The new front-end Narrow-Band electronics for the LEP Beam Orbit Measurement system

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Abstract

The LEP Beam Orbit Monitoring (BOM) has 504 BPM's of which 448 are read with a Narrow-Band processing electronics (NB), using amplitude to phase detection [1,2].

The performance of this system has been limited for several reasons mainly related to the analogue signal treatment. These effects influenced the beam position offset for both e+ and e- beams, respectively. It also created non-linearity for positions measured around zero values and hence a large dispersion in the scaling factors among BPM's.

In order to overcome these problems, mainly due to the high frequencies spectrum (up to 5 GHz), the front-end electronics has been redesigned involving:

- A new ringing filter, with single resonator and very high rejection of all spurious frequencies,
- An amplitude to phase conversion Normalizer, which is no more influenced by the beam intensity, nor by the beam polarities and presents an excellent linearity over the full position range.

The new design described in this paper has reached its goals: an average beam orbit resolution of 10 µm, a position difference between beams smaller than 60 µm and a scaling factor dispersion of 3% rms.

These improved performances have been highly beneficial to the LEP operation and vertical orbit correction down to 0.4 mm rms. has allowed to reach a beam polarization exceeding 50 %.

1. INTRODUCTION

The main beam parameters relevant to the NB BOM system are summarized in Table 1.

Table 1: Beam Parameters

Beam	Injection	Circulating	
Nominal intensity	10*10^9	300*10^9	p/b
Beam dynamic	46		dB
Position dynamic	30	30	dB
Bunch width	80 to 120		ps
Bunch spacing	> 0.6 to 88.9		µs

From which the important ones are:

- The total signal **dynamic** (beam intensity and position), which easily exceed 76 dB.
- The **width** of the beam induced signal, which is smaller than 120 ps, corresponding to a very broad frequency spectrum up to > 5 GHz.

The main NB BOM design parameters, as required for the LEP operation, are summarized in Table 2.

Table 2: BOM Parameters

Beam	@Inject.	Circulat.	
Max. Position Aperture	25	25	mm
Accuracy of Scaling Factor	1	1	%
Linearity (rms.)	1	1	%
Resolution (rms.)	100	10	µm
Zero Posit.(rms.) vs. intens.	100	10	µm
Offset {(e+) - (e-)} (rms)		10	µm
X / Y coupling		≤ -60	dB

Among them the critical ones are:

- The **Stability** of the measurement for a centered beam as function of the beam intensity.
- The very high **Resolution** (< 10 µm)
- The negligible **Offsets** differences.

Figure 1 summarizes the basic schematics of the narrow band processor.

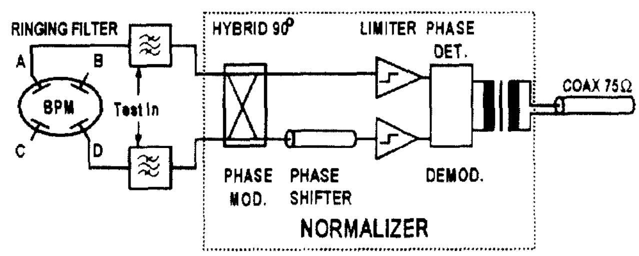

Fig. 1 : Narrow Band Processing Scheme.

2. PROBLEMS ASSOCIATED WITH FIRST VERSION

The first generation NB System has shown problems [2,6] that did not allow to keep the performances within the required specifications, and in particular:

- The average **Horizontal position** showed an offset of -0.8 mm for the e- beam.
- The **Orbit diff.** between e+ & e- was -0.8 mm (Fig.4).
- The **Scaling factors** were respectively -5% for the e- and -15% for the e+ with an rms dispersion of 8%.
- The **Linearity** curve was showing irregularities around the central position.
- The **Position dependence** on the beam intensity, particularly at the injection intensities.

The reasons for these unsatisfactory results had to be found in the performances of the front end electronics.

The ringing **Band Pass Filter**, a Gaussian type with double resonator, showed poor high frequency rejection. The presence of spurious frequencies induced different phase distortions for e+ and e-, resulting in orbit differences. The triggering time was dependent on the inverted ringing polarities of e+ and e- beams (half a period) contributing also to the offset.

In addition, mismatch between the output impedance of the filter and the 90° Hybrid generates reflected waves which perturbed the signal phase. This problem was solved by increasing the length of the interconnecting cables, so that all reflections would arrive after the acquisition instant [5].

