BPM electronics

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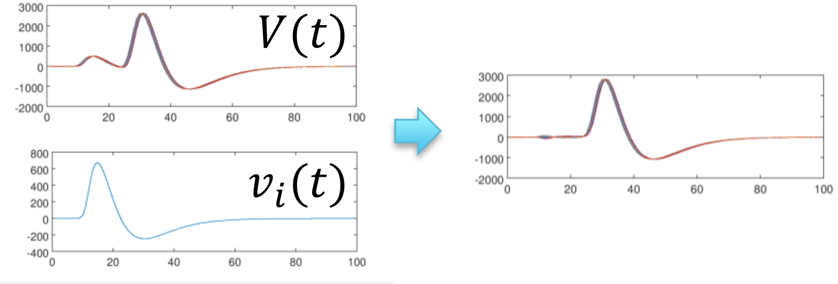
Study items from last session

- Bunch length variations to be considered
  - Variable bunch length implemented in the simulation. Range clearly stated in specification: 0.7 – 1.2 ns (FWHM)
- Can VNA style corrections be used?
  - Unlikely. A method of recovering the individual beam signals from the set of waveforms was implemented but performed less well than the other methods.
- Use on-board DAC to generate similar signals
  - Pending.
- RF full detuning effects to be considered
  - Pending.
- Can an algorithm be found that does not need beam calibration
  - The VNA method, but it has already been ruled out.

Comparison of compensation methods I

- Waveform compensation
    - Sample-by-sample adjustment of the amplitude of the waveform samples
    - Requires template waveforms (and hence making assumptions about the bunch and signal processing)
- Power compensation
    - Adjustment of the calculated power of the waveforms
    - Requires power compensation parameters (calculated from template waveforms)
- VNA-style compensation
    - Beam-independent, but requires knowledge of the stripline S-parameters



$$V(t) = \rho_0 v_c(t) + \rho_9 v_i(t)$$

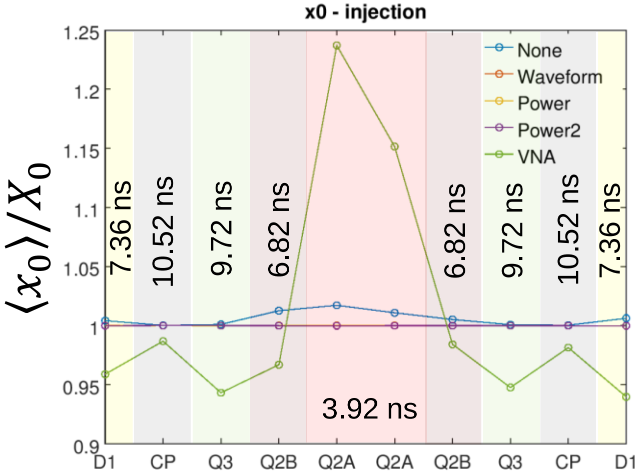
$$\sum V(t)^2 = \rho_0^2 \sum v_c(t)^2 + 2\rho_0\rho_9 \sum v_c(t).v_i(t) + \rho_9^2 \sum v_i(t)^2$$

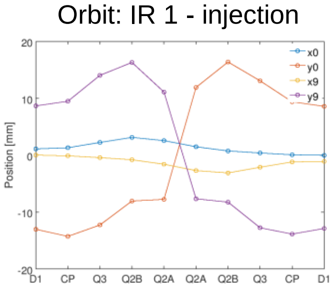
Can be solved for ρ_0 if ρ_9 is known

$$\rho_{R0} I_0(\omega) = \frac{I_1(\omega) \cdot S_{59}(\omega) - I_5(\omega) \cdot S_{19}(\omega)}{S_{10}(\omega) \cdot S_{59}(\omega) - S_{19}(\omega) \cdot S_{50}(\omega)}$$

Current cancels out when taking Δ/Σ

Compensation of comparison methods II



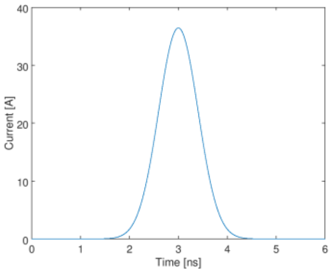


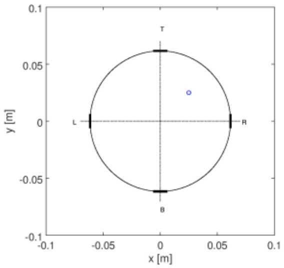
- Consider two beams with equal intensity (=$3e11$) and bunch lengths of 75 mm*
- Using the specified injection orbits for each BPM (IR 1), calculate the position of the first beam using several different methods to account for the presence of the other beam
- X_0 is the calculated position of the beam taking into account only the geometry
- x_0 is the position of the beam calculated from the digitized (and compensated) ensemble of waveforms
- The VNA method performs very poorly and was eliminated from consideration
- Waveform and power compensation perform similarly well, but waveform compensation is much more computationally intensive

