BPM READ-OUT ELECTRONICS
BASED ON THE BROADBAND AM/PM NORMALISATION SCHEME

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Abstract

Recently developed circuit modules, used for the processing of position signals of electrostatic ("button"-type) pickups are presented. The concept is based on the broadband ("monopulse") AM/PM normalisation technique. The short integration time (≈ 10 ns) makes this read-out electronics suitable for single-bunch position measurements nearby interaction areas and in linear accelerators. Details on circuit design and technology, as well as the practical realization are shown. The results discussed include beam position and orbit measurements made with a set of 40 units at the FEL-undulator sections of the TESLA Test Facility (TTF) linac.

1 INTRODUCTION

Each *beam position monitor* (BPM) (Figure 1) basically consists out of a *pickup* station for the signal detection and a set of *read-out electronics* (often 2 channels for horizontal and vertical plane) for signal processing and *normalisation*.
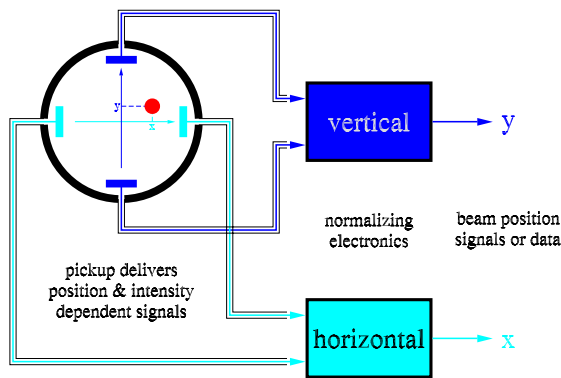

Figure 1: BPM principle.

A single electrode of a BPM pickup delivers a signal voltage

$$V_{\text{elec}}(\omega, x, y) = s(x, y) \, Z(\omega) \, I_{\text{beam}}(\omega) \qquad (1)$$

which is proportional to the beam intensity $I_{\text{beam}}(\omega)$ (e.g. bunch charge) and to the beam-to-electrode distance (x, y) (e.g. tranverse beam displacement) or coupling which is covered by a sensitivity function $s(x, y)$. In case of high energy electron accelerators the frequency spectra of $I_{\text{beam}}(\omega)$ is of no concern; for the BPM system the bunches behave like dirac impulse excitation signals. The transfer impedance $Z(\omega)$ of the pickup electrode (centred beam) depends on the type of BPM pickup (e.g. button, stripline,

cavity-BPM, etc.) and its geometry. It also fixes (roughly) the frequency range of the following signal processing system.

The BPM read-out electronics extracts the beam position (displacement) information from the analogue signals of the pickup electrodes. In order to simplify the normalisation procedure and to reduce the nonlinearities of $s(x, y)$ two symmetrically arranged electrode are sensed in each plane (see Figure 1). The read-out electronics *normalises* the electrode signals and therefore performs a beam intensity independent beam position measurement.

For each plane (horizontal or vertical) the corresponding BPM pickup electrodes supplies two signals (A and B). For symmetry reasons the *amplitude-ratio* $\hat{a}/\hat{b}$ is a beam-intensity independent function of the beam displacement:

$$\text{beam-position} = f(\frac{\hat{a}}{\hat{b}}) \qquad (2)$$

which is processed by the presented broadband AM/PM technique [1]. The read-out system outputs an analogue pulse signal, from which the flat peak value is proportional to the beam displacement. Further data acquisition techniques are required to digitise the signal for use in the control system.

2 THE AM/PM PRINCIPLE

The amplitude-ratio, and such the beam-position, is measured with the *AM/PM signal processor* by converting the ratio into a phase-difference – the *amplitude modulation* (AM) converts into a *phase modulation* (PM). Practically the conversion is realized by a 90^0 hybrid junction, which is extended at one output port with a 90^0 delay-line.

