SuperKEKB

SuperB Linac
Beam Position Monitor

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Acknowledgements

- Thank you for your hospitality!
  - It has been a great pleasure to visit KEK and work with all of you.
    - Kazuro Furukawa, Ryo Ichimiya, Fusashi Miyahara, Masanori Satoh, Tsuyoshi Suwada, other people
  - Looking forward to continued collaboration

- Developments
  - Congratulations on progress so far
  - Much work completed
  - Great to get beam test results on short notice
  - Two solutions appear likely to meet requirements
    - At least for single bunch
    - And immediately after meeting we start looking at synthetic 2 bunch data.

Charge

- Review linac beam position monitor development
- Suggest:
  - possible improvements
  - how to evaluate performance
  - Path forward

Overview

- Scope
  - ~100 stripline BPMs in linac
- Requirements
  - Beam charge range: 0.1 to 5nC (10 nC?)
  - Resolution σ_{xy} < 10 microns at 1 nC
    - <100 microns at 0.1 nC
  - Scale: 10 micron resolution requires measurement to ~0.2%
  - Two bunches at 96 ns separation
- Schedule
  - Demonstrate performance by fall 2013
  - Order production units January 2014
  - Start commissioning Oct 2014

Nanobeam Scheme

Emphasis on emittance preservation requires

- Excellent alignment
  - ➔stability of postion
  - ➔stability of BPM calibration
- Avoidance of wakefields
  - ➔ resolution of 2 bunch measurement
  - Detect / correct wakefield effects

Costs

- I cannot compare cost of systems
  - too many variables to grasp in a short visit

- Recommend:
  - At least consider other commercial ADCs
    - VME or microTCA
    - From Struck, Echotech, or other source

Overall Recommendations

- Evaluate:
  - Noise
    - Effective number of bits (ENOB)
    - Front-end noise
  - Linearity
    - Third-order intercept (IP_3)
    - Set attenuators to optimize noise vs. linearity
      - Understand signal level at every potentially non-linear stage
    - Important for
      - stability with clock phase variation
      - Stability with beam current variation
- Study:
  - Position algorithm
  - Calibration
  - 2-bunch algorithm
  - Document procedures

Overall Recommendations (2)

- Need additional staff to:
  - perform studies,
  - Develop algorithm
  - grad student or post-doc?
    - maybe 2 additional people
- Need synchronous acquisition of BPMs, other pulse-pulse diagnostics
  - Very difficult to understand jitter, drift, optics without synchronous asquisition
  - linac is a different machine every pulse when you look at high resolution

Evaluate ADC Noise

- Does ADC deliver expected performance?
  - VME ADC noise level without signal matches ADC spec
  - Evaluate with signal present
  - Useful for Libera or VME
- Procedure
  - Inject signal from generator at level -1 dB_{FS}
  - Through bandpass filter if possible to remove harmonics
  - Acquire data
  - Fourier transform
  - Remove DC, center frequency
  - Inverse transform
  - Evaluate rms noise
  - Missing bits = log2(rms*sqrt(12))
  - Effective bits = Nbits- missing bits
- Or fit data to sine function and subtract fit to get residual noise
- Can measure with and without head Amp / Libera front end

Evaluate Linearity

- Linearity crucial for stability against
  - Clock phase
  - Beam charge variation
- Assume linearity well-characterized by third-order intermodulation performance
- Measure Third-order intercept (IP_3)
- Inject 2 tones (F_1 & F_2) separated by a few MHz through combiner
- Each tone at Full scale -7dB (so sum doesn't saturate)
- Evaluate spectral components at $2*F_1-F_2$ and $2*F_2-F_1$
  - Either by digitizing with ADC and fft
  - Or spectrum analyszer on analog signal

