# Technical Systems Configurations -- Electrical

Subsystem: Instrumentation – Multi-Bunch Beam Position Monitors (MBBPM)
Author: S.R.Smith
Revision: 0.0
Date: April 3, 2001

Multi-bunch BPMs measure the beam position of each bunch in a train of up to 190 bunches. They are employed in the diagnostic regions of the linac to establish a program for fast kickers which straighten out the bunch train. This compensates for transverse wakefield kicks. Emphasis is on high bandwidth and bunch-to-bunch precision. Stability and precision of centering is of secondary importance.

1. Requirements:

| **Parameter** | **Value** | **Conditions & Comments** |
|---|---|---|
| Resolution | 300 nm rms<br>@ 0.6 x $10^{10}$ $e^-$ / bunch | for bunch-bunch displacement frequencies below 300 MHz |
| Bandwidth | 200 MHz | 3 dB |
| Resolution vs. Charge | Resolution proportional to 1/Q | Below 0.6 x $10^{10}$ $e^-$ / bunch |
| Position Range | ±2 mm | |
| Bunch spacing | 2.8 ns or 1.4 ns | |
| Number of Bunches | 1 – 95<br>1 - 190 | @ 2.8 ns<br>@ 1.4 ns |
| Beam current dynamic range | $1\times10^9$ to $1.4 \times 10^{10}$ | Particles / bunch |
| Linearity | 1% over 1mm offset<br>10% from 1 mm to 2 mm | |
| Accuracy | 100 microns | rms |
| Stability | 5 microns<br>20 microns | Over 24 hours<br>Over 3 months |
| Number of BPMs | 278 | |
| Distortion | 200 nm rms | See conditions below |

Table 1. MBBPM Requirements.

The most critical requirement is that an incoming straight bunch train appear to be straight to an accuracy of 200 nm rms in the following conditions: for a 270 ns long bunch train of nominal bunch charge within 0.5 mm of center, having bunch-to-bunch charge variation not exceeding 5%, and the head-to-tail charge slewing not exceeding 0.5%. That is the MB BPM should not cause feedback to significantly mess up a straight bunch train.

2. Technical Description

## 2.1. Transducers

Stripline pickup elements will be used. Possible parameters are shown in Table 2. Striplines are to have 50 Ohms impedance. The length, 100 mm, puts the peak of the frequency response of the stripline near 714 MHz, the bunch-spacing frequency. The transverse size is not critical; resolution is improved by smaller radii, but halo interception is worse close in. Angular coverage is also not critical, as long as there is sufficient signal to achieve the 300 nm resolution requirement.

| Parameter | Value | Conditions |
|---|---|---|
| Length | 100 mm | 0.7 ns round trip time |
| Stripline Impedance | 50 Ohms | |
| Radius from beam CL | 6 mm | |
| Beam pipe radius | 10 mm | |
| Angular coverage | 7% | $\phi/2\pi$ per strip |
| Beam Coupling ($Z/2\cdot\phi/2\pi$) | 1.75 $\Omega$ | ?*Vdt* over stripline impulse per unit charge |

Table 2. Multi-bunch BPM stripline pickup parameters.

### 2.2. Electronics

An RF hybrid forms sum and difference signals in a 350 MHz bandwidth around 714 MHz. Sum and difference signals are bandpass-filtered and digitized. The bandpass filters suppress frequencies which would be aliased by the digitizer. The difference channel may have higher gain than the sum channel to improve resolution at the cost of some loss of transverse dynamic range. Digitization may be direct, using a very high speed digitizer, or indirect, where the waveform is stored in analog memory at full speed and played back and digitized at lower speed in a lower-speed digitizer. Down conversion, matched filtering, and deconvolution of bunch-by-bunch position from the bunch-train response is to be done digitally. Calibration is provided two ways, by introducing tones into the front end of the electronics, and by recording the response of the system to single bunches of beam. The tone calibration establishes the BPM centering, while the single bunch waveform provides the kernel used to deconvolute the position of each bunch from the composite waveform. Electronics will be located in Tunnel Electronics enclosures (TEE's) recessed into the tunnel walls.

| Parameter | Value | Comments |
|---|---|---|
| Processing Frequency | 714 MHz | Center frequency |
| Analog bandwidth | 350 MHz | Full width |
| Required resolution | 200 nm | rms |
| Amplitude Resolution | 13 bits | Effective bits @ 200 MHz |
| Difference/Sum Gain Ratio | 8 | |
| Digitizer Resolution | 10 bits | Eff. bits after differencing |
| Required resolution | 200 nm | rms |
| Noise Figure Budget | 19 dB | Over thermal noise |

Table 3. Multi-bunch BPM Processor parameters.

## 3. Technical Issues

### 3.1. Bandwidth.

High bandwidth for a BPM usually means > 10 kHz at a storage ring, or > 20 MHz at a linac, so the 200 MHz bandwidth required here is beyond the current state-of-the art.

### 3.2. Resolution.

Amplitudes must be compared to a resolution of $10^{-4}$ in a 200 MHz bandwidth. The differential gain on the difference channel with respect to the sum channel reduces the required amplitude resolution by p;ossibly a factor of eight.

### 3.3. Bunch-Train Reconstruction Artifacts.

Reconstruction of bunch-by-bunch position from a bunch train waveform has not been done. We are currently trying to demonstrate this with data taken at the ATF at KEK.

### 3.4. Digitization.

Digitization remains an issue. Currently fast, high resolution ADC's aren't quite suitable. Extrapolation of recent trends in speed and resolution vs. time suggests that this will not remain a barrier to implementation of a fast ADC-based system, but such improvements are not guaranteed, especially since we don't know what the communications markets will demand. Analog sampling chips are not currently up to the job, either. Here we are prototyping a custom chip to see if we can push this technology sufficiently.

### 3.5. Algorithm Verification.

We are currently working with the ATF at KEK to verify that our preferred bunch-by-bunch reconstruction algorithm can do the job with real accelerator data. Results are not yet conclusive.

### 3.6. Radiation Hardness.

Radiation hardness of these electronics is desirable, but since this is a relatively small system, we can afford to run cables to a shielded enclosure.

## 4. Discussion of Configuration Choices

High bandwidth at high resolution leads us to stripline pickups, since striplines can have very high beam coupling with inherently wide bandwidth. Differencing at the front-end is probably required to achieve the required resolution.

## 5. References

5.1. Stephen R. Smith, *NLC Beam Position Monitors*, NLC Collaboration Meeting, Fermilab, May 31, 2000.

5.2. Stephen R. Smith, *NLC Beam position Monitors*, NLC Accelerator Physics Meeting, http://www-project.slac.stanford.edu:80/lc/local/notes/bpm/NLCaccphysFeb1501.pdf, Feb. 15, 2001.

5.3. Peter Tenebaum, *Spectral Content of the NLC Bunch Train due to Long Range Wakefields*, LCC-Note-0015, May 1999, http://www-project.slac.stanford.edu/lc/ilc/TechNotes/lccnotes/PDF/mbbpm.pdf.