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DESIGN OF A MULTI-BUNCH BPM FOR THE NEXT LINEAR COLLIDER[1]

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Abstract

The Next Linear Collider (NLC) design requires precise control of colliding trains of high-intensity ($1.4x10^{10}$ particles/bunch) and low-emittance beams. High-resolution multi-bunch beam position monitors (BPMs) are required to ensure uniformity across the bunch trains with bunch spacing of 1.4ns. A high bandwidth (~350 MHz) multi-bunch BPM has been designed based on a custom-made stripline sum and difference hybrid on a Teflon-based material. High bandwidth RF couplers were included to allow injection of a calibration tone. Three prototype BPMs were fabricated at SLAC and tested in the Accelerator Test Facility at KEK and in the PEP-II ring at SLAC. Tone calibration data and single-bunch and multi-bunch beam data were taken with high-speed (5Gsa/s) digitisers. Offline analysis determined the deconvolution of individual bunches in the multi-bunch mode by using the measured single bunch response. The results of these measurements are presented in this paper.

1. OVERVIEW

The multi-bunch (MB) BPMs were designed to operate over a wide range of conditions (Table 1) allowing for testing to be performed at SLAC and KEK. The MB BPMs are used by the sub-train feedback, which applies a shaped pulse to a set of stripline kickers to straighten out a bunch train. These are qualitatively different from the quad (Q) and feedback (FB) BPMs due to their high bandwidth and relatively relaxed stability requirements. The primary requirement on the MB BPMs is a bunch train that generates a BPM signal, which is straight.

Table 1: BPM Specifications

Parameters	Value	Comments
Resolution	300 nm rms at $0.6x10^{10}$ e^- /bunch	For bunch-bunch displacements freq. Below 300 MHz
Position range	±2mm	
Bunch spacing	2.8 or 1.4 ns	
No. of bunches	1-95 1-190	2.8ns 1.4ns
Beam current	$1 x10^9$ $1.4x x10^{10}$	Particles per bunch
No. of BPMs	278	

2. IMPLEMENTATION

Figure 1 shows a simplified block diagram of the multi-bunch front-end chassis. The BPM chassis contains directional couplers, non-reflective switches for transfer function measurements, sum and difference hybrid, bandpass filters for noise rejection, and sold-state amplifies. The BPM chassis takes the two x or y inputs from the BPM buttons and takes the sum and difference. The BPM signal is then amplified in order to run it on a long cable to a digitiser outside the radiation area. The front-end has a feature where a single tone can be injected into the inputs of the sum and difference hybrid for calibration. Thus allowing the operators to perform a transfer function.

Figure 1 Block diagram of the BPM front-electronics

To obtain the bandwidth and performance requirements, several custom components were designed at SLAC. The first component is the heart of the front-end chassis, a stripline 5/4λ sum and difference hybrid illustrated in figure 2. The hybrid operates at 600MHz with a 300MHz bandwidth. The phase variation at the output across the bandwidth is ±5 degrees.

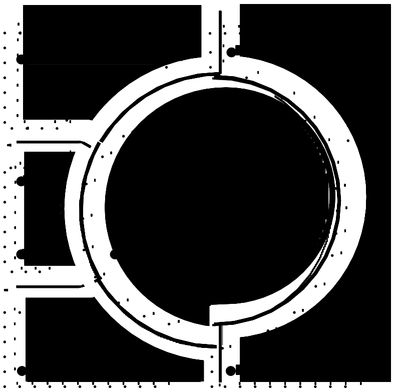

Figure 2 Stripline 5/4λ Hybrid

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The next custom component is a four-tap directional coupler that is shown in figure 3 and allows one to inject a single tone into the Hybrid and perform a transfer function calibration. The four-tap configuration allows the bandwidth to be stretched. This has the affect of a constant coupling ratio across the frequency band. This allows one to remove the phase variation in the hybrid and cable losses and insertion losses of other components. Also the calibration will allow one to remove any non-linearities in the digitiser that will be discussed later in the paper.

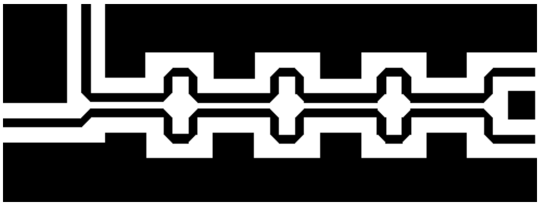

Figure 3 Stripline directional coupler

Other RF custom components such as amplifiers and switches were bought from manufactures and then integrated into a circuit board. Special care was taken to lower insertion losses by using low-loss dielectric materials.

