution of the accelerator complex. The pre-processing associated with each PU is outlined in Fig 7. A bunch-synchronous timing reference is derived initially from a machine RF source, and from the Σ signal after injection. All three PU signals are base line restored and integrated. The integrals are stored into memory. The tagging keeps track of where in memory the data pertaining to a given machine timing is stored.

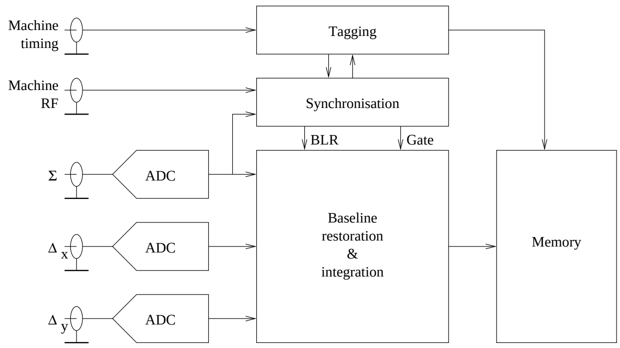

Fig 7: Block diagram of signal processing

The actual calculation of positions can be deferred until data are requested. Only a small fraction of the accumulated data will usually be requested for display by the machine operators. However, several operators may request different parts and different types of post-processing to be applied. Post-processing is delegated to a general purpose computer that also collects and transforms the data into a format suitable for transmission to the operator's consoles, and that connects to the acquisition hardware via a local bus or network (*Fig 8*).

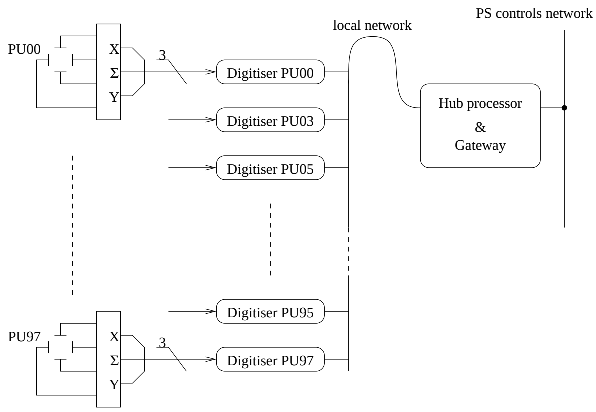

Fig 8: System architecture

Measurement requests will arrive via the standard Base-T Ethernet TCP/IP PS controls network. Typical requests include single turn trajectories for a given bunch, trajectory over a small number of turns for a given bunch, the position of a given bunch in one or two PUs over a large (~100k) number of turns, or the mean of the positions of a given bunch or of all bunches through all PUs over a small number of turns. Several different requests may have to be dealt with in the same cycle.

Measurement requests contain a timing specification in terms of ms since the start of a cycle, plus some number of revolution periods and a bunch (or bucket) number. Machine timing signals indicating start of cycle, beginning and end of the calibration interval, injection, various RF gymnastics triggers, ejection and a ms reference clock will be provided.

4.6 The integration algorithm

The centre of charge of a bunch is found by integration over the bunch length. The signal has a LF cut-off frequency of 150 kHz, resulting in a baseline that is not at zero potential (see *Fig 4*). In order to get an accurate integral, the baseline must first be restored.

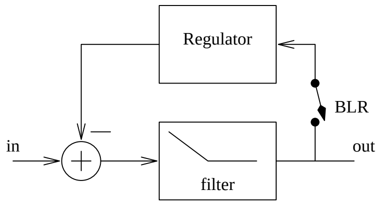

Fig 9: Principle of base line restitution

This is done by passing the samples through a numerical low-pass filter with a characteristic that is complementary to the high-pass response of the analogue channel, extending the lower cut-off frequency down to DC:

$$\frac{y}{x} = \frac{1 - az^{-1}}{1 - z^{-1}} \qquad (2)$$

where the numerator, with $a \approx 0.99$ provides a 150 kHz zero and the denominator a pole at +1, i.e., a pure integrator. Doing this will make the baseline flat, although it will not generally be zero. Even a slight bias in the sampled data will make it drift an arbitrary amount in either direction.

