BPM ELECTRONICS FOR THE B-FACTORY e⁻/e⁺ LINAC AT KEK

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Abstract

The Beam Position Monitors' (BPM) electronics is under development for the B-Factory injector [1]. Over 35 dB dynamic range in beam current is expected if electron, positron and machine commissioning is taken into account, with an extra ± 12 dB for position displacement measurements. Analog processing is performed at 120 MHz in a synchronous detector with an internal local oscillator. The design required a series of trades between the detector frequency, bandwidth, S/N, cost and a relatively easy electronics tuning.

Introduction

The B-Factory linac will accelerate up to 10 nC (> 6 x 10^{10} electrons) in a 10 ps electron bunch to a final energy of 8 GeV. Beam displacements will be measured by the BPM for orbit correction. Data acquisition will be made in a snap shot fashion for beam oscillation studies due to the strong wakefield effects. In parallel, screen, wire scanner and wall current monitors will be used. The beam must be kept within ±100 μm of the 10 mm radius vacuum chamber center for suitable operation of the accelerator.

System Overview

Striplines were selected due to their relative high output voltage in the low frequency range. Three monitors of an eventual total of 75 have been installed [2, 3]. The 130 mm long electrodes have four-fold symmetry in respect to the central axis, with an electrode aperture of 32 mm. The downstream electrode side is shorted to the beam pipe while the other is attached to 50 Ω SMA vacuum feedthroughs. The electrode opening angle is 40°.

The hardware consists of the following blocks: a) Front-end, b) detector and c) external A/D circuit (Fig. 1). At the front end the induced electrode signal is stretched in time by the band-pass filter (BPF) and amplified. At the detector the signal is split into the RF mixer port and the limiting amplifiers (L/A) to generate the Local Oscillator (LO). The peak value of the low-pass filtered IF is proportional to the beam charge density and beam position. This is acquired by the sample and hold and digitized for computer processing to determine the horizontal and vertical displacements.

Front-End Circuit

After transmitting the 2 ns doublet through a maximum of 45 meters of coaxial cables, a 120 MHz Gaussian type BPF with a bandwidth (BW) of 3.75 MHz stretches the signal to a 300 ns burst.

From the beam spectrum signal (Fig. 2) it was found that the maximum sensitivity was around 200 MHz, however, 120 MHz was chosen because

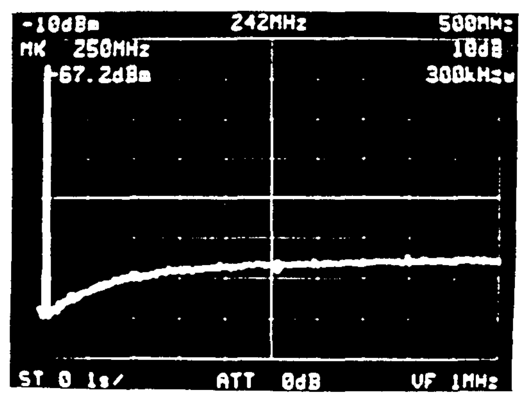

Fig. 2
Pickup frequency spectrum obtained with a 4.6 nC electron single bunch after 41 meters of 10-D coaxial cable; span 500 MHz, 10 dB/div.

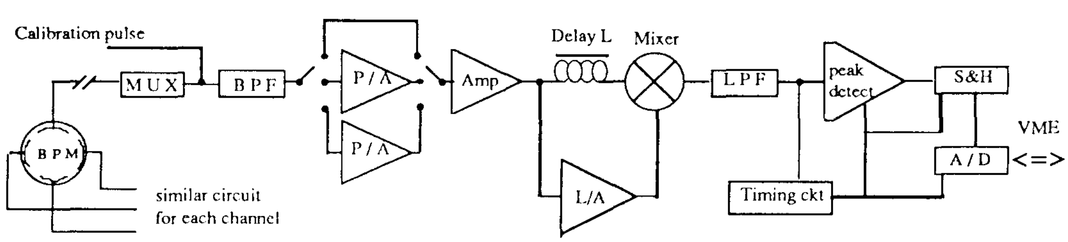

Fig. 1 BPM circuit block diagram.

the in-expensive limiting amplifiers performance is better. Lower frequencies were not possible because of the S/N which should increase with the new 200 mm long electrodes. The present limit was set by the space availability. The 3.75 MHz BW selection allows a low frequency S&H circuit.

When the BPF network is excited by an impulse it resonates at its center frequency f_o for a time which depends on its Q value ($Q = f_o/BW$). The peak voltage is given by:

$$Vp = 2(q)(Z_t)BW \tag{1}$$

where q is the beam current charge, Z_t the transfer impedance of the electrode and BW the BPF's bandwidth. Available power for the worst case is -65 dBm, which made it necessary to further reduce the noise by selecting low noise figure and narrow-band pre-amplifiers and installing a series of filters along the electronics. The amplifier input noise voltage is determined by its noise figure, and is proportional to $\sqrt{BW}$ in Hz.