The digitiser that was chosen for this experiment is a Tektronix 684. Analysis Tektronix 3054, which uses the same type of digitiser as the Tektronix 684, shows a phase noise problem with the digitiser. Figure 4 shows the baseband frequency spectrum of a Tektronix 3054 compared to an HP (Agilent) infinium scope. The figure illustrates that the Tektronix scope digitiser is dominated by low frequency in-band spurious noise while the Agilent infinium scope is dominated by noise at 284MHz.

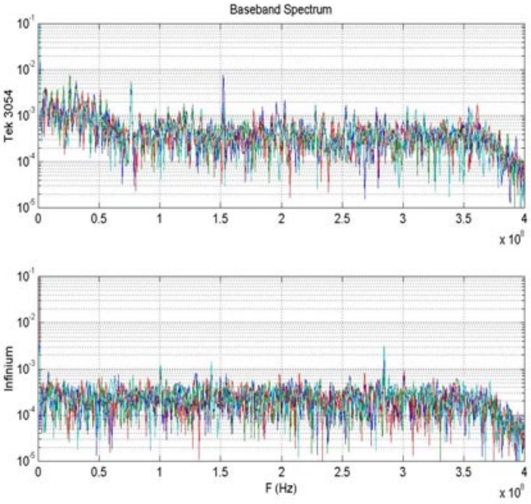

Figure 4. Baseband Frequency spectrum

This phase noise problem with the Tektronix scope will affect the resolution on the BPM as shown in Table 2. However, there is a significant cost differential between the Agilent and Tektronix scopes thus the Tektronix 684 was chosen for this test.

Table 2: BPM Digitisers Resolution Specifications

Bandwidth	50-MHz	100-MHz
HP (Agilent)	14µm 7.5 effective bits	10µm 8 effective bits
Tektronix	15µm 7.3 effective bits	12µm 7.7effective bits

3. RESULTS

Three Y-position BPMs chassis were installed in the KEK Accelerator Test Facility (ATF). The toroid current was recorded with each data set. The data presented in this paper is with toroid current of 1e^9 particles per bunch. Figure 5 shows the results of a frequency spectrum of a single-bunch beam stimulus.

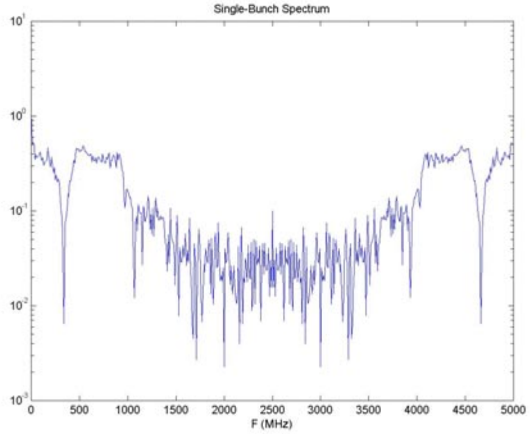

Figure 5. Frequency spectrum of a single bunch beam

Because the single bunch beam calibration data was digitised at separate times a phase error was injected into the signals illustrated in Figure 6. This phase error was corrected by writing a MATLAB script that ensured the digitisers started digitising at the same time.

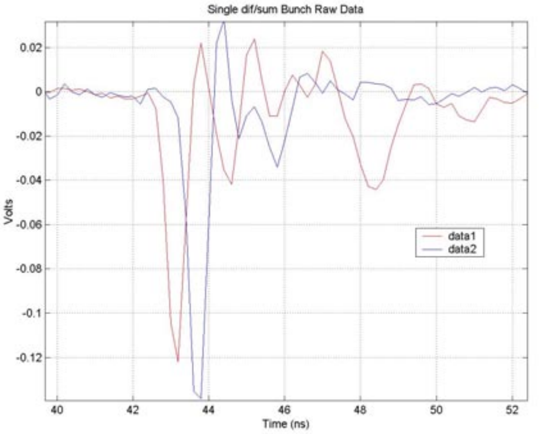

Figure 6. Single bunch raw beam data

The single bunch data was corrected using the tone calibration data that was taken at 600 MHz, which is the center frequency of the hybrid and RF coupler. Using the corrected single bunch data, an inverse matrix was generated that was used to correct the multi-bunch data.

The multi-bunch raw data is shown in Figure 7. In this figure, both the sum and difference signals are displayed. Examination of this data determined that there eighteen bunches in the accelerator. This figure shows that the difference signal comes before the sum signal. This delay can be removed with a MATLAB script.