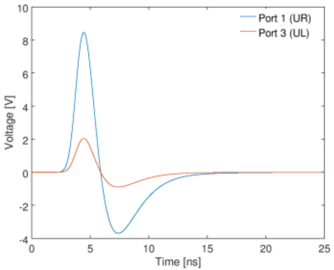
*shorter than the minimum quoted in the specification

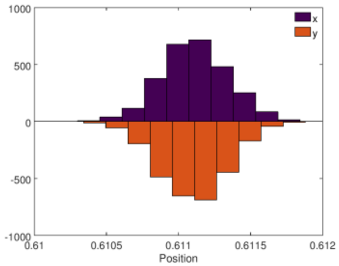
Simulation properties

- Consider a single beam travelling through the Q1 BPM
  - 25 mm off axis in both horizontal and vertical directions (max operational range)
  - variation in waveforms solely due to asynchronous phase of sampling clock and random noise applied during digitization







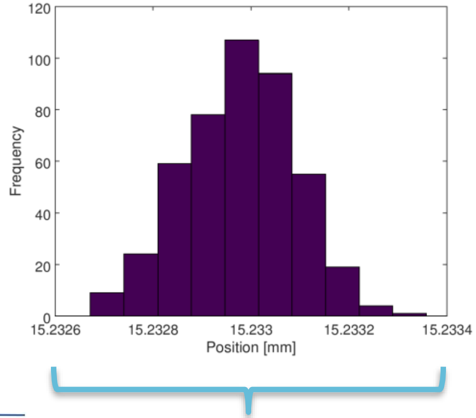


(Δ/Σ)

Simulation properties	
Beam 0 intensity (i_0)	2.3×10^{11} (max)
Beam 0 bunch length (σ_0)	0.95 ns (mid-range)
Cable	LCF12-50JFN [100 m]
Filter	Absorptive [273 MHz]
Sampling frequency	3994.9 MHz (1 in 255)
ADC	12-bit, ±0.5 V, use 2/3
Attenuator step size	2 dB
Random noise	1.5611 counts

Specification

- Target: averaged Closed Orbit (CO) measurement stable to within 2 µm on a 10 hour timeframe
- Frequency of CO measurements = 25 Hz i.e. once every 40 ms
  - Train makes 450 revolutions of the LHC in this time
  - Train consists of 2,760 bunches
  - So each CO orbit measurement gives the average of ~1.25 million individual bunch position measurements



0.8 µm

- Histogram plot of the **mean** position for 450 bunch trains (of 2760 bunches)
- Error on mean = 5.3 nm
- NB: a linear calibration constant equal to half the BPM radius has been used for these results. In reality a 2D polynomial will be required to correct the non-linearity. The true errors will therefore be higher.

Factors that could affect position

Bunch length [ns]	Closed orbit position
0.70	15.232944 mm ± 5.4 nm
0.95	15.232977 mm ± 5.3 nm
1.20	15.232938 mm ± 4.8 nm

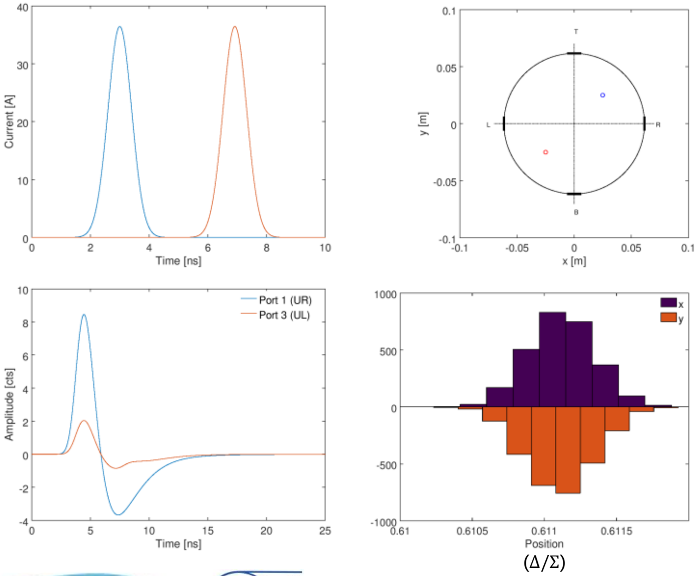
Closed orbit measurement differs by up to 0.04 μm as bunch length varied