The **Normalizer** problems were mainly related to the comparator circuit which had internal crosstalk between channels and duty cycle variation versus signal amplitude (from threshold up to 20 dB overdrive). Also cross-talk between normalizing channels, due to the use of common circuitry to reduce the power consumption, was responsible for the transfer function non-linearity.

3. NEW ELECTRONICS

3.1. Band-Pass Filter [3]

Because of the amplitude to phase modulation processing, a pair of filters should present matched time response characteristics, with tolerances of ±2‰ at least over the minimum digitalization time (6 to 7 oscillations periods).

The filters are installed directly on the button electrodes and therefore are exposed to very high radiation intensity (for LEP200 > 20 kGy/year). Once installed in the LEP, the filters parameters should stay stable since no further calibration is possible.

These restrictive conditions have suggested the choice of a single resonator filter which offers the following advantages:

- Simple circuit, which means better reproducibility, reliability, long term stability.
- Stable phase.
- No trigger uncertainty, because the first oscillation is the largest one[6].

The price to be paid is a much longer damping time, which has been fixed to 600 ns for 60dB attenuation.

The important design parameters are then:

- Output level at the 6th period ≥ Original filter,
- No spurious resonances up to 5 GHz,
- Identical response from the Calibration Input,
- Radiation resistance (> 120 kGy).

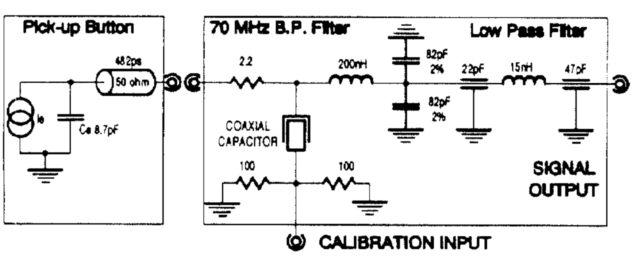

Fig. 2 : BP Filter schematics.

Figure 2 shows the filter circuit. The electrode capacitance is integral part of the filter and is loaded by an equivalent impedance of 2kΩ at the resonance frequency; this solution gives the maximum output signal. The spurious resonances are suppressed by the low pass filter, made with two feed-through capacitors.

The calibration signals are injected via a 1 pF coaxial capacitor and signal responses are now identical for both beam and calibration inputs.

The production quality of the filter units has allowed the matching at 2 ‰ of the 6 time domain parameters (see table 3.) without any trimming, and with an efficiency above 90% for the 2000 units.

Table 3: Filter parameters.

	Central Values	Tolerances Individ.	Pair
Frequency Domain :		δ [‰]	δ [‰]
Central Frequency	70 MHz	1.4	0.15
Bandwidth (-3 dB)	3.6 MHz	2.0	0.02
High freq. rejection (>300MHz to 5GHz)	>50 dB		
Temperature coeff.		0.05	
Time Domain :		δ [‰]	δ [‰]
-Beam V(peak-peak) 3rd	258.5 mU *	3.0	1.3
-Beam V(peak-peak) 6th	155.3 mU *	4.8	1.3
-Calib. V(peak-peak) 3rd	5092 mU *	10	1.3
-Calib. V(peak-peak) 6th	3080 mU *	10	1.3
6th zero cross. delay	71670 ps	1.2	0.8
Oscillating period	14236 ps	1.2	0.5
Long term stability : matched tol.> 2 years			

* Relative Units

3.2 Normalizer [4]

In their new realization the two normalizing channels are totally independent and separated by an RF shielding box.

The **90° Hybrid** is a wide band type (BW = ±30%).

The **Phase shifter** delay line is now located between the 90° hybrid and the dual limiter. It has been realized using a 50 Ω micro-strip of 3.57 ns on the PCB mother-board. The delay has been trimmed to the accuracy of 80 ps.

The **Dual limiter** and phase demodulator is a thick film hybrid, which can be used in other applications. This normalizing circuit present an output duration proportional to the burst intensity. The latch function of the comparator is used to obtain an adjustable hysteresys (see Fig. 3). This facility allows for a zero input offset and a completely symmetric switching (50% duty cycle), even at the lowest threshold limit. The adjustable hysteresys corresponds to a threshold control over 26 dB, and gives the possibility to maintain the output signal duration (400 ns) independent of the beam intensity. In order to avoid uncertainty of the comparators steady state, a reset signal is automatically generated after 600 ns.