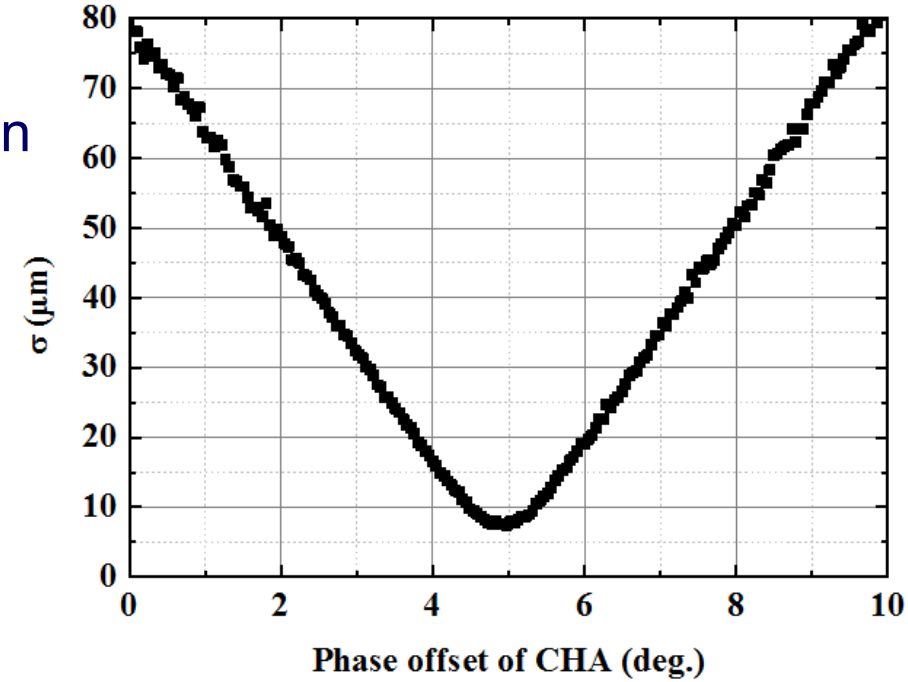
Libera “Brilliance”

- Advantages
  - Demonstrated resolution < 10 microns
  - Includes timing (EVR)
  - EPICS driver exists

- Disadvantages
  - No online calibration
  - Must measure offsets as function of attenuator setting
    - Load into calibration tables
    - Repeat how often?
  - Impulse response has more tail > 96 ns than VME
  - Requires precise phase alignment of BPM signals

Phase Matching

- Libera requires phase matching
  - requires 5ps matching to get 10 micron resolution
  - Resolution slope ~ 3 microns/ps
  - Why?
    - Not summing over entire waveform?
    - Nyquist band edge violation?
- Phase matching is time-consuming
- Rough matching with cable extension
- Fine tuning with phase shifter
  - Phase shifter changes attenuation
    - Causes position offsets
- Concern that phase matching implies matching of filter phases as well



Further Steps for Libera

- Measure ADC resolution
  - How many effective bits?
- Linearity
  - Measure IP_3
  - Can Third-order products be 60 dB below signal?
    - signal < IP_3 – 30 dB
- Evaluate 2-bunch performance
- Frequency is not optimum
  - F=522 MHz (near peak of stripline response)
  - But cable loses ~ 10dB at 522 MHz
  - Maximum signal is at lower frequency
  - Cannot calibrate with stripline-to-stripline coupling (coupling = 0 at 522 MHz)
  - Recommend lower frequency
    - Maybe 200 MHz or 320 MHz

Linac-Specific VME Module

- VME module integrating Head Amp & ADC
  - Should yield few micron resolution from design
  - NEW: Measure ~10 micron resolution with low-charge beam
- Issues:
  - ADC shows “glitch” every 10th sample
    - Fix:
      - Adjust ADC to FIFO timing
      - Limit bandwidth of signal to ADC
        - » Causes loss of ~-14 dB at 300 MHz
  - Expect resolution <10 microns from design
    - Measure σ~22 microns with calibration tone
    - Measure σ ~60 microns with impulse-like tone
    - Need to understand why resolution isn’t as expected
  - Needs EPICS driver

VME Recommendations

- Understand why resolution isn't as expected
  - ADC input network?
  - Is ADC noise low enough?
  - Is ADC linearity good enough?
  - Filter response
    - Tails extending across Nyquist zone boundaries?
    - 2^{nd} passband in filter response at 900 MHz?
- Verify ADC performance
  - Noise (enob)
  - Linearity (IP_3)
- Verify Head Amp / Bandpass Filter performance
  - Noise (nV/sqrt(Hz) or dBm/Hz)
  - with spectrum analyzer, or through ADC
  - Linearity (IP_3)

