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Monitoring Beam Position in the Multibeam Accelerators

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Outline

- Introduction
- Proposed method
- Signal processing
- Noise estimate
- Conclusions

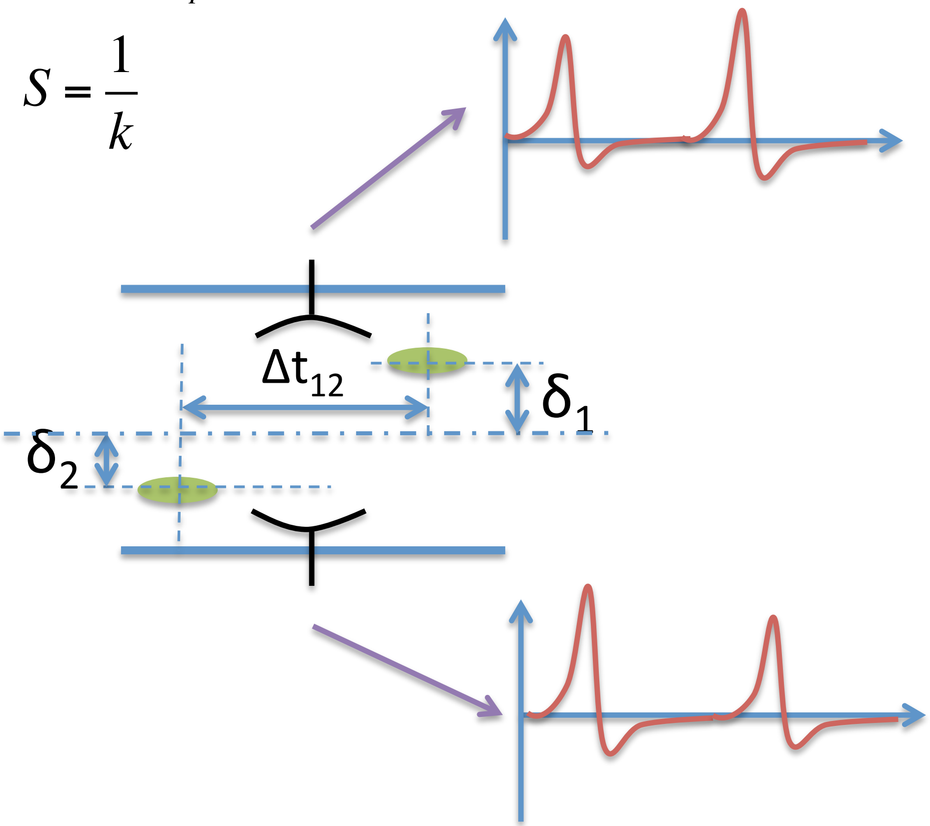
Basic Assumptions

- Accelerating structure is passed few times by the same bunch moving all times in the same direction
- At each pass beam has different trajectory, which we need to measure
- Beam losses from pass to pass are small
- Beams at different energies are separated in in time and this separation is fixed by design
- The phases of accelerated and decelerated beams are shifted by 180°

Two Pick-up Electrodes in the Arc

$$y = k\frac{U_{up} - U_{down}}{U_{up} + U_{down}}$$

$$S = \frac{1}{k}$$



Bunches, separated by a flyby time Δt_{12}, have different positions then each PUE sees different longitudinal "center of gravity" and there is a phase shift between two signals. For a processing unit, utilizing signal processing at frequency ω, and small displacements of the first and the second bunches δ_1 and δ_2 ($S\delta_1, S\delta_2 \ll 1$, where S=1/k is a sensitivity coefficient) we can write the linearized equations:

$$V_{up} = V_1\left(1 + S\delta_1\right)\sin\omega\left(t + \Delta t_{12}/2\right) + V_2\left(1 + S\delta_2\right)\sin\omega\left(t - \Delta t_{12}/2\right)$$

$$V_{down} = V_1\left(1 - S\delta_1\right)\sin\omega\left(t + \Delta t_{12}/2\right) + V_2\left(1 - S\delta_2\right)\sin\omega\left(t - \Delta t_{12}/2\right)$$

