Strip-Line BPM for ATF

H. Hayano and T. Naito
National Laboratory for High Energy Physics
Oho 1-1, Tsukuba, Ibaraki 305 Japan

Abstract

The beam position monitor (BPM) for the accelerator test facility (ATF) is designed to have less than 40μm precision. The BPM employs a strip line type pickup and an one-shot conversion electronics. This system is an extension of SLAC's, especially of FFTB BPM's. The system design and the development status of the prototype BPM are described.

1. Introduction

The ATF is the test beam facility to realize several future technologies of linear accelerator, damping ring and final focus system for the Japan Linear Collider. The BPM is required to have several μm resolution and repeatability within 500μm from center during optics tuning operation at the both of $2\text{x}10^{10}$ single bunch beam intensity and $2\text{x}10^{10}$ of 20 multi-bunch. This BPM will be used for S-band LINAC, beam transport, damping ring and so on. The system, which is an extension of SLAC FFTB's, is designed to meet the requirement for multi-bunch beam and to use it everywhere in the ATF.

2. Strip Line Monitor

Strip lines were selected as a pickup for their enhanced low frequency response. Since the low frequency components in the signal are almost proportional to the strip line length, a longer strip line provides a better signal to noise ratio. In this application the strip line length was determined as shorter as possible to get compactness and applicability everywhere in the ATF. After some compromise with electronics speed, 80mm was chosen for its length. One end of the strips is shorted to the chamber wall. Figure 1 shows a cross section and side view of the monitor. The vacuum chamber is made by stainless steel. The aperture was determined to have a beam stay clearance greater than the aperture of S-band accelerator structure. The electrode transverse dimensions were determined with the code "POISSON" to present a 50Ω characteristic impedance and to have large stereo-angle for large signal within maintaining 50Ω.

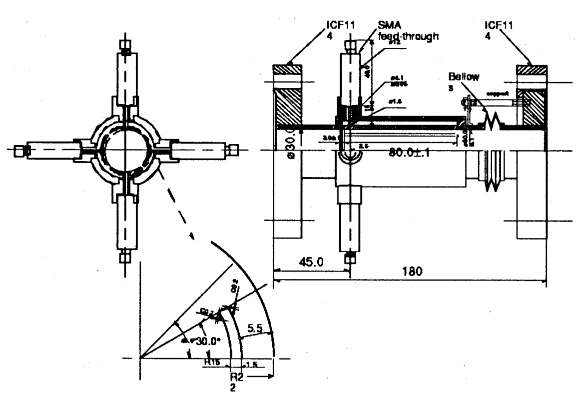

Figure 1. *Transverse cross section of the ATF BPM pickup.*

3. Signal Processing Scheme

The strip line signal consists of two pulses of opposite polarities. Each pulse has the shape of the beam bunch. The pulses are 0.5ns apart which corresponds to twice the length of the strip line. Since the bunch length is a few millimeter, the induced pulse width on the strip line will be 10 picoseconds or so. We can treat them as impulses since the electronics works in the low frequency region, and since the high frequency components are eliminated by long coaxial cables and low pass filters in the electronics. The expected signal wave form is calculated by an approximation formula[1] which estimates an impulse response for long dispersive cables. The impulse areas are estimated using the charge in the bunch and the beam coupling coefficient to the pickup electrode. A geometrical coupling coefficient 0.167 is used. Figure 2 shows an example of the expected signal at the front of the electronics and stretched output.

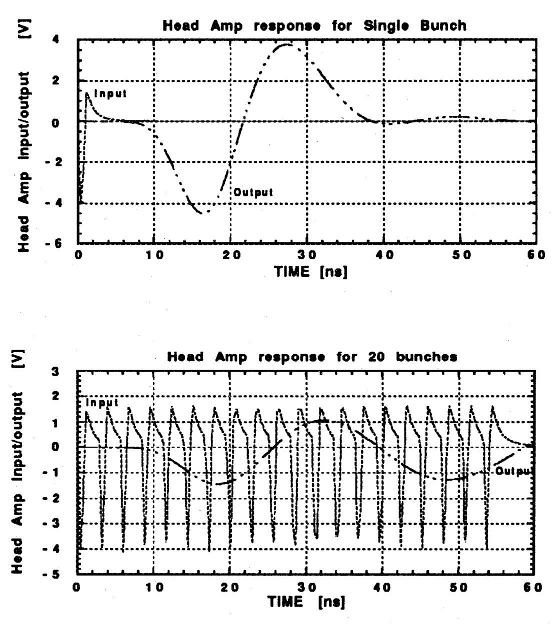

Figure 2. *Expected wave form at the front of electronics and the output for single bunch and 20 bunch train.($2\text{x}10^{10}$ 50m RG-223/u)*

Four RG-223/u coaxial cables will be used in one BPM for the signal transmission from the strip line