Bunch charge	Closed orbit position
5e9	15.232896 mm ± 6.8 nm
5e10	15.232960 mm ± 5.5 nm
2.3e11	15.232977 mm ± 5.3 nm

Closed orbit measurement differs by up to 0.08 μm as bunch charge varied

Add second beam

- Positioned opposite end of BPM to the first beam (max anticipated offset?)
  - Equal intensity (max)
  - Same bunch length (mid-range)



Simulation properties	
Beam 0 intensity (i_0)	2.3×10^{11} (max)
Beam 9 intensity (i_9)	2.3×10^{11} (max)
Beam 0 bunch length (σ_0)	0.95 ns (mid-range)
Beam 9 bunch length (σ_9)	0.95 ns (mid-range)
Bunch crossing timing	3.92 ns (Q1)
Cable	LCF12-50JFN [100 m]
Filter	Absorptive [273 MHz]
Sampling frequency	3994.9 MHz (1 in 255)
ADC	12-bit, ±0.5 V, use 2/3
Attenuator step size	2 dB
Random noise	1.5611 counts

Two beam results

	Beam 0	Beam 9
Target	15.232942 mm	-15.232942 mm
Uncompensated	15.416821 mm	-15.414105 mm
Compensated	15.231842 mm	-15.233208 mm

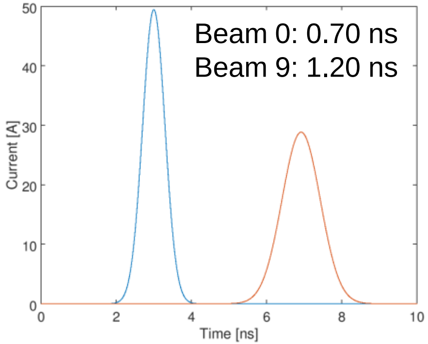
Adding the second beam in the specified location shifts the apparent position by:
184 µm (beam 0)
-181 µm (beam 9) (without compensation)

Using the method of power compensation (assuming 0.95 ns width bunches), the shift is:
-1.1 µm (beam 0)
-0.3 µm (beam 9)

When non-linearity taken into account, beam 0 shift likely to already be close to 2 µm level

Changed bunch length

	Beam 0	Beam 9
Target	15.232942 mm	-15.232942 mm
Uncompensated	15.406058 mm	-15.426068 mm
Compensated	15.232942 mm	-15.233361 mm

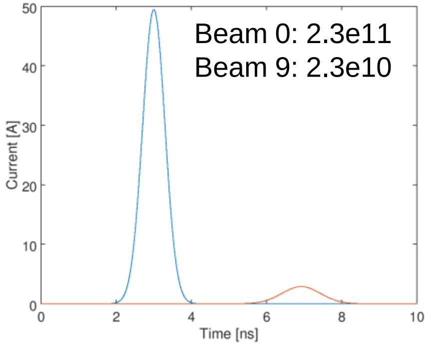


Changing the bunch lengths of both beams shifts the apparent position by:
173 µm (beam 0)
-193 µm (beam 9) (without compensation)

Using the method of power compensation (assuming 0.95 ns width bunches), the shift is:
0.1 µm (beam 0)
-0.4 µm (beam 9)

Changed bunch charge

	Beam 0	Beam 9
Target	15.232942 mm	-15.232942 mm
Uncompensated	15.253587 mm	-12.503724 mm
Compensated	15.232876 mm	-15.138006 mm



Changing the bunch lengths of both beams shifts the apparent position by:
20.6 µm (beam 0)
2.73 mm (beam 9) (without compensation)

Using the method of power compensation (assuming 0.95 ns width bunches), the shift is:
-0.07 µm (beam 0)
94.9 µm (beam 9)

Conclusion

- Power compensation now the baseline method for compensating for the other beam
- 2 µm tolerance over the entire operational range likely to be extremely challenging once real-world effects taken into account