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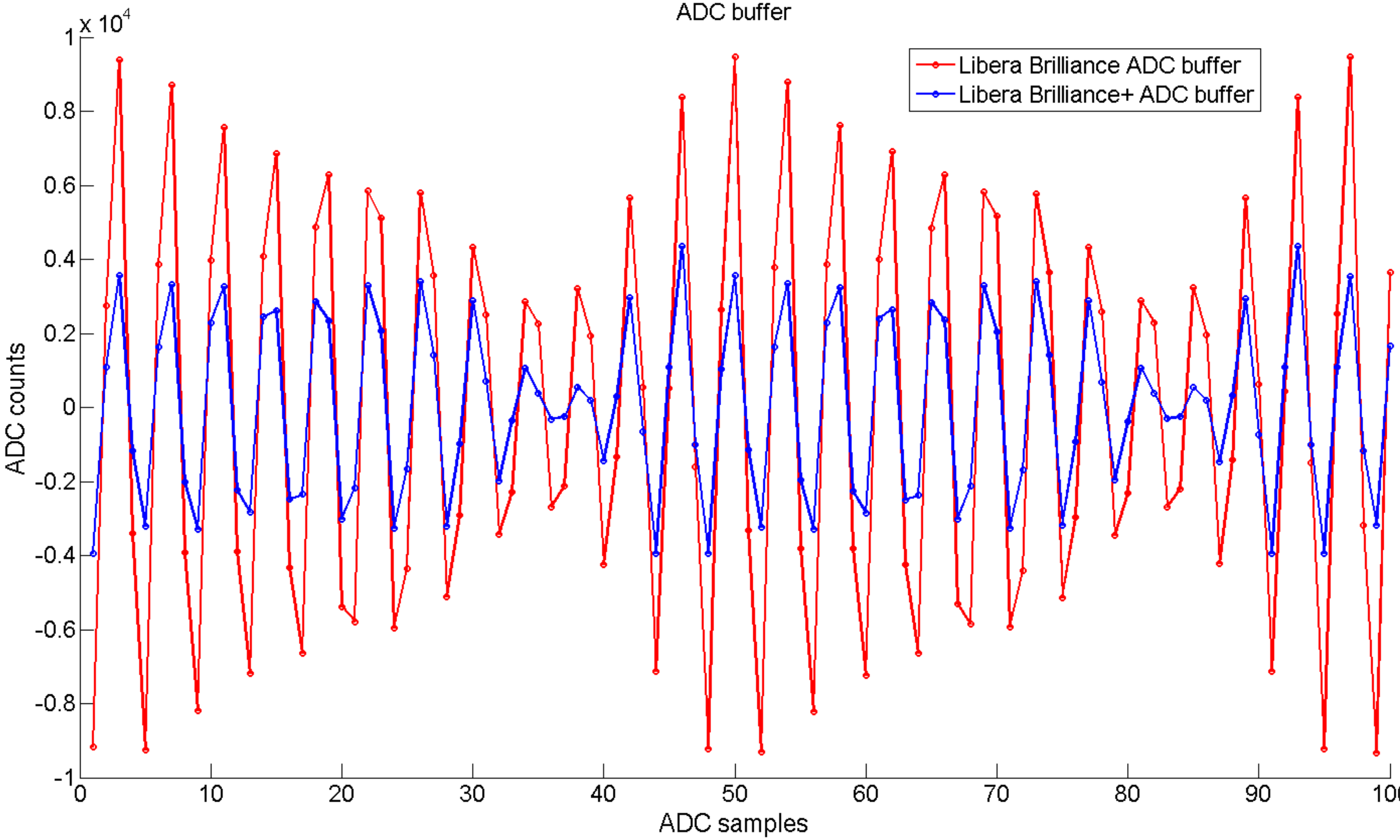
Trace of Beam Signal in Libera BPM