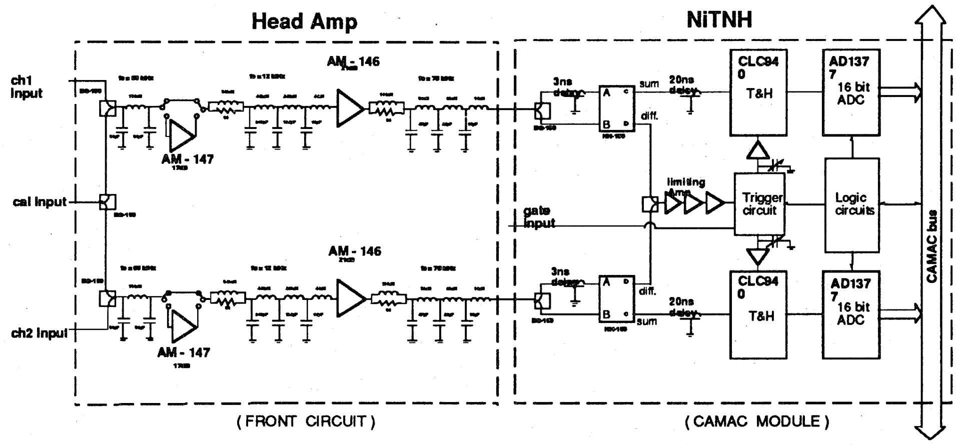

Figure 3 Block diagram of the BPM electronics.

pickups to the electronics front end. The four cables will have identical lengths matched to within 100ps. Unit lengths vary from 30m to 80m depending on the distances from the electronics hut. Since the electronics works at about 50MHz, signal reduction by the coaxial cables is expected to be -3.2dB to -8.8dB at that frequency.

The processing electronics is derived from the SLC FFTB electronics which has two identical channels for two pickups and detects signals by Track&Hold (T&H) circuits. The electronics for two pickups consists of a pulse stretcher amplifier (called Head Amp), T&H and digitization (NiTNH) and a pulse generator for electronics calibration (TPG). The signals through the long cables are fed into the Head Amp, then amplified and stretched by gaussian lowpass filters to get wider pulses with good signal to noise ratio (S/N) which are acceptable for the T&H circuit. The output of the Head Amps are connected to the input of the NiTNH by matched RG-223/u cables. Inside the NiTNH, the trigger signal is generated from its input by creating a difference between itself and its 3ns delay. Its circuits work like a coupler, though the derived signal is like a differentiated one and its 0-cross point does not move with signal amplitude. This trigger generation is derived from the stretched pulse and presents the advantage of being less sensitive to the Head Amp input wave form. Because of this stretching effect, we do not need to pay much attention to the calibration pulser wave form. The main signals come out of the coupler are delayed to compensate for the delay of the trigger generation circuit. The signals are tracked and held at their first extreme by the self-generated trigger. After holding, they are digitized by 16-bit ADCs and latched until the read operation is completed. To remove the electronics offset, pedestal levels are measured in advance during calibration and subtracted from the readings.

A beam position will be calculated by

$$X = k * \frac{V2 - Gx*V4}{V2 + Gx*V4}$$

$$Y = k * \frac{V1 - Gy*V3}{V1 + Gy*V3}$$

where k is geometrical coefficient and Gx and Gy are the gain ratios V2c/V4c and V1c/V3c respectively between two channels, which are obtained by calibration in advance. Since the electronics is adjusted to have a very flat gain ratio with the amplitude, the gain ratios are taken as a constant or a linear function of the amplitude summation (V2+V4 or V1+V3). These calculated positions X and Y are the first order approximation only.

4. Design of the Electronics

The design of the electronics for high resolution and high precision is made for both Head Amp and NiTNH. For high resolution, the thermal noise in the signal had to be reduced. For high precision, the electronics was required to have good linearity within a dynamic range for off-centered beam signals. Figure 3 shows the block diagram of the electronics. The design effort was made on the following items.

4.1. Noise reduction

The thermal noise voltage e_n is expressed by

$$e_n = \sqrt{4kTBR}$$

produced by the resistor R. Normally we are working with 50Ω impedance at room temperature and the bandwidth B is the only parameter we can control. Since the amplitude of the signal pulse is proportional to the square of bandwidth in the case of low-pass filter, the signal to noise ratio (S/N) is proportional to $B\sqrt{B}$. Though wider bandwidth is better for high S/N, the bandwidth is limited by the Track&Hold slew rate and the acquisition speed to get enough accuracy for holding of largest pulses. The 25 MHz bandwidth which stretches the 0.5ns input pulse to a 10ns pulse is used on account of the Track&Hold speed.

