How to correctly simulate with the SPS impedance model?

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Content

- SPS impedance model
- RF fast-sine vs rf-kick-interp

Present SPS impedance model

- 1 travelling wave object (800 MHz)
- 230 resonators (max fr: 8.5GHz, min bw 94kHz)
- 2 impedance tables
  - Resistive_wall.dat (up to 100GHz, logarithmic spacing)
  - totWrongZSME_imp.dat (up to 5GHz with 166kHz frequency spacing)

Basic discrete Fourier transform stuff

- N data points at times $t_n = n\,\Delta t$ with $n = 0 \ldots N - 1$
- $t_{max} = (N-1)\Delta t$, $t_{period} = N\Delta t$
- Maximum (Nyquist) frequency $f_c = \pm 1/2\Delta t$, $\Delta f = 1/N\Delta t$

Press et al., Numerical Recipes, 3rd ed

Induced voltage

$$V_{ind}(t) = \int_{-\infty}^{\infty} \lambda(t-\tau)w(\tau)d\tau = Re\int_{0}^{\infty} Z(\omega)\lambda(\omega)d\omega$$

- In BLonD different objects to compute V_{ind}:
    - InducedVoltageFreq (uses given impedance $Z(\omega)$)
    - InducedVoltageTime (uses given wake $w(\tau)$, computes convolution via frequency domain)
    - InducedVotlageResonator (only for resonators, uses semi-analytic method)
- Maximum frequency determined by profile.bin_size (corresponds to Δt)
- Frequency resolution Δf determined dynamically

Which method to chose?

Some considerations (mainly for resonators):

- Bunch lengths on the order of 5ns -> 200 MHz
- With 64 bins per RF-bucket, Nyquist frequency ~ 6GHz
- To resolve a resonator, need frequency spacing < band width (otherwise front wake);
  impedance model suggests $\Delta f < 90kHz$ (2 f_rev = 86kHz)
- My criterion:
  If resonator is broad-band (bandwidth >> Δf) and low-frequency part important ($1 \ll \omega_r\,\sigma$) -> chose frequency domain, otherwise time domain

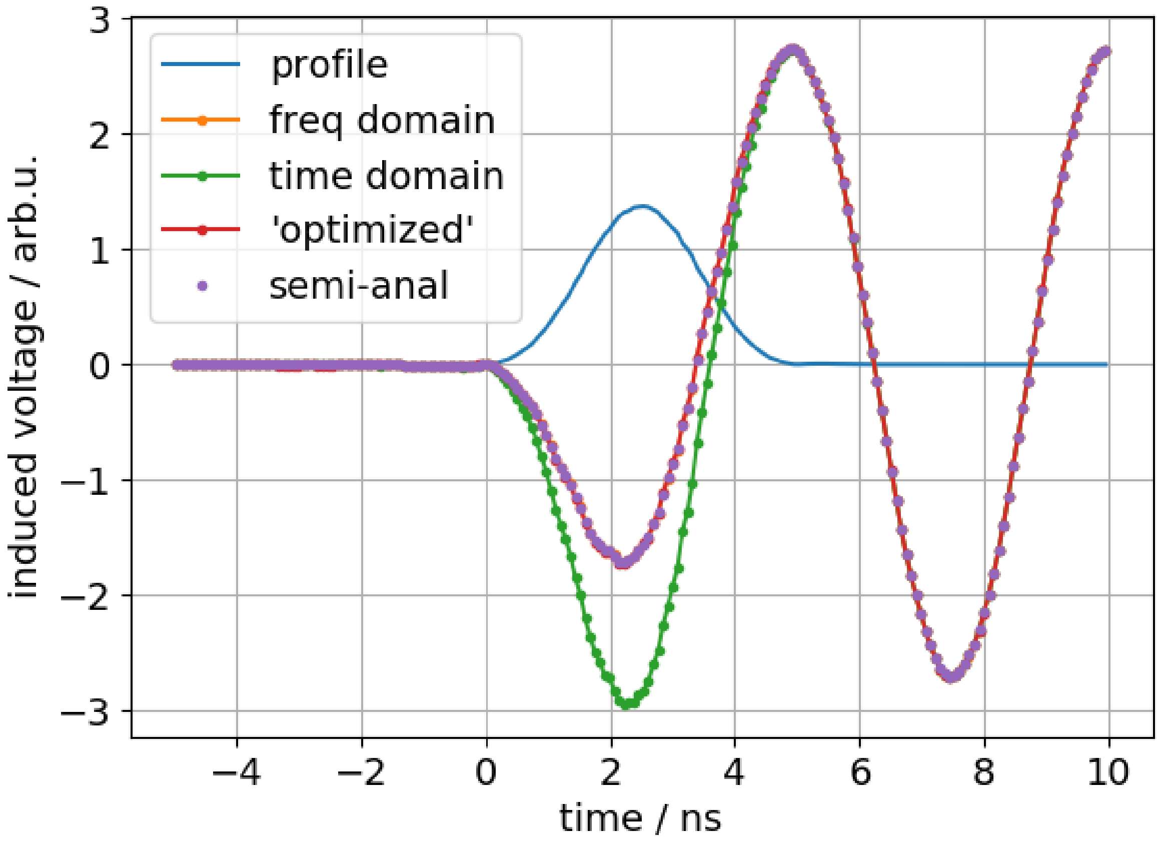
Induced voltage, example Gaussian bunch

Compute V_ind (resonators only) from impedance model using

- all resonators with InducedVoltageFreq (orange)
- all resonators with InducedVoltageTime (green)
- Optimize by applying criterion from last slide (red)
- Semi-analytic method (purple)

With 64 bins per RF-bucket

Induced voltage, example Gaussian bunch



Timings:

- Frequency: 8 ms
- Time: 84 micro s (135 micro s for 256 bins per RF-buckets)
- Optimized: 127 micro s
- Semi-analytic: 62 micro s

Example scanning bins/RF-bucket, df, #macro-particles

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V_ind computed
with InducedVoltageFreq

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Convergence rf_kick_interp vs fast_sine

- With same initial distribution:
- run n turns using fast_sine -> keep this as reference
- run n turns using rf_kick_interp -> vary bins/RF-bucket
- Compute $\chi^2 = \sum_{macroparticles}(refbeam.dt - beam.dt)^2$
- Similar for energies of particles

SPS parameters with V200 = 7MV

Convergence rf_kick_interp vs fast_sine: **10k** macroparticles

Convergence rf_kick_interp vs fast_sine: **1M** macroparticles

Runtime rf_kick_interp vs fast_sine