A feedback regulator, that only gets to see samples from the baseline, acts on the input in order to adjust the output baseline to zero. The BLR signal, provided by the synchronisation, tells which samples are on the baseline. The same treatment is applied to all three signals, Σ, Δ_x and Δ_y.

Following baseline restoration, the integral over the length of each bunch is found simply by adding together the samples belonging to a given bunch. Again, the synchronisation system tells which samples are to be taken as part of a bunch, using a signal baptised 'Gate'. The length of this Gate is not very critical, because it starts and ends when the beam signals are near zero. Integration is also applied to all three signals. The three integrals are then stored in the digitiser's memory.

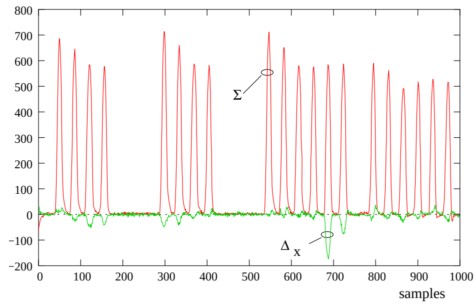

Fig 10: Σ and Δx signals after base line restoration

All RF buckets are thus treated and stored, irrespective of whether there's beam in them or not. This is necessary to limit the complexity of locating a requested measurement in memory.

4.7 Synchronisation

4.7.1 *Reference frequency generation*

A timing reference to produce the Gate and BLR signals must be derived from the Σ signal by locking to it a locally produced frequency, using a numerical Phase Locked Loop (PLL). Referring to *Fig 11*, a phase accumulator θ is advanced by f every period of the sampling frequency F_s, such that θ overflows at the rate of the revolution frequency F_{rev}. The phase accumulator is used to address a phase table that contains h periods of the Local Oscillator (LO) signal. The LO frequency is thus $h{\cdot}F_{rev}$.

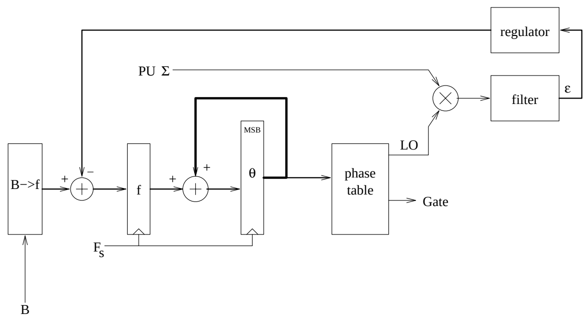

Fig 11: Principle of reference frequency generation

The LO is mixed with the incoming Σ signal and the product is low-pass filtered to extract a phase error (ε). This phase error is then fed back through a suitable regulator to correct the value of f. The regulator keeps the phase relation between the PU and LO signals, and consequently the phase accumulator, constant.

The value of f represents the value of the revolution frequency F_{rev} according to:

$$f = \frac{AF_{rev}}{F_s} \tag{3}$$

Here A is the full-scale value of the phase accumulator. A suitable initial value for f is provided by the block labelled B->f according to *Fig 6* and (3).

Other phase table columns are added to produce a Gate and a BLR signal, for the use of the integration and base line restitution algorithms. At the end of each Gate period, i.e., at the end of each bunch, the integrals are stored into memory. As already stated, the actual position calculation can be deferred until data are requested for display.