Courtesy of Instrumentation Technologies

Signal Processing

For the small displacement we can neglect the second order terms and assuming V_1=V_2=V_0 receive

$$U_{up} \approx 2V_0 \cos(\omega \Delta t_{12}/2)\left[1 + \frac{\delta_1 + \delta_2}{2}\right]$$

$$U_{down} \approx 2V_0 \cos(\omega \Delta t_{12}/2)\left[1 - \frac{\delta_1 + \delta_2}{2}\right]$$

$$\hat{y} = k\frac{U_{up} - U_{down}}{U_{up} + U_{down}} = \frac{\delta_1 + \delta_2}{2}$$

The processing frequency should be multiple of the revolution (repetition) frequency but not equal to RF frequency.

Amplitude processing gives average position of the beams. Phase processing gives:

$$\varphi_{up} \approx \frac{S(\delta_1 - \delta_2)}{2}\tan(\omega \Delta t_{12}/2)$$

$$\varphi_{down} \approx -\frac{S(\delta_1 - \delta_2)}{2}\tan(\omega \Delta t_{12}/2)$$

$$\Delta\varphi = \varphi_{up} - \varphi_{down} = S(\delta_1 - \delta_2)\tan(\omega \Delta t_{12}/2)$$

For k=10 mm, 100 microns difference gives 0.01 radians (0.57°) relative phase shift.

Phase shift gives information on the difference in the orbits.

Four Pick-up Electrodes

$$x_{ave} = k_x \frac{U_B - U_A + U_C - U_D}{U_A + U_B + U_C + U_D}$$

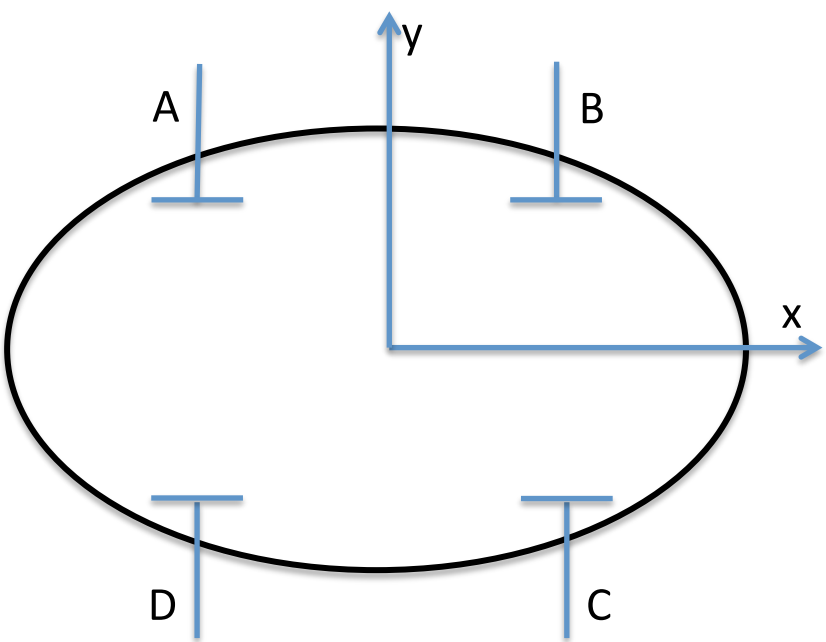
$$y_{ave} = k_y \frac{U_A - U_C + U_B - U_D}{U_A + U_B + U_C + U_D}$$

$$V_A = V_0\left(1 - S_x\delta_{x1} + S_y\delta_{y1}\right)\sin\omega\left(t + \Delta t_{12}/2\right) + V_0\left(1 - S_x\delta_{x2} + S_y\delta_{y2}\right)\sin\omega\left(t - \Delta t_{12}/2\right)$$