VME Recommendations (2)

- Change input bandwidth to center frequency 180 MHz
  - (now it is 300 MHz)
  - This lowers Q of filters
  - Plenty of signal to noise
  - Works better with ADC input network
- Improve filter response
  - Keep tails of filter response below -50 dB at Nyquist zone edges
    - (if possible)
  - Remove 2nd passband near 900 MHz
- Improve ADC input network
  - Maintain response to 200 MHz then roll off
- Understand algorithm
  - How many samples should be included?
  - How should attenuators be set to optimize noise vs. non-linearity?
    - Keep signal levels < IP_3 – 30 dB (3rd order products < -60 dB)

VME Recommendations (3)

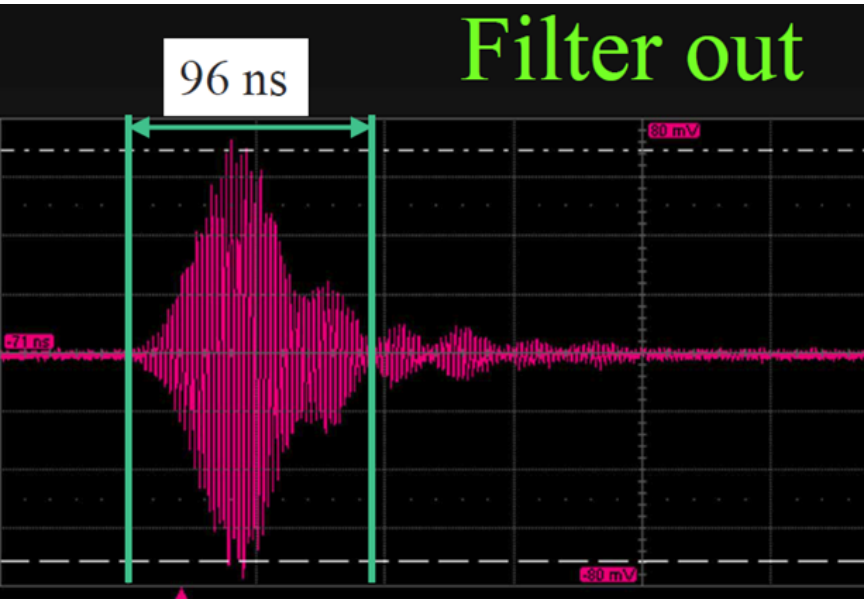
- Possibly improve head amp noise figure
  - This is low priority, not very important
  - Already better than needed for required resolution