4.7.2 *Loop dynamics*

The synchronisation loop can be modelled as a discrete-time feedback system. Its transfer function can be expressed as polynomials in the 'z' domain. A possible small signal open loop transfer function that will yield a stable closed loop system is:

$$H_o = \frac{hz^{-1}}{A\left(1-z^{-1}\right)} \cdot H_m \cdot \left(\frac{z^{-1}}{1-0.996z^{-1}}\right)^3 \cdot \frac{\left(1-0.999z^{-1}\right)^2}{1-z^{-1}} \cdot z^{-n} \tag{4}$$

The first factor represents the phase accumulator, modelled as a pure integrator. A is the full-scale value of the phase accumulator and h is the accelerator harmonic number. H_m is the mixer, modelled as a pure gain, function of the sum signal amplitude and usually of the order of a few hundreds.

The next factor is a low-pass filter that rejects everything except the low-frequency terms of the phase error. Its corner frequency is a compromise between loop settling time and rejection of F_{rev}.

The fourth factor is the feedback regulator, starting with a pole at +1, i.e., an integrator, to force the steady-state phase error to nought. Two real zeroes are needed to make the loop stable. Finally, the last factor, z^{-n}, represents the inevitable pipeline delay of the physical implementation of the loop.

The stability of the loop can be assessed by examining the root-locus of the closed system with the regulator gain K_r as the independent variable. All poles must lie within the unit circle. The optimum setting of K_r depends on the beam intensity through the mixer gain H_m and on the harmonic number h. Therefore it will have to be set appropriately prior to beam injection. The loop behaves acceptably over a range of K_r of more than 20 dB. The phase error should settle in 20 to 100 µs.

The filter coefficients have been chosen to reduce the multiplications to simple shift-and-add operations, in order to make them easy to implement in FPGA logic: $0.996=1-2^{-8}$ and $0.999=1-2^{-10}$. C-language and MatLab implementations of the algorithm have been used to assess its stability with real acquired beam data, and are available on request.

4.8 Operational aspects of the accelerator

4.8.1 Injection

Injection and RF gymnastics are similar in that the system must switch from one frequency reference to another without losing phase lock. The reference frequency generation block is extended as shown in *Fig 12*. Switches select the reference frequency source and phase error taps. The switches are controlled through a table that associates a set of switch settings with each relevant accelerator timing event. While one branch of the duplicated signal path feeds the regulator in order to keep the loop locked, the parameters of the other are changed in anticipation of the next event. The switch table should be freely programmable during system operation. Likewise for the phase table.

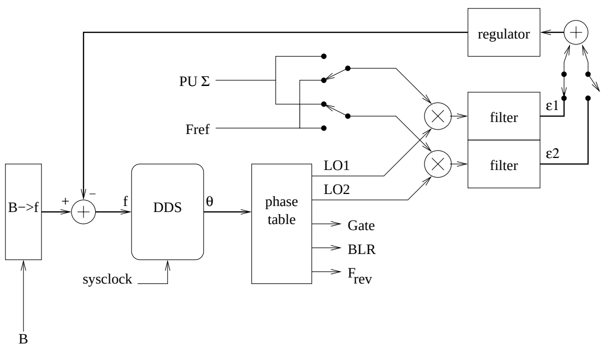

Fig 12: Dealing with injection & RF gymnastics

Prior to injection, while there is no beam signal yet to lock onto, an externally provided signal F_{ref} at the revolution frequency serves to both lock the PLL and provide a bucket numbering reference. At injection, a timing pulse signals the arrival of the beam in the machine. The signal that is presently available for this purpose has a resolution of 1/8 of a revolution period, irrespective of the harmonic number of the accelerator. Switch changes must be synchronised to the reconstructed F_{rev}, because each PU has a different phase with respect to the common reference. At injection, the PLL reference must be switched from the external F_{rev} to the PU's sum signal. Coincident with that event, the LO frequency is switched from F_{rev} to $h{\cdot}F_{rev}$, in such a way as to minimise the phase discontinuity. (The phase tables for these two frequencies must be correctly aligned.) The task of keeping the appropriate settings for switch and phase tables and distributing them to the acquisition hardware at the right times belongs to the system hub processor, the same that also collects the data and communicates with the PS control system. Initialising and maintaining these tables is CERN's responsibility.

