A logarithmic processor for beam position measurements applied to a transfer line at CERN

H. Schmickler, G. Vismara, CERN, Geneva, Switzerland

Abstract

The transfer line from the CERN proton synchrotron (PS) to the super proton synchrotron (SPS) requires a new beam position measurement system in view of the LHC.

In this line, the single passage of various beam types (up to 7), induces signals with a global signal dynamics of more than 100 dB and with a wide frequency spectral distribution.

Logarithmic amplifiers, have been chosen as technical solution for the challenges described above.

The paper describes the details of the adopted solutions to make beam position measurements, with a resolution down to few 10^{-4} of the full pickup aperture over more than 50 dB of the total signal dynamics.

The reported performances has been measured on the series production cards, already installed into the machine and on one pickup in the transfer line.

1 BEAM PARAMETERS

1.1 Beam types

Here is a non-exhaustive list of the transfer line beams.

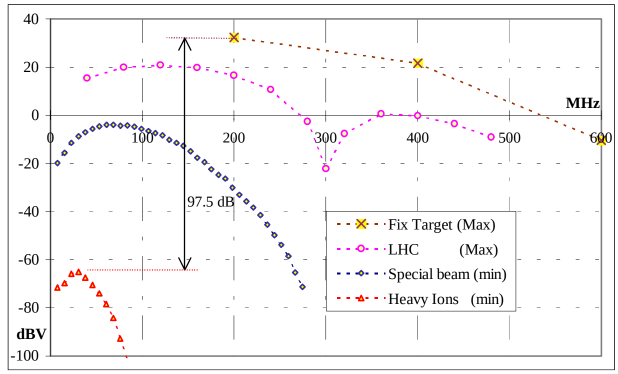
Table 1: Transfer line beam types

Beam Name	Number of bunches	Bunch width	Bunch spacing	Intensities (minimal)
Fix Target	2000	1.7	5	$1*10^9$
LHC	1 to 84	2.1	25	$5*10^9$
Special	1,8,16	4.8	262	$5*10^9$
Heavy Ions	16	6.2/15	131	$2.6*10^8$
		ns	ns	Charges/b

Due to the very low intensity of the heavy ions beams, long coupler pickups have been chosen. Their transfer impedance shows a maximum at about 100MHz, which is a good compromise for the various beams present in the transfer line. The position sensitivity corresponds to 0.54 dB/mm.

1.2 Signals spectral distribution

The signal spectra at the coupler's output are illustrated in fig. 1. In order to illustrate the large dynamic range, the most intense beams have been represented at their maximum intensity, while the weakest beams at their minimum intensity.



1.3 Global dynamic

The intensity dynamic corresponds to 97.5 dB, to which one should add a position dynamic of at least 25 dB.

Figure 1: Spectral distribution of various beam types

2 DESIGN CONSIDERATIONS

None of the existing electronic processors can cover the whole dynamic range.

Since the various beams are transferred at time interval in the range of seconds, it is acceptable to select a tailored processor to each individual beam. In practice, two processors can handle all the various situations.

The conditions associated to this choice are:

- No reliability reduction, hence no mechanical switching elements
- No significant power consumption increment
- Similar position resolution for the various beam
- Negligible costs increment

2.1 Beam grouping

2.1.1 Narrow Band

The most critical case corresponds to the "Heavy Ions" beam, which shows the largest spectral lines at 22.89 MHz. At this frequency, the "Special" beam is only 7 db below its maximum level and being over 40 dB larger, it can be treated by the same narrow band processor.

The bandwidth choice (BW = 1.3 MHz) is determined by the compromise between the time required to build up a stable signal level and the required long dumping time, to allow a proper measurement to be done, in the case of single LHC bunch.

2.1.2 Wide Band

The "Fix target" and "LHC" beams have respectively fundamental and 5th harmonics tuned at 200 MHz hence use the same processor. To avoid tuning problems the bandwidth can be as wide as 12 MHz.

They induce very large signals, which can be derived from the main path by a coupler or a voltage divider.

This way of grouping allows to compress by 40 db the required dynamic since the most intense beams are shifted in between "Special" and "Heavy Ions" beams.

The two processors can be identical but working at different frequencies.

The choice of a logarithmic processor [1] makes the realization quite simple.

It is reminded that the position is obtained by

$$\mathbf{P = K_{(h,v)}*[\log(R) - \log(L)]}$$

3 CIRCUIT DESCRIPTION

3.1 Splitter

The signal splitting is obtained by a 26 db resistive voltage divider to provide an accurate ratio and 50 Ω matching over the whole BW apart around 22.8 MHz caused by the BP filter tuning

3.2 Band-pass filters

3.2.1 Narrow band BP filter (f_o = 22.8 MHz)

It is made of a single L, C serial resonator. To obtain a relatively high Q, a 2:1 transformer is used to reduce the serial resistance.