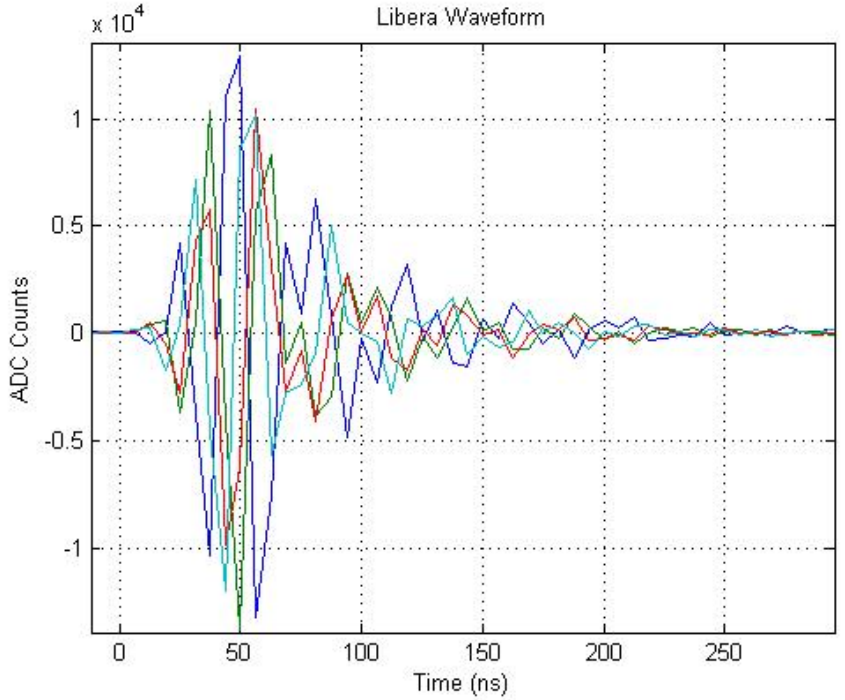
Measuring Two Bunches

- Two-bunch performance is important for identifying and correcting wakefield kicks
- Measurement of two bunches not yet demonstrated
- Recommendations:
  - Beam test
    - Create artificial 2nd bunch with splitter, delay, combiner
    - Expect to measure same position of two bunches
  - Offline synthetic 2nd bunch
    - Record waveforms from single bunch beam
    - Add signal from opposite strip, delayed by 96 ns
    - Expect 2nd bunch position opposite of 1st.
- Test with 2 bunch beam as soon as possible

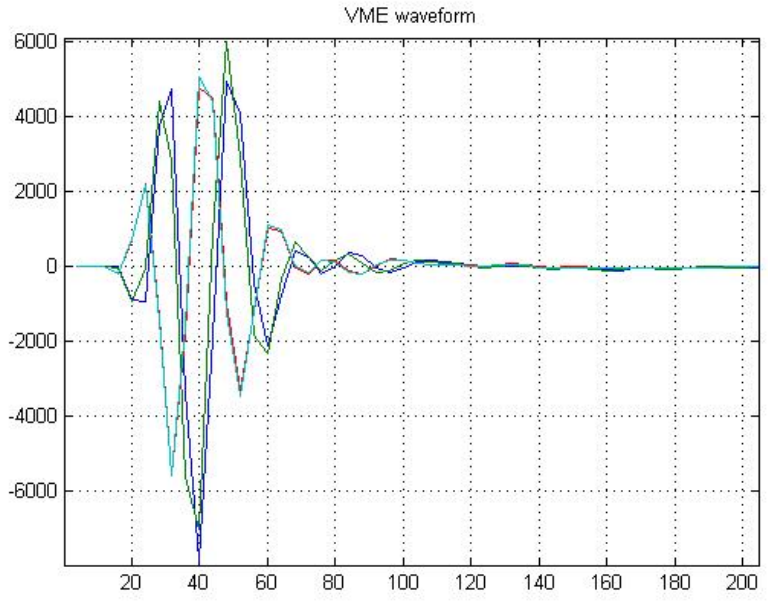
Time-Domain Response

Libera:





VME:



Comparison

Feature	Libera	VME	Comments
Single bunch resolution	Good	Good	
Two-bunch resolution	Not demonstrated	Not demonstrated	See impulse response
Impulse response	~20% @ 96 ns	3% @ 96 ns	VME much cleaner
Calibration	Static, invasive, Must generate table with offset vs. attenuator	Dynamic, potentially continuous	Calibration very important
System integration	Chassis includes EVR, processor, multiple BPMs?	VME crate Processor EVR Multiple BPMs	Cost?
EPICS integration	Driver exists	Needs driver	Cost, time
Development environment	Access to Libera		develop, modify algorithms

Risks

- How open is Libera processor for algorithm development?
- Cost?
- Schedule
  - One turn of design & evaluation by December
- Who will develop 2 bunch algorithm?
- What if 2 bunch algorithm doesn't meet requirements?
  - Add one (or a few) dedicated wakefield detectors
    - For example fast scope like existing system
    - But preceded by ringing filter and analog difference/sum hybrid to increase resolution by x16
      - 3 bits for ringing time of 60 ns
      - 1 bit for hybrid

Recommendation

- Both solutions appear to meet single bunch resolution requirement
- Neither demonstrates 2 bunch performance yet
  - VME time domain response looks better for 2 bunch measurement
- Libera appears to have noise floor just below 10 microns
  - Limited by phase matching
- VME should get much better than 10 micron resolution at 1 nC
  - Presently limited by ADC input network, possibly excess noise
- Calibration is very important
  - VME can calibrate frequently (or continuously)

- Suggest SuperB pursue VME solution

Thank you