4.8.2 RF gymnastics

For some types of cycle, the beam undergoes manipulations that change the number of bunches, or the spacing between them. Typically, these operations span several tens of microseconds on a constant energy plateau. An example is the triple-splitting of LHC bunches (*Fig 13*): before splitting, there are six bunches at harmonic number *h*=7, and after splitting there are 18 at *h*=21.

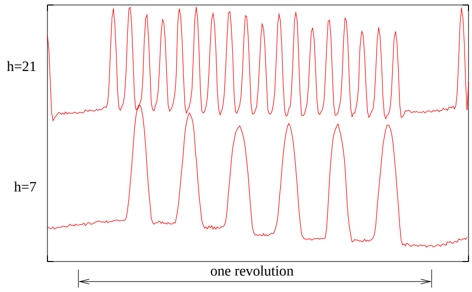

Fig 13: Bunch splitting on LHC beams

These operations are similar to the injection event, insofar as they are dealt with by switching to different phase table columns for the generation of the LO, Gate and BLR signals under the control of an external timing signal triggered at an appropriate instant. These timing signals are produced by the PS timing system.

4.9 Timing signals provided by the CERN accelerator control system

The timing system of the PS is based on VME plug-in modules 'TG8'. This module receives timing messages over a dedicated multi-drop network and produces /TTL output pulses on front panel outputs or interrupts to the VME crate backplane. The TG8's outputs are internally resynchronised using a free-running local clock at 4.096 MHz, and thus have a uniformly distributed jitter of 244 ns. The resolution of these timings is 1 ms. In addition, a TG8 will accept an external clock that is often used to add delays or to resynchronise to locally interesting frequencies, such as in our case, the beam revolution frequency or its eightfold multiple.

The injection timing for the trajectory acquisition is produced by the same TG8 as the one that is actually used to effect the injection. As such, any jitter affects both the actual injection and the acquisition equally, so that these events remain aligned. That is not true for so-called C-triggers however. These are locally created and therefore are usually poorly aligned with 'identical' C-triggers created elsewhere in the PS complex. It is therefore not possible to reliably get an acquisition showing fast events such as kicks or ejection. A clean solution for this problem is still being sought.

In order to make sure that all acquisition hardware marches to the same beat, an accurate 10 MHz source is available to be used as a reference for the ADC sampling clock. To avoid race conditions involving the timing signals, these will be resynchronised to the same 10MHz also. That last point is not part of this tender.

4.10 Calibration

The system will be calibrated at least twice a year. On request, a calibration system simulates a single-bunch beam circulating in the machine at an F_{rev} of 312.5 kHz during the first 100ms of every acceleration cycle. The system shall have calibration start and stop inputs to control this. The acquisitions from this interval are analysed by software in order to derive a set of calibration data, which is subsequently used to correct the actual measurements. This software is implemented in the post-processing computer and not part of the supply subject of this tender.

4.11 Data organisation

The data coming out of the pre-processing stage consists of triplets, each consisting of values representing the Σ, Δ_x and Δ_y integrals respectively. These are stored into consecutive memory locations. The memory is used as a circular buffer and can thus contain data pertaining to several acceleration cycles. At each occurrence of a C timing impulse, i.e., every ms, a tag, consisting of a small integer identifying the cycle, together with the current memory address pointer is stored in a table. (The C-table.)

A measurement at a given C-timing can be then be found by looking up the address from the table and rounding that value to the nearest multiple of 3*h. Appropriate offsets for bunch and turn number are then added:

$$A = C(x) + 3ht + 3b \tag{5}$$

with *A* the address of the desired data, *C(x)* the rounded C-table entry, *h* the machine harmonic number, *t* the number of turns and *b* the bucket number.

Timing events are almost all coincident with a C-timing. Exceptions are the injection and ejection timings, which are synchronised to $8 \cdot F_{rev}$. These must be stored as dedicated entries in an ad-hoc table.