For high precision, i.e. a linearity of better than 2 % over 60 dB, the input signal was divided in three with some overlapping. A remote-controlled switch selects either: the low, medium or high gain for the three linac operation modes.

Synchronous Detector

To avoid klystron modulator signals and other sources of noise, a synchronous receiver was adopted. Precautions must be taken with the mixer due to its inherent high order harmonic distortion.

The front-end electronics signal is split into the RF mixer port and the L/A stage. The two signals should arrive with a maximum phase difference of ± 3° at the mixer to get a rectified burst at the IF output with a minimum distortion. The signal, whose peak is proportional to the beam charge density and displacement, is filtered by a second-order network.

Normally signals from two opposing electrodes are added at the L/A stage input, but for circuit simplicity, easy of tuning and to assure a small phase difference with minimum effort, each electrode has been provided with its own detector. In this way, neither the electric length of the coaxial lines which connect the electrodes to the electronics, nor the BPF center frequency and BW must be trimmed to match the two channels. Normally trimming must be done in the lab initially, and again in the field after installation, requiring considerable manpower and access to the accelerator. Another benefit was that the power in the last limiter didn't have to be split, which allowed the LO power requirements to be met without driving the last limiter amplifier to high power levels with accompanying large phase shifts.

The limiter stage consists of four SL 532 C low phase shift limiters with 12 dB gain. The output is buffered by a wide band amplifier (MWA 130) followed by a LPF.

External A/D Circuit

The importance of proper pulse stretching shows up in the A/D Section. If the BPF burst is short, the electronics must be fast, which normally results in high cost, offsets and drifts. But, if it is too long, the amplitude is small, leading to noise problems.

The output signal of the previous section i.e. the filtered IF signal is split, one part is fed into an RF peak detector and the other to a voltage comparator (shown as timing circuit in Fig. 1). Normally a S&H is used instead of the peak detector, but the hold trigger pulse in this circuit suffers from jitter because its origin depends on the signal amplitude. With the mentioned circuit the jitter is unimportant up to a certain point. Since the peak detector was constructed with a low capacitance to follow quick changes, the droop is high and a slow acquisition S&H was necessary. A buffer amplifies and transmits the signal to the A/D converter.

In addition to the hold trigger, the A/D commands are derived from the comparator. To remove the electronics offset, pedestal levels are measured in advance by means of the general linac trigger.

The 12 bit charge A/D [4] located in another module, communicates via VME bus with the host computer. Horizontal and vertical beam displacements (x,y) are calculated [2] from two facing electrodes by the ratio Δ/Σ (eq. 2), (Fig. 2)

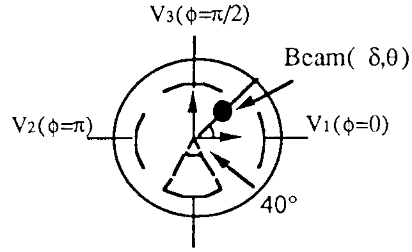

Fig. 2 BPM cross section

$$x = S_b \frac{V_1 - V_2}{V_1 + V_2}, \quad y = S_b \frac{V_3 - V_4}{V_3 + V_4}, \tag{2}$$

where S_b is the position sensitivity determined by the mechanical arrangement of the electrodes.

The 8 channels of the A/D allow measurements from two monitors per module.

Circuit Performance

The circuit has a dynamic range of 61 dB, which has been divided into three, each having a range of 34 dB with a linearity of 2 % for beam displacement measurements of 100 μm. Fig. 4 shows two signals: a) the BPF output when excited by a test pulse equivalent to a single bunch of 4.6 nC and b) the output of the mixer's LPF with the same input conditions. Noise level was very low, the minimum detected input signal at the test bench was - 84 dBm. Thus it is expected that the resolution will remain even during machine commissioning. Further testing is necessary to determine long-term stabilization capabilities. It is foreseen that the new electrodes and electronics will be tested during the next run.

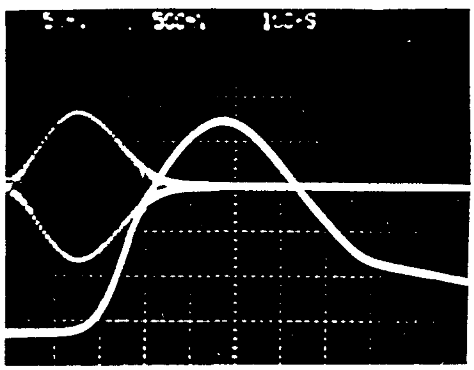

Fig. 4
Filtered detector output v.s. BPF output
500 mV/div., 50 mV/div., 100 ns/div.

Conclusions

A BPM prototype has been tested with beam. The 120 MHz selection allows the usage of in-expensive low phase limiters while the 3.75 MHz BPF's BW provides enough stretching to use a low frequency peak detector circuit. By using one detector for one electrode, no cable length nor filter match between channels is required. The circuit is working within the expected dynamic range and linearity. A 200 mm stripline, rather than the present 130 mm line, is foreseen to enhance the S/N at the detectors frequency.

Acknowledgments

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