The BP filters should be matched per pairs on two parameters: the central frequency and the BW.

The first condition is required to obtain an identical pedestal for the various beams the processor has to treat; in this case, a unique calibration is required.

The BW matching is important for single bunch measurement, in order to obtain a constant differential signal at least during the integration or digitalization time.

3.2.2 Wide band BP filter (f_0 = 200 MHz)

It's also a single resonator, where the Q is determined by the serial resistance of voltage divider (3.3 Ω) to produce a 12 MHz bandwidth. The logamp bandwidth (5MHz) is the limiting factor in the chain; rise time < 100 ns allows for a stable output during the integration time.

3.3 Logarithmic amplifier

The choice of the AD8306 logarithmic amplifier (logamp) has been determined by the following considerations:

- The non-conformance to the log transfer function and the resulting position measurement error.
- The dynamic range inside which this parameter is maintained.
- The standby facility of this chip allows a simple electronic switching between processors, while keeping the power consumption low and stable.
- The availability of a limiter signal output, to be used as auto-trigger facility.

Starting from 100 dB dynamic with a nominal ± 3 dB non-conformity, one ends up with at 66 dB (± 0.2 dB) dynamic range, in the frequency range 10 to 400 MHz.

One logamp for each BP filter is required.

The auto-trigger is obtained from the OR function of the two right channels; this signal has a very short pulse length (BW > 500 MHz), hence a retriggerable monostable drives the digitizer.

3.4 Control logic

The control logic allows the selection of:

- The most appropriate processor (enable function).
- Either the difference of the log (≡ Position) or individual log output (≡ Intensity * Position)
- The output bandwidth, according to the integration time, in the range .5 to 5 MHz.

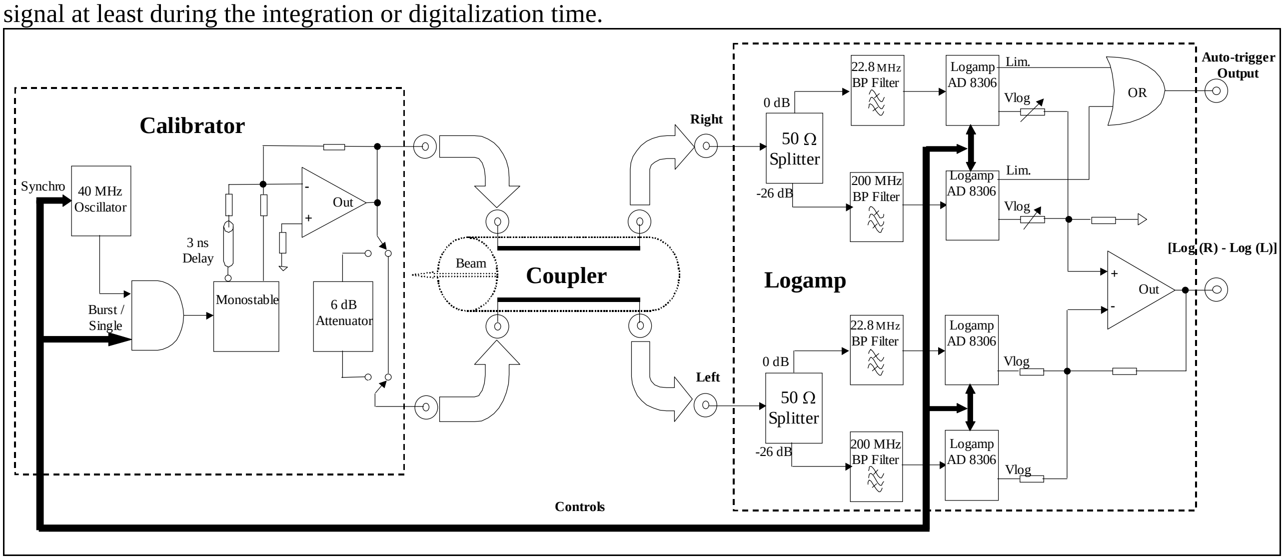


Figure 2: Calibrator - Coupler - Logamp Normalizer Block Diagram.

3.5 Output stage

The differential amplifier, capable to drive 50 Ω load, will produce an output signal proportional to the position, with a sensitivity of 10 mV/mm.

Two trimmings are required to adjust the slope of the logamps at 22.8 MHz and 200 MHz and maintain the central position in ± .2 mm over the whole dynamic range.

4 MEASUREMENTS

A 30 units serial production has been realized, tested and installed in the transfer tunnel. Each unit gives measurements of the horizontal and vertical beam positions. The logamps are housed in a shielded box of 140 x 70 x 40 mm.