The C-table should be able to store about 8k tags. This corresponds to the longest time the system may store data before wrapping around and overwriting old data. (2^{27} bytes, 2 bytes/sample, 3 channels, h=7, F_{rev}=437kHz)

4.12 Diagnostics

In order to be able to set up the system, and to verify its correct operation, it is necessary to be able to make short (1k) records of any two signals from the following list: Σ, Δ_x, Δ_y, gate, BLR, LO, ε, F_{rev}, F_{ref}, θ, f, timing inputs and action switch bits. Sample rates range from the raw ADC conversion rate down to about one sample/ms in a binary or 1-2-5 sequence.

Since there is no way to pre-calculate the exact phasing of the beam signal with respect to the externally applied F_{ref}, it is necessary to align the phases of the LO, the gate and BLR signals manually during system setup. It is also necessary to inspect the phase error and the frequency to make sure the loop locks reliably. This is CERN’s responsibility.

The acquisition of the diagnostic data should have a flexible triggering: It should be possible to use any of the timing inputs as a trigger, and it should be possible to delay the recording by a programmable number of ticks at the sample rate selected. Inputs of duration less than one sample should be stretched to one sampling period, so that very short pulses remain visible even at low sampling rates. Multiple pulses within one sampling period need not be resolved.

Finally, there shall be a logic output dedicated to supplying the reconstructed F_{rev}, in order to compare it with the analogue beam signals using an oscilloscope.

4.13 Timing-action matrix

Associated with each timing event are actions that appropriately change the settings of the system. A dynamically reprogrammable matrix controls the settings of switches that select appropriate reference frequency sources and LO, BLR and Gate columns during the acceleration cycle. The table below shows the typical actions that must be taken for each of the possible timing inputs. Each column corresponds to a timing input and each row is an action.

Table 1: Timing-action matrix

	SCY	Cal_Start	Cal_Stop	Inj	H-Change	ELFT	Spare
Set switches	x		x			x	
Clear C ctr	x						
Acquisition start		x		x			
Acquisition stop			x			x	
LO toggle			x	x	x		
Gate/BLR toggle			x		x		
RF toggle			x	x			