Since the Track&Hold IC has a bandwidth of about 150MHz to track fast signals, it in itself has much thermal noise. However its contribution to the S/N is decreased by the gain of the Head Amp. To realize around 1μm resolution, the S/N should be over around 4000. A wide band amplifier and low pass filter scheme is adopted for larger signal gain and less noise. In this scheme, the signal is amplified over the frequency range of the filter cutoff and the noise is eliminated outside the band width of the filter. In this application to the ATF, we have to treat both of multi-bunch and single bunch. They have a very different enhancement of low frequency components.

The enhancement of multi-bunch beam is comes from the frequency components of the train width. The elimination of the amplifier gain is required for that. We estimated required gain, NF and output power for the amplifier using "PSpice" program. The selected models are Anzac AM-147 and AM-146 respectively. The low pass filters have gaussian responses in order to get a flat crest for accurate holding. The AM-147 is skipped for the multi-bunch case.

4.2. Linearity

Even if pickup signals are not linear with the beam position, there is an advantage to pick up signals by linear electronics for further higher order corrections. The 1μm detection precision of relative beam movement within 500μm from center is required for optics tuning. From this requirement, we find by numerical estimation that the electronics needs less than 0.024%/dB slope of non-linearity over a 1.45dB range. This good linearity region should be matched to the signal level of a centered beam of 2×10^{10} single bunch and for multi-bunch. This signal level should apart from the amplitude of ADC saturation, because the signal level will run around with beam position movements.

The main non-linearity components come from saturation and distortion of the amplifiers in the Head Amp, and the T&H trigger slewing with input amplitude.

Since the RF amplifiers we found have 'lossless feedback' based on a directional coupler feedback circuit which provides a lower noise figure and a higher linear output, they have relatively poor reverse isolation. To avoid distortion caused by output impedance miss-match, we adopted matching inductances just before the gaussian low pass filters. For the first stage amplifiers, the low pass filters are placed in the input to eliminate unwanted high frequency components which will cause distortions. Since it was difficult to meet both low NF and high output power, we compromised to the low NF side for a compact and low power consuming Head Amp. So there is saturation in the high output region which comes from the first stage AM-147 amplifier.

When the trigger slews with its amplitude, the T&H holds the signal away from the crest and loses linearity because the crest is not flat enough. To easily achieve the above requirements, we have to adjust the trigger timing to cross the signal crest just at 2×10^{10} for a centered beam signal. In that case the allowable slewing will be less than 74ps/dB, and it is easily attainable.

4.3. Position offset by the electronics

The contribution of the electronics to beam position offset comes from an electronics offset and a gain difference between the four channels. The electronics offset is corrected by subtracting the pedestal level. The gain difference is also corrected by using gain ratio functions which are measured by using the calibration pulser fed into the calibration port of the Head Amp. The gain ratio measurements are done by changing the amplitude of the signal for the entire ADC dynamic range, and the correction functions are obtained by a linear fit as a function of summation of two ADC readings. This correction function should be flat except non-similarity of channels caused from saturation and distortion. The non-flat gain ratio of the correction function expresses a different non-linearity for each channel and will produce an error for the correction in the case of an off-centered beam.

To flatten a gain ratio, it is important to make the circuit identical for each channel and to adjust the signal propagation delay difference which mainly comes from delay lines and filters, and results in the T&H trigger slewing and its sweeping over the signal crest. For this purpose the NiTNH has an independently adjustable trigger for each channel with the same slewing. In order to retain exchangeability of the Head Amp, we should adjust the propagation delay difference for the Head Amp itself. The required adjustment accuracy depends on the magnitude of trigger slewing, and is around 5ps for 1μm offset.

5. Development Status of the Electronics

We now have a proto-type stripline pickup, a Head Amp and a NiTNH. The test stand using moving wire with 0.1μm positioning repeatability has been completed to build. However a Test Pulse Generator of CAMAC module is under designing stage, we can use HP8131A pulse generator as a calibration source and high voltage pulse generator for a grid pulser as a simulated beam on a wire. The first trial to make the electronics work as a BPM system is now under going. We found several problems in the self-trigger generation part of NiTNH. The main problem is a noise come from outside. It causes miss-trigger problem at the comparators and trigger jitters problem which affects directly on the resolution. Though we used a four layer printed circuit board for a good ground plane, we have to make further shield for the limiting amplifier stage which has 400MHz band width and also for comparator ECLs. We will report the detailed trails at the conference.

Acknowledgements

The authors would like to thank J.-L. Pellegrin, S. Smith and S. Williams for their detailed discussion and support for BPM electronics work for the FFTB project at SLAC.

References

[1] R. L. Wigington, N. S. Nahan, "Transient Analysis of Coaxial Cables Considering Skin Effect", Proc. IRE 45, pp. 166-174, February 1957.

[2] H. Hayano, J.-L. Pellegrin, S. Smith and S. Williams "High Resolution BPM for FFTB", submitted to N.I.M. 1992.