$$V_B = V_0\left(1 + S_x\delta_{x1} + S_y\delta_{y1}\right)\sin\omega\left(t + \Delta t_{12}/2\right) + V_0\left(1 + S_x\delta_{x2} + S_y\delta_{y2}\right)\sin\omega\left(t - \Delta t_{12}/2\right)$$

$$V_C = V_0\left(1 + S_x\delta_{x1} - S_y\delta_{y1}\right)\sin\omega\left(t + \Delta t_{12}/2\right) + V_0\left(1 + S_x\delta_{x2} - S_y\delta_{y2}\right)\sin\omega\left(t - \Delta t_{12}/2\right)$$

$$V_D = V_0\left(1 - S_x\delta_{x1} - S_y\delta_{y1}\right)\sin\omega\left(t + \Delta t_{12}/2\right) + V_0\left(1 - S_x\delta_{x2} - S_y\delta_{y2}\right)\sin\omega\left(t - \Delta t_{12}/2\right)$$



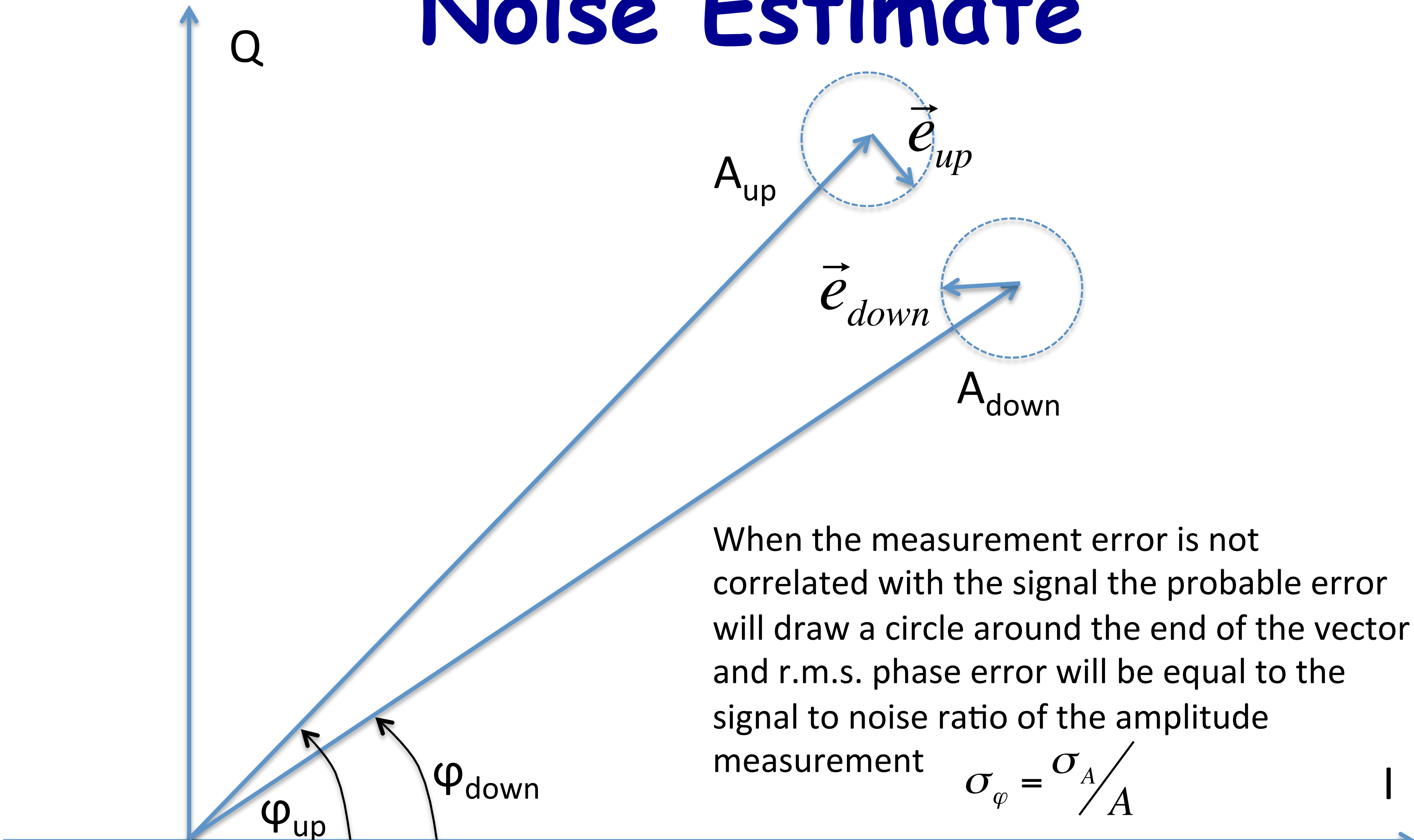
$$x_{diff} = \frac{k_x}{\tan\left(\omega\Delta t_{12}/2\right)}\left[\left(\varphi_B - \varphi_D\right) - \left(\varphi_A - \varphi_C\right)\right]$$