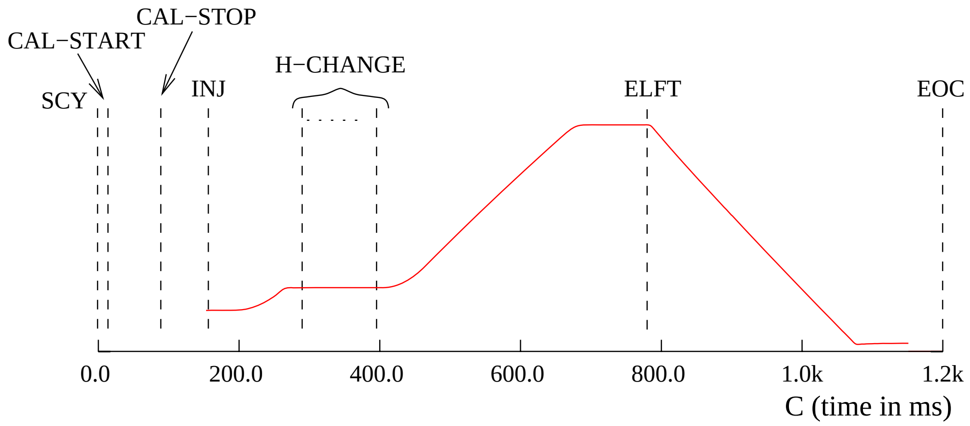

Fig 14: Timing events

- SCY is Start of CYcle. It corresponds to C0, the zero millisecond mark. The local C-counter should be cleared. The applied F_{ref} at this time will normally be the 312.5 kHz calibration frequency. The phase table entries for LO, BLR and Gate are appropriate for the upcoming calibration. The system software will fill the alternate LO, BLR and Gate tables in anticipation of the Inj event.
- Cal_Start is usually set at C5. It causes the calibration system to simulate the injection of a single-bunch beam. The acquisition of calibration data starts. Cal_Stop is usually set at C95. The calibration generator is stopped, and so is the acquisition. The system software provides new phase table contents and sets the initial sync loop frequency in anticipation of the Inj event. The system may then read out calibration data, if needed. An F_{ref} signal at the correct frequency and phase for injection will appear about 20 ms before actual injection.
- Injection takes place near C170. The reference frequency source is switched from ‘RF’ to ‘PU’. LO is toggled because the F_{ref} frequency was at F_{rev}, whereas the beam is at h· F_{rev}. Software sets the inactive LO, BLR and Gate columns of the phase table in anticipation of the first H-change event, if any.
- H-change events may or may not occur during a cycle. Harmonic changes imply a change of LO frequency and of Gate and BLR timings, effected via the appropriate switching actions. Software then sets the inactive LO, BLR and Gate columns of the phase table in anticipation of the next H-change event.
- ELFT (End of Last Flat Top) signals that the magnetic field is going to be ramped down. Normally all beam has been ejected shortly before, and thus acquisition can be stopped and switches can be set in anticipation of the next

calibration. The reference frequency source is 'CAL'. The system software must set the proper initial sync loop frequency (312.50 kHz) and provide the correct LO, BLR and Gate settings for the phase table.

- EOC is End Of Cycle. The next cycle start about 30ms after EOC.

Note that some inputs, such as, e.g., the H-changes, can profitably be logically OR-ed together, in order to save on the required number of inputs. For diagnostic reasons, it must be possible to trigger the actions by software, in order to simulate the occurrence of a timing signal in software, and so test its effects.

4.14 Operational conditions

The equipment will be mounted in standard 19" equipment racks. It can occupy a maximum of 40U of rack space. It will be powered from standard Swiss 230VAC 50Hz sockets. Connections for power supply should be at the rear, while connections for analogue signals and computer networks may be either at the front or the rear.

The equipment will run non-stop for about 300 days per year. Shutdown periods allowing for maintenance are normally from the end of December until the end of March.

4.15 Environmental conditions

The equipment will be installed in the PS Central Building, (Bat.353). This building is equipped with air conditioning. Nevertheless, the equipment should be able to function within the 0° to 40°C temperature range.

4.16 Information and Documentation Management

4.16.1 Engineering Drawings

All engineering drawings produced by Contractors and Suppliers for the AB complex that are deliverable to CERN are classified as External Drawings. They shall be prepared with a Computer Aided Design (CAD) system and be stored in the CERN Drawing Directory (CDD). More details can be found in Annex 1.

4.16.2 Schematic diagrams, software and firmware

The contractor shall supply documentation, schematic diagrams and source files, in machine-readable format, of sufficient detail to allow CERN to determine the characteristics of inputs and outputs, to help troubleshooting and to make minor changes and upgrades.

4.16.3 Document Standards

CERN has certain standard software for documents which shall be used by the supplier. See Annex 1.

4.16.4 Planning and Scheduling

4.16.4.1 Responsibilities

The contractor is responsible for the detailed scheduling of the work, as detailed in Annex 1.

5. APPLICABLE DOCUMENTS

Please refer to the cover letter or Instructions to Bidders for the complete list of enclosed documents which form part of this Invitation to Tender.

Please note that the quality assurance documents, CERN standards and Purchasing documents referred to in this Technical Specification are on the enclosed CD-Rom entitled "CERN Official Documents".

5.1 Standards

The material must comply with CERN safety standard IS23 regarding the issues of fire resistance and the emission of toxic or corrosive fumes in case of fire, and with the CERN safety code C1, regarding the safety of electrical equipment and installations.

5.2 On-site work regulations

If work is to be carried out on the CERN site, attention is drawn to the fact that CERN has specific rules concerning e.g. safety regulations applicable to works of Contractors at CERN, access to and activities on the CERN site, occupational health and safety on the Organization's site and special health and safety matters.

