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Tevatron Closed Orbit Beam Position Measurements in Short Gate Mode

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Abstract

This note presents some thoughts on how to do closed orbit measurements using the short gate mode of the new Tevatron BPMs. For all of the methods discussed, problems are identified and candidate solutions are presented. The open questions about these candidate solutions are summarized at the end of the document.

1 Introduction

Beams-doc-1124 and Beams-doc-1134 show a proof of principle for a single turn position measurement using the short gate mode of the new Tevatron BPMs; this is also known as Plan B mode. For a single measurement on two bunches, with a gate of about 800 ns, it gave a proton resolution of about 11 microns and a Pbar resolution in the range of 20 to 40 microns.

The question now arises how to perform a closed orbit measurement. There are two families of solutions to the problem:

- The Echotek board produces a series of single turn short gate measurements for some number of consecutive turns. This series of measurements is then averaged to give the result.
- Echotek card is programmed to make a single measurement covering many turns but the filters are programmed to zero all data except that acquired within short gate during each turn.

The first family of solutions has the advantage that the first part has already been demonstrated; all that remains is to do the averaging. The second family of solutions has the advantage of elegance but it is not yet known if the Echotek board has the flexibility to be programmed as required.

2 Problems with the First Family of Solutions

Quite to my surprise, I realized that doing the averaging for the first family of solutions may turn out to be difficult! There are two ways to do the averaging,

4 channels per BPM
4 bytes (2 16 bit words) per channel
47,700 turns per second
10 BPMs per backplane
Total: 7.6 Mbytes/s on the backplane

Table 1: Estimate of backplane bandwidth required to move one (I,Q) pair per channel per turn to the front end computer. The estimate does not include other traffic or control overheads.

taking the vector sum of (I,Q) pairs or the scalar sum of the magnitude of (I,Q) pairs. Both have their problems.

2.1 Scalar Sum

In this mode, some hardware or software has to compute compute $\sqrt{I^2+Q^2}$ for each turn. It is not known if the FPGA which we have ordered has hardware to multiply. It is also not known if the FPGA has enough spare real estate to implement a software multiply and software square root.

If the computation cannot be done on the Echotek board, then we need to transfer one (I,Q) pair per channel per turn to the front end computer. We need to understand if we have the backplane bandwidth to do this. My estimate of the required bandwidth is given in Table 1 and the bottom line is 7.6 Mbytes/s of data, not including control signals and other traffic. This would be reduced if the background closed orbit measuremetns did not sample every turn. This option would also imply new work for the code which runs on the front ends.

2.2 Vector Sum

In this mode, the Echotek board has to compute the sum of I and the sum of Q, summed over all of the individual turns in the closed orbit measurement. This is easily done, either on the FPGA or, possibly, on the Grey chip itself. The sums are sent to the front end computer at the end of each closed orbit measurement. Therefore there is no backplane bandwidth issue.

The problem with this solution lies in the five-fold phase instability that arises because the harmonic number of the Tevatron, 1113, is not even divisible by 5. Figure 1a) shows the vectors in (I, Q) space which correspond to 5 consecutive measurements of the signal on a BPM cable. Part b) shows the vector sum of these 5 measurements. The magnitude of the final sum vector is 1.8, in units in which each measurement has a length of 1. For comparison if one added magnitudes or removed the phase instability, the length of the sum would be 5, in the same units.

I have not yet computed how badly this loss of information degrades the position resolution. This should only be a problem for measurements which are limited by the number of bits in the digitizer.