$$y_{diff} = \frac{k_y}{\tan\left(\omega\Delta t_{12}/2\right)}\left[\left(\varphi_A - \varphi_C\right) + \left(\varphi_B - \varphi_D\right)\right]$$

Common Straight

- The common straight, where acceleration/deceleration occurs, is passed by all bunches
- To obtain information on position of each particular bunch we can process the pick-up signal at different frequencies (more analyses is required)

Noise Estimate



When the measurement error is not correlated with the signal the probable error will draw a circle around the end of the vector and r.m.s. phase error will be equal to the signal to noise ratio of the amplitude measurement $\sigma_\varphi = \sigma_A / A$

M. Znidarcic et al., "Testing of New Hadron Beam Phase and Position Monitor at CIEMAT Laboratory," DIPAC'11, Hamburg, MOPD26, p. 104. For the described system r.m.s. position noise is 3×10^{-4} and phase noise is 1.75×10^{-4} radians

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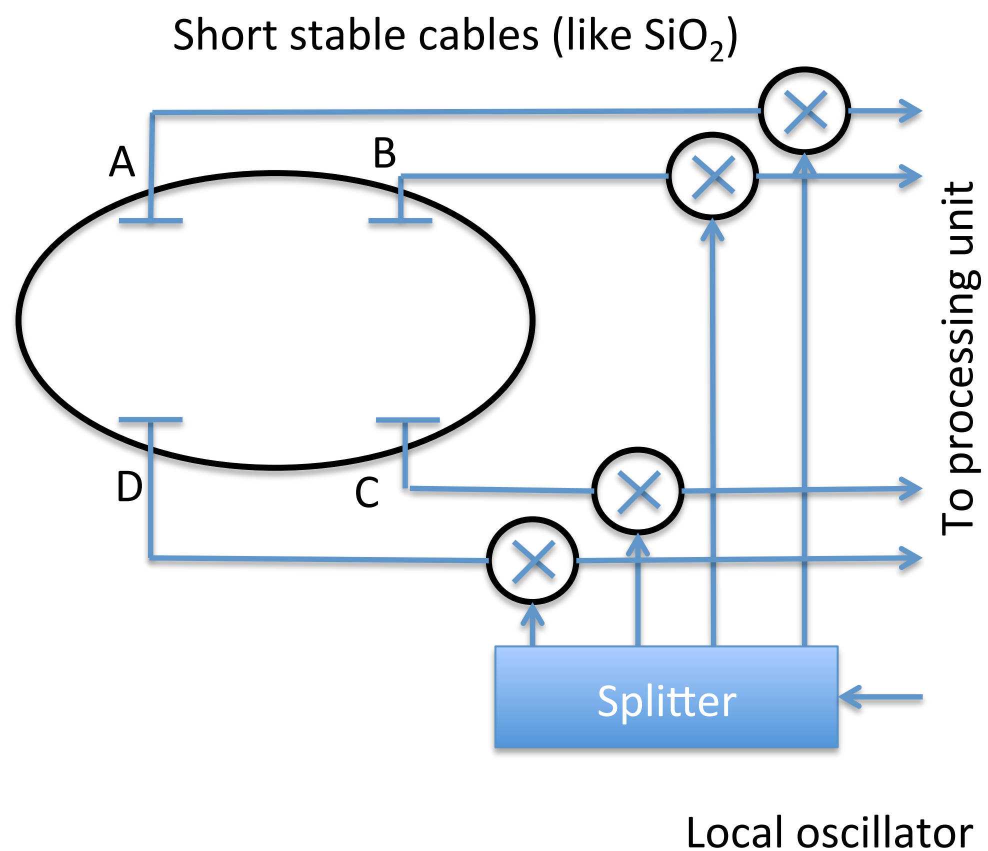
Offset Measurement