6. QUALITY

6.1 Quality Assurance Provisions

The Bidder must be able to demonstrate that he has an adequate quality control system, which is appropriate to the subject of the specification. The equipment delivered shall be accompanied by test reports demonstrating its correct operation.

7. TESTS

7.1 Tests to be carried out at the Contractor's premises

CERN reserves the right to be present, or to be represented by an organization of its choice, to witness any tests carried out at the Contractor's or his subcontractors' premises. The Contractor shall give at least 10 working days notice of the proposed date of any such tests.

7.2 Tests to be carried out at CERN

Tests will be carried out at CERN, both in the lab, with simulated signals, and on the actual running accelerator. CERN will provide the necessary analogue and timing signals in order to do these tests, insofar as this does not conflict with the normal operation of the accelerator.

8. DELIVERY AND COMMISSIONING

8.1 Provisional Delivery Schedule

A contract will be placed end of June 2006. Delivery of a working prototype is scheduled for September 2006. Commissioning of the complete system for all forty pick-ups should take place in late autumn 2006 and the system must be operational for March 2007. CERN accelerator specialists will assist in commissioning the system.

8.2 Packing and transport to CERN

All equipment shall be delivered DDU to CERN site Prévessin/France or Meyrin/Switzerland goods reception unless otherwise stated. The Contractor is responsible for the packing and, where included, the transport to CERN. He shall ensure that the equipment is delivered to CERN without damage and any possible deterioration in performance due to transport conditions.

8.3 Handling at CERN

8.3.1 CERN Supplied Items and Services

CERN will provide rack space, ventilation, cooling, power, network connections (not to the outside of CERN), analogue PU signals and timing signals, conditioned for and routed up to the equipment's inputs.

8.3.2 Contractor's Installations at CERN

None.

8.4 Acceptance and guarantee

Provisional acceptance will be given by CERN only after all items have been delivered in accordance with the conditions of the contract including documentation referred to in this Technical Specification, all tests specified have been successfully completed and all test or other certificates have been supplied to CERN.

The guarantee period is defined in the commercial documents.

8.5 Service

8.5.1 Commissioning

The contractor shall provide on-site commissioning for up to ten working days following installation of the equipment. Commissioning shall be scheduled at a time that the accelerator is running, in order to verify operation under realistic circumstances. It must not disturb the machine's operation however. The accelerator normally runs from April to December.

8.5.2 Maintenance

The equipment shall be covered by a warrantee period of two years following provisional acceptance of the equipment. The contractor shall provide hardware maintenance and software support for a minimum duration of 3 years, possibly extended to up to ten years in the context of a maintenance contract. On-site intervention may be needed.

Once the system is operational, and once the old system has been removed, upgrades can only be applied during the yearly shutdown period of the accelerator complex, from January to March, unless these upgrades are indispensable for the continuing operation of the system.

8.5.3 Training

The contractor shall provide training and software in order to allow CERN personnel to update, trouble-shoot and improve the system.

9. CERN CONTACT PERSONS

Persons to be contacted for technical matters:

Name/Department/Group	Tel-Fax	Email
Jeroen Belleman - AB/BDI In case of absence: Ulrich Raich – AB/BDI	**Tel:** +41 22 767 2921 **Fax:** +41 22 767 8200 **Tel:** +41 22 767 2632 **Fax:** +41 22 767 8200	Jeroen.Belleman@cern.ch Uli.Raich@cern.ch

Persons to be contacted for commercial matters:

Name/Department/Group	Tel-Fax	Email
Ivo Lobmaier In case of absence: Anders Unnervik	**Tel:** +41 22 767 8836 **Fax:** +41 22 767 7450 **Tel:** +41 22 767 3245 **Fax:** +41 22 767 7450	Ivo.Lobmaier@cern.ch Anders.Unnervik@cern.ch