4.1 Calibration Measurements

The BW dispersion is limited to 3% rms. for both filters and the NB filters are matched within 0.2 % rms.

The typical response of three different simulated positions is represented in fig.3.

It can be noticed that for a centred beam the stability is excellent; ±100 µm over > 70 dB dynamic. It becomes 3 times worst when the beam is offset by half the gain of an individual amplifier stage of the logamp (6 dB • 11 mm). The noise response versus input level, when measured by integrating over 1 µs tends asymptotically to 18 µm. For integration time of 100 ns this value rise to 50 µm.

In absence of input signal, the logamp has the maximum gain, hence the largest noise approaching the .9 mm rms.

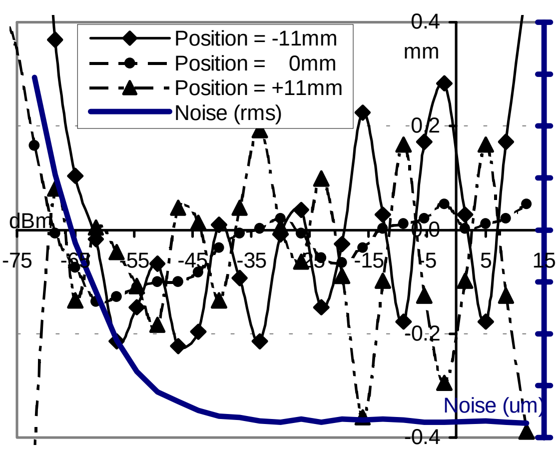


Figure 3: Position errors and noise versus input level

Figures 4, 5 show this, when looking at the difference output (U-D) just before the beam arrival.

4.2 Beam Measurements

Beam measurements have been done on one unit placed nearby the coupler.

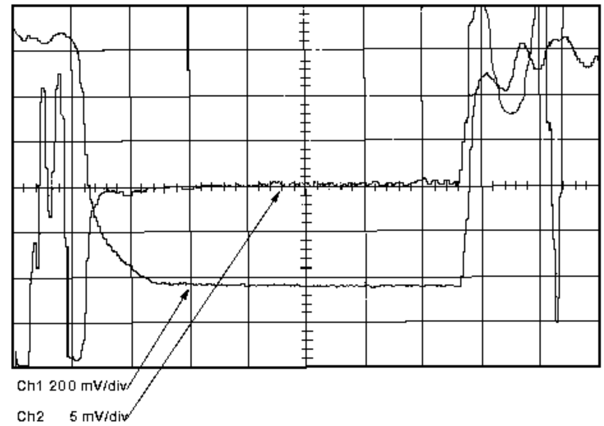


Fig. 4 Fix target beam response -D & [U-D]

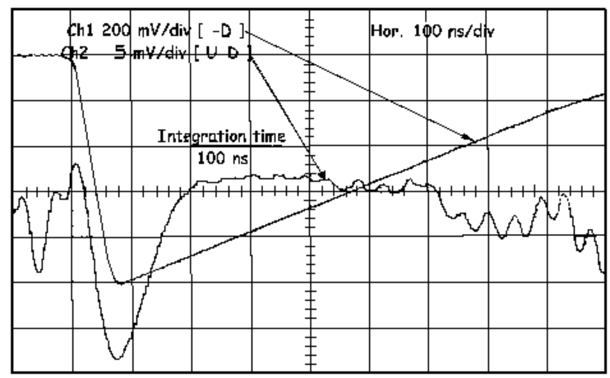


Fig. 5 Single LHC bunch beam response -D & [U-D]

Figure 4, 5 show the logamp processor response to a fix target beam (WB filter) and to a single LHC bunch (NB).

The position's sigma, including the beam jitter on the vertical plane, measured over 100 ejection cycles, is <50 µm for the fix target beam and <80 µm for the single LHC bunch.

It has to be noticed that settling time of the whole chain (NB), before a good measurement can be done, is ~200 ns, which corresponds to a 10 dB reduction on S/N.

The processor requires an accurate beam simulation, in order to correct for position offset and sensitivity.

5 CONCLUSIONS

When signals having a wide variety of frequency spectral contents has to be treated, the logamp appears to be the best choice.

The reasons are the total independence on the input frequency (up to >500MHz) and the true rms. detection. The processor allows single bunch or burst measurements and can resolve between bursts separate by >1 µs.

The system will be fully commissioned during the operations period of the year 2001.

REFERENCES

[1] G. Vismara, " Signal Processing for Beam Position Monitors", BIW 2000 pg 36 Cambridge, Ma AIP Conf. Proc. 546 Figure 3: Position errors and noise versus input level