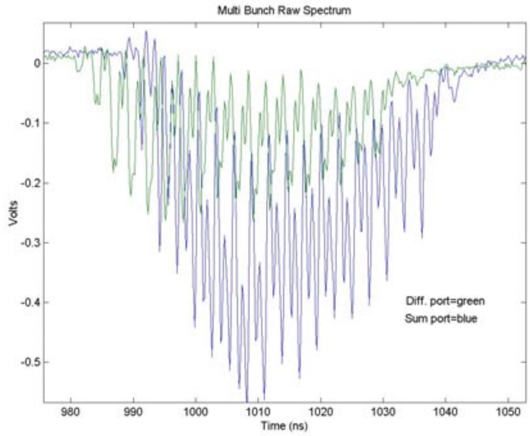

Figure 7. Multi-bunch raw beam data

Figure 8 shows the corrected multi-bunch data down-converted to baseband and low-pass filtered. The data illustrates that the same BPM has the same signal over seven turns of data. However, the data shows that there is only –15dB of isolation between the sum and difference ports. The RF simulations of the hybrid design predicted more than 20 dB of isolation over the bandwidth of the device.

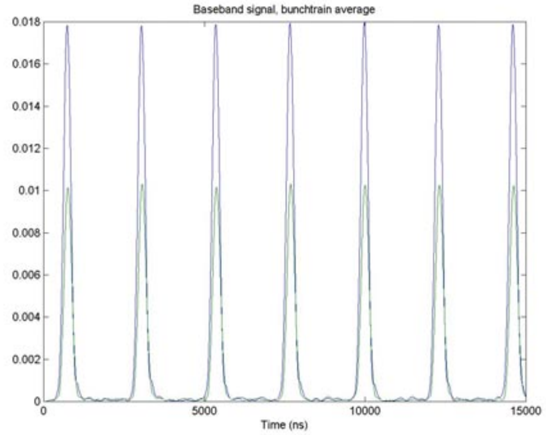

Figure 8. Multi-bunch baseband corrected beam train data

By sampling the maximum signal on the sum and difference ports, the position of the beam as a function of turns can be calculated. The equation for the Y-position is defined as:

$Y=R/2(\Delta/\Sigma)$ where,
R is the radius of the beam pipe,
$R/2=6000$microns
Δ is the difference signal from the BPM chassis,
Σ is the sum signal from the BPM chassis.

Figure 9 shows that the beam position varies 40 microns over seven turns. This is just one BPM however; all three BPMs have the same position resolution.

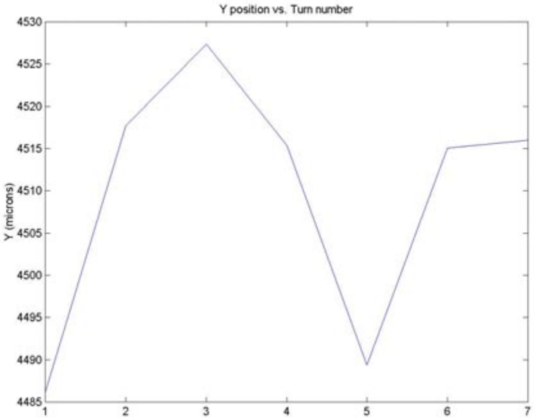

Figure 9. Multi-bunch Y-position over seven turns data

4. SUMMARY

A multi-bunch BPM was built at SLAC and tested at KEK. The BPM electronics can resolve both single and multi-bunch fills. The data clearly indicates that the multi-bunch BPM electronics can measure the beam to within 40 microns. However, the design goal of measuring the beam position within 1 micron was not achieved. The goals were not accomplished due to possible problems in the hybrid that had isolation between the sum and difference ports of –15dB. The timing jitters in the digitiser lead to the larger position resolution. When performing the tone calibration, we discovered that a single shot recording was needed to align the data. Because the tone calibration was done at SLAC, the data was taken at KEK did not use this recording technique.

Currently, a modified Y-position BPM chassis is being installed in PEP-II. Once this BPM is fully installed measurements will be taken to determine if the methodology used to gather data at KEK was flawed or the hardware needs to be improved.

Another solution to solve this problem of position resolution is to use a higher frequency 1428MHz and perform hardware downconversion thus operating at an IF frequency of 200-MHz. The advantage of this solution is a better signal to noise ratio, smaller components, and less sensitivity to phase noise in the digitisers.