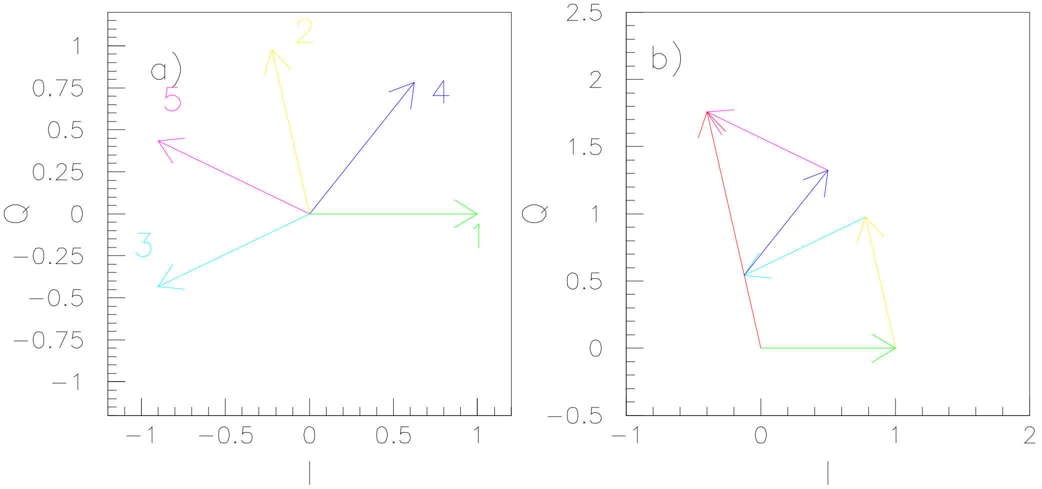

Figure 1: Part a) shows a cartoon in (I, Q) space of 5 consecutive measurements in the short gate, single turn mode. All measurements have the same magnitude but their phases differ by $2\pi/7$. The numbers indicate the order in which the measurements were taken. Only 5 of the 7 possible phases are present because the digitizing clock comes back into phase with the RF frequency every 5 turns. The red line in part b) shows the vector sum of these 5 consecutive measurements. The other lines in part b) show the intermediate steps in the sum.

3 Solution by Redefinition

Another possible solution to this problem is to define it out of existence. Can we decide that closed orbit measurements will only ever be made in long gate mode? Who would make such a decision? In any case, it is premature to recommend this decision at this time.

4 A Wild Solution: Changing the Sampling Frequency

At present the digitizing clock is designed to run at 7/5 $f_{RF} = 74.3$ MHz. If the scaling factor were changed to a rational fraction with 3 or 7 in the denominator then the phase instability problem would disappear and the vector sum method would work trivially. The candidate frequencies are 4/3 $f_{RF} = 70.8$ MHz, 10/7 $f_{RF} = 75.8$ MHz, and 5/3 $f_{RF} = 88.5$ MHz, I am not really sure how many things this would affect and what would need to be checked. The things that I can think of are:

- The image frequencies would show up in different places. Is this better or worse? Does the filter need to be specified differently?
- If we choose 4/3 f_{RF} we undersample worse than at 7/5 f_{RF} and, therefore, lose more information. I have not checked this quantitatively. In the other cases, we would gain information.
- The timing board would need to be respecified.
- Are there other components on the boards which are tuned to narrow frequency bands?
- Does this make the boards difficult to reuse for other projects such as new main injector BPMs?

I hesitate to recommend this choice since we have a proof of princple for all other desired operating modes for operation at 7/5 f_{RF}. We have no such demonstration at another frequency and we do not understand the Grey chip very well. For example we have not yet understood why the timing change made by Peter Prieto, discussed in Beams-doc-1066, had the effect that it did. Finally, if any orders already placed need to be modified, then there is a new cost issue to consider. My guess is that one of the other solutions can be made to work and we can avoid dealing with this.

5 Summary and Conclusions

Several ideas about closed orbit measurements with the short gate mode have been presented. Listed below are a set of questions, the answer to which can guide our choices.

1. How important is it to have closed orbit measurements with the short gate mode? The answer to this will govern how much work we do looking at the other options.

2. Can the Echotek board be programmed to integrate over many turns but zero out data not inside the short gate? If so, this is the most elegant and robust solution.

3. Can we live with the loss of resolution which the fivefold phase instability causes in the vector sum mode? Will this remain true in the future? If so, this is the solution with the least work.

4. Is it possible for the Echotek board to compute the magnitude of each (I, Q) pair? It sounds as if the answer will be no.

5. Is it possible to move one (I, Q) pair per channel per turn across the backplane? This should be easy to answer.

6. Can we change the digitizing frequency to something with 3 or 7 in the denominator? This would have been the most elegant option if we thought of it earlier. I don't know if it is too late to consider this.