The **Phase to amplitude** demodulation is obtained with an EXOR (Eclips Light 10E107) which has symmetric and very fast switching time. The output signal (140 MHz) is then filtered by a symmetric RC low-pass filter (6 dB/octave at 40 MHz) and send via a 75 Ω video buffer driver and an insulation transformer on the coaxial cable to the digitizing card.

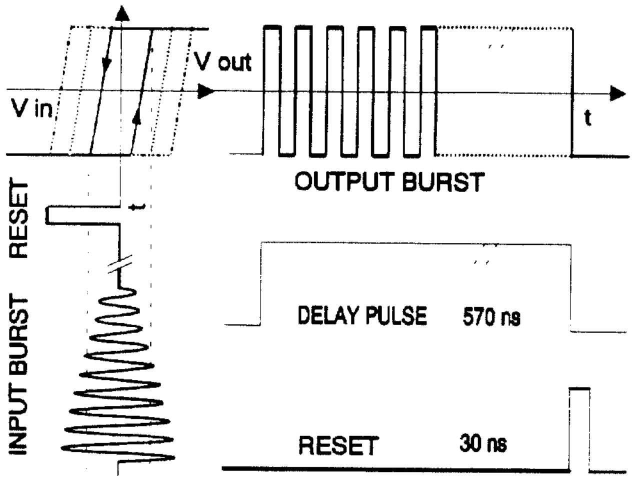

Figure 3 : Limiter Operating Principle.

The Normalizer performances are given in Table 4.

Table 4: Main Performances of the Normalizer.

Input	Average	
Minimum threshold level (peak to peak)	2.5	mV
Adjustable threshold range	26	dB
Maximum input level (peak to peak)	10	V
Output		
Sensitivity vs. input ratio	7.96	mV/dB
Stability vs. input overdrive	3.0	‰
Linearity (rms.)	1.8	‰
Normalizing channels crosstalk	< -60	dB
General		
Radiation resistance	15	kGy
Power consumption	.85	W

4. Results

The performances of the new front end electronics have been measured with the beam, on the LEP machine, using a motorized (X, Y) PU, over a range movement of ±10 mm with a resolution of 10 μm. The beam position stability has been checked and compensated by using two PU on each side. The following parameters have been measured, on a limited range of ±5 mm, for both e+ and e−:

- **Slope coefficient**: In the vertical plane its value is 1.0 for e− and 0.983 for e+, while on the horizontal plane it is 0.971 for e− and 0.958 for e+. The dispersion of these values, for different H or V coordinates, is < 3 ‰rms.
- **Linearity:** The measurement accuracy has been limited by the mechanical error which is of the same order of magnitude. On both planes it is <20 μm rms.
- **X/Y coupling:** The effect is negligible and below the measurable limits of -46 dB.

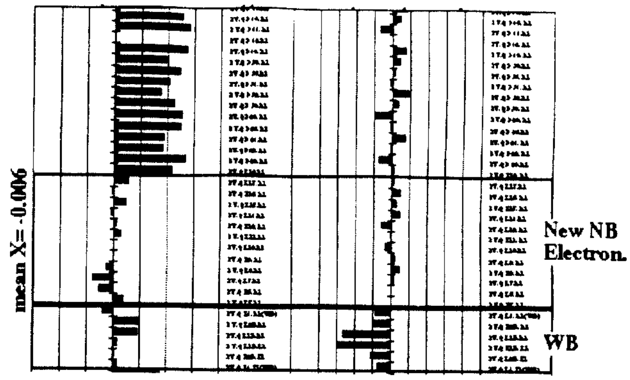

Fig. 4: e+& e− orbit diff. with old (top) and new electronics.

The new electronics has been installed in the LEP machine during the 92/93 shut-down. The figure 4 shows that the problem of the horizontal offset is cured by the new electronics [6].

5. Conclusions

The NB BOM system has now reached its nominal design performance[7]. The BOM stability and reproducibility has been demonstrated by the Study of the LEP Beam Energy and the Tides effects [8]. A last step remain to be done, which is the replacement of the Flash ADC to reach the utmost overall accuracy and resolution.

6. Acknowledgments

The author is grateful to J. Borer, C. Bovet, A. Manarin, G. Morpurgo for the suggestions and discussions which have made this work successful. J.L. Pasquet for his help.

7. References

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