For the analysis it is sufficient to simplify the two sine-wave burst ("ringing") shaped input signals of the pickup electrodes to stationary sine-wave voltage functions v_A and v_B:

$$v_A(t) = \hat{a} \, e^{j \omega t} \qquad (3)$$

$$v_B(t) = \hat{b} \, e^{j \omega t} \qquad (4)$$

They have same frequency and are in phase, but the amplitudes $\hat{a}$ and $\hat{b}$ differ due to the beam displacement and are bunch charge dependent. At the outputs C and D of the hybrid-with-delay circuit the signals:

$$v_C(t) = \sqrt{\frac{\hat{a}^2 + \hat{b}^2}{2}} \arctan\left[\frac{\hat{a}\sin(\omega t) + \hat{b}\cos(\omega t)}{\hat{a}\cos(\omega t) - \hat{b}\sin(\omega t)}\right] \qquad (5)$$

$$v_D(t) = \sqrt{\frac{\hat{a}^2 + \hat{b}^2}{2}} \arctan\left[\frac{\hat{a}\sin(\omega t) - \hat{b}\cos(\omega t)}{\hat{a}\cos(\omega t) + \hat{b}\sin(\omega t)}\right] \qquad (6)$$

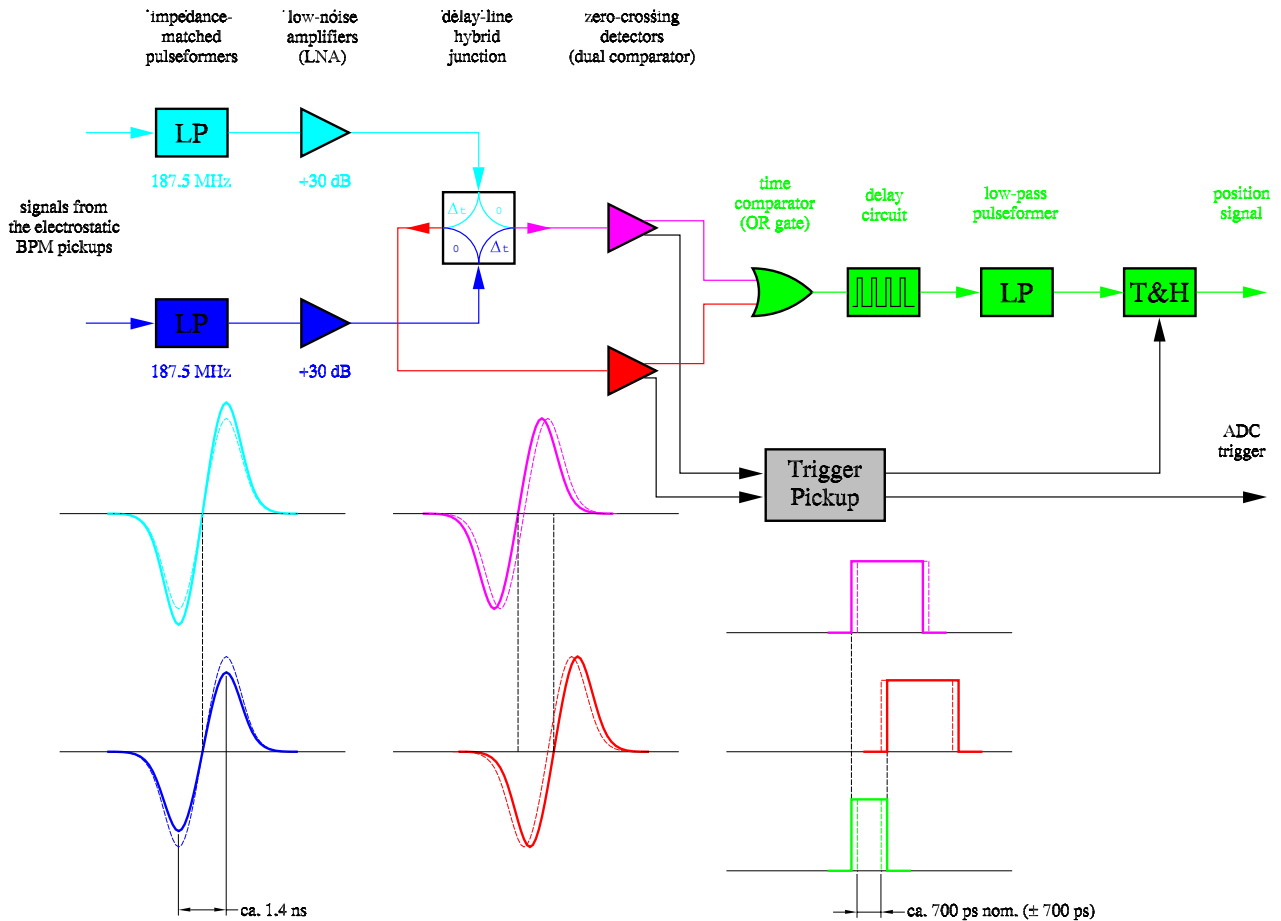[1]For an overview of normalisation schemes see [1, 2]