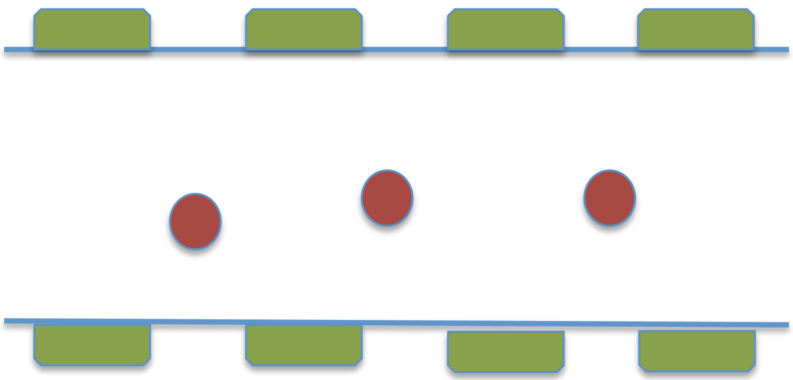
- The cable length mismatch, phase shifts in the analog circuits and other errors result in the systematic error for the determination of the beam position
- It is possible to use a signal generator and splitter to measure the phase shift of the whole system but this is time consuming and requires access to the accelerator
- Better way is use low repetition rate mode in the ERL (possibly intercepting the beam at the highest energy) and fitting the ring down signal from the front end filter

Suppression of the Cable Drift

The temperature changes and other slow processes can change physical length of the cable or phase velocity of the signal in the cable. To suppress the drifts one can lower the processing frequency to the range where the sensitivity to the variations of delays is less. Unfortunately, it also lowers the sensitivity to the position difference due to the $\tan\omega\Delta t_{12}/2$ term. To have both high sensitivity to the differential beam position (and low noise) and to suppress influence of drifts we can convert down the PUE signals.



BPM for FFAG



Add extra pick-up electrodes (total quantity 2*(N+1))
Amplitude U of the signal induced on each PUE is (vector) sum of signal of each beam. Nominal level and linear coefficients on the signal level for small deviations from can be easily found with numerical simulations.

$$v_i = \frac{U_{up\,i} + U_{up\,i+1} - U_{down\,i} - U_{down\,i+1}}{U_{up\,i} + U_{up\,i+1} + U_{down\,i} + U_{down\,i+1}}$$

$$h_i = \frac{U_{up\,i} - U_{up\,i+1} + U_{down\,i} - U_{down\,i+1}}{U_{up\,i} + U_{up\,i+1} + U_{down\,i} + U_{down\,i+1}}$$

$$\vec{x} = M_H \vec{h}$$

$$\vec{y} = M_V \vec{v}$$

Conclusions

- Proposed method of measuring beams position looks promising
- Proper choice of the processing frequency is required
- Expected performance is on par with regular BPMs
- Existing hardware can be used