Figure 2: Monopulse AM/PM read-out electronics.

have the same amplitude, but the amplitude-ratio of A and B is converted into a phase-difference:

$$\Psi_{C-D} = 2 \operatorname{arccot}\left(\frac{\hat{a}}{\hat{b}}\right) \qquad (7)$$

The AM/PM BPM signal processing was introduced first in the *Tevatron* (FNAL) as narrow bandwidth system [3]. The single bunch capability was added in the installations at *LEP* (CERN) [4] and *HERA-p* (DESY) [5]. The successful operation in those large scale, high energy particle accelerators are due to some major advantages of the AM/PM BPM read-out method:

- The full beam displacement range is covered, including a large dynamic range (> 40 dB) of beam/bunch intensities, without attenuator/amplifier switching or feedback circuits.

- The AM/PM method offers a reliable beam position measurement, also at small beam displacements, when subtraction methods (e.g. Δ/Σ signal processing) may fail.

- The AM/PM BPM electronics can be devided into a few simple basic subcircuits:

passive networks, linear amplifiers, digital gate functions and analogue comparators. There is no manufactur dependence for high integrated and/or specialized semiconductor circuits.

- All the needed semiconductors and parts are available in radiation resistant (!) bipolar process technology.

3 MONOPULSE AM/PM READ-OUT ELECTRONICS

Instead of operating – time-consuming – a burst of RF sine-wave oscillations, the *monopulse* AM/PM scheme processes the beam position from a single pulse, which is the slightly "integrated" – by lowpass pulseformers – pickup signal. The technique was proposed by D. Cocq (CERN) as analogue signal processor for the LHC BPM-system [6]. It offers a couple of additional features:

- Direct processing of the button or stripline BPM pulse signals through simple lowpass pulseformers.

- Short integration (measurement) time for single bunch position measurements with little intra-bunchspacing.

- Relaxed tolerances for matching the input filters.

- Improved sensitivity for low intense bunch signals.

A set of 40 monopulse BPM units where developed for the read-out of 20 electrostatic ("button"-type) pickups, which are located inside the FEL-undulator sections of the TTF linac. The BPM electronics are realized by subdividing each BPM unit into "rf-block" modules mounted on a VXI C-size PCB. Figure 2 gives an overview on the schematics and the principle of operation.
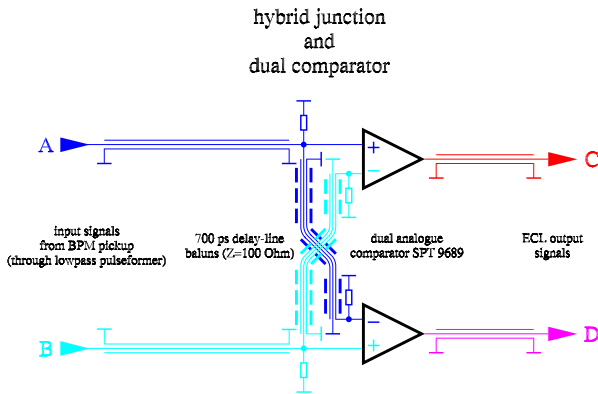

Figure 3: Monopulse AM/PM conversion circuit.

Basic part is the delay-line balun based hybrid-junction and the following pair of zero-crossing detectors (dual comparator) (see Figure 3). Here the amplitude-varying signals from the two pickup electrodes – after passing impedance-matched (absorbing) lowpass pulseformers and 30 dB low-noise amplifiers – are converted into time-varying signals. The analogue comparators act on the zero-crossings of their difference-input signals and outputs bunch charge independent digital ECL-level signals.
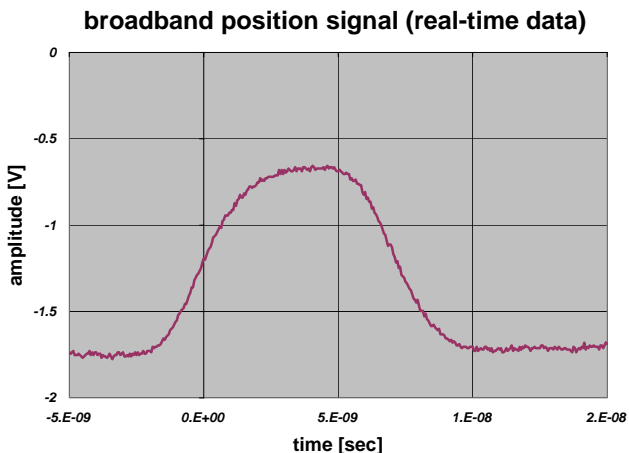

Figure 4: Processed beam position (displacement) signal.

The following time comparator (OR gate) compares both signals to a short ECL pulse (nominal width ca. 700 ps); it's width, respectively area is proportional to the beam displacement. For a simplified integration this pulse signal is "lined-up" four times by use of programmable digital delay circuits. Figure 4 shows the lowpass-integrated, ≈ 10 ns long beam position signal. For adapting to the data acqui-

sition system at TTF a high-speed track&hold amplifier is used to freeze the peak value of this displacement signal for an adequate amout of time.
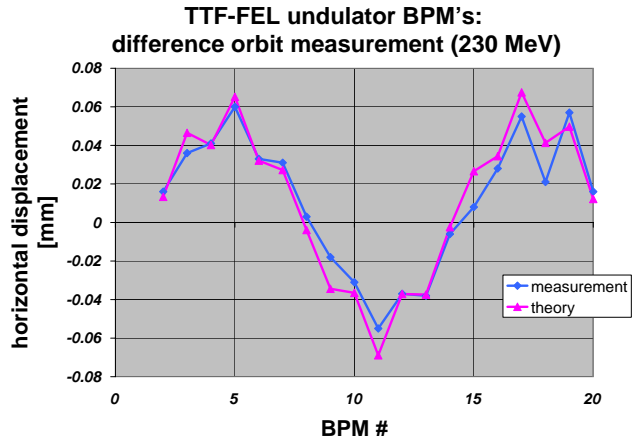

Figure 5: Orbit in the FEL-undulator sections of TTF.

The TTF FEL-undulator BPM system operates since spring 2000 (see Figure 5). With the *Onsemi* ECLinPS Plus family gates and the SPT 9689 dual comparator used in the electronics hardware a **single-bunch, single-pass resolution $< 10~\mu$m** (10 mm dia. beam pipe) was achieved, while the **integration (measurement) time keeps within ≈ 10 ns**.

Several modifications and re-developements are underway to improve the displacement range limitations (only ≈ 70 %), as well as the rather limited intensity range (5...10). The moderate linearity of the read-out electronics can be corrected by applying an automatized calibration routine to each individual BPM unit.

4 REFERENCES

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