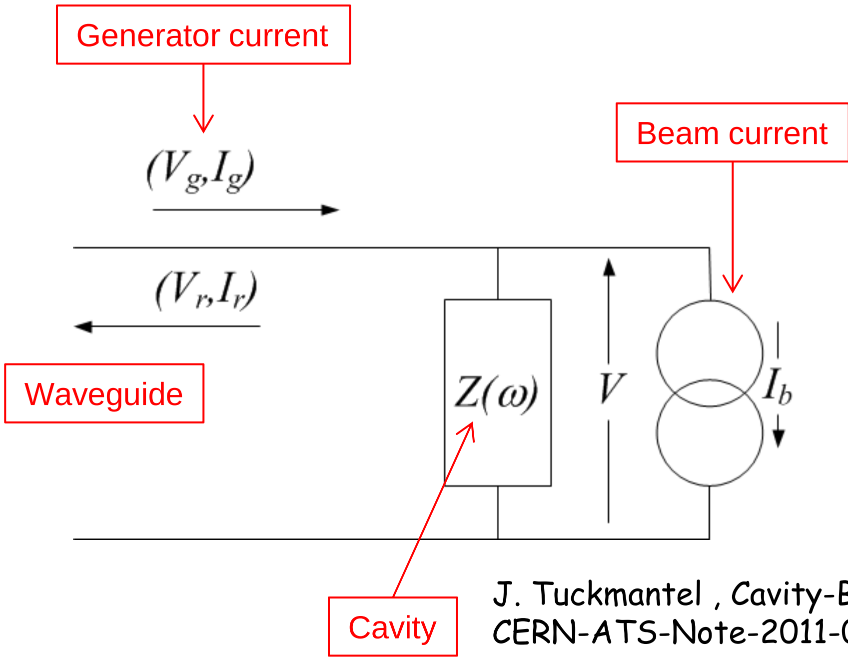
Linac 4 Low Level RF

Compensation of Transient Beam Loading caused by Beam Gaps

P. Baudrenghien , J. Galindo, J. Noirjean
BE/RF/FB

Effect of beam gaps without regulation



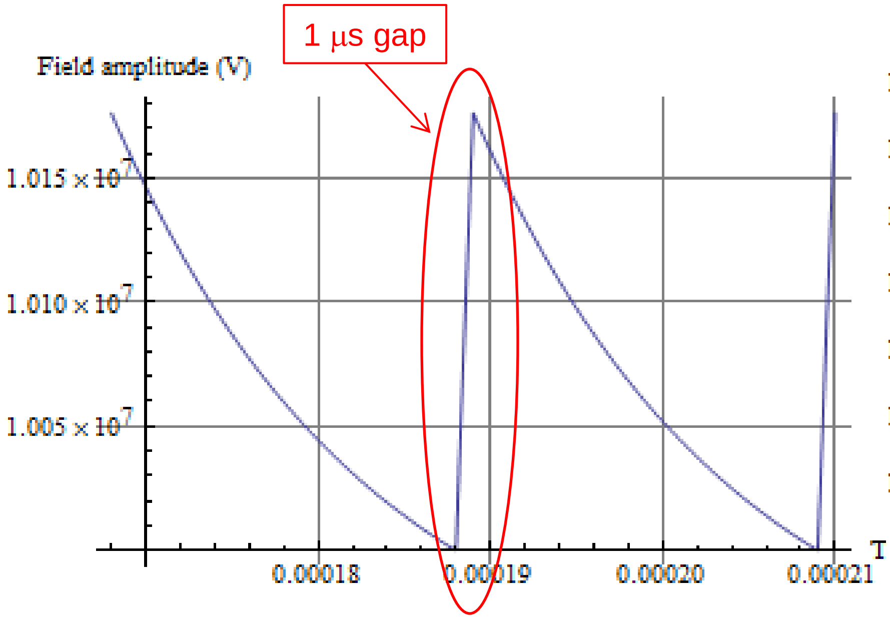
Cavity filling time (inverse) — Detuning — Generator current — Beam current

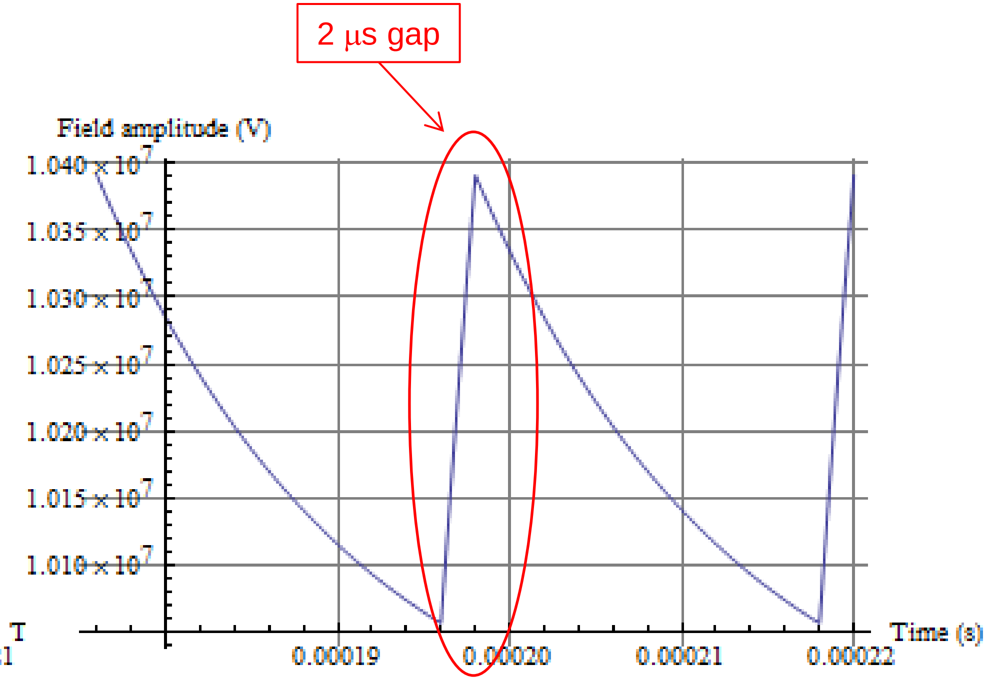
$$\begin{cases} \dfrac{dv_I(t)}{dt} + \dfrac{\omega}{2Q_L} v_I(t) + \Delta\omega\, v_Q(t) = \omega R/Q \left[i_{gI}(t) - \dfrac{i_{bI}(t)}{2} \right] \\ \dfrac{dv_Q(t)}{dt} + \dfrac{\omega}{2Q_L} v_Q(t) - \Delta\omega\, v_I(t) = \omega R/Q \left[i_{gQ}(t) - \dfrac{i_{bQ}(t)}{2} \right] \end{cases}$$

J. Tuckmantel , Cavity-Beam-Transmitter Interaction Formula Collection with Derivation, CERN-ATS-Note-2011-002 TECH

- Transients in the beam current result in transients in the cavity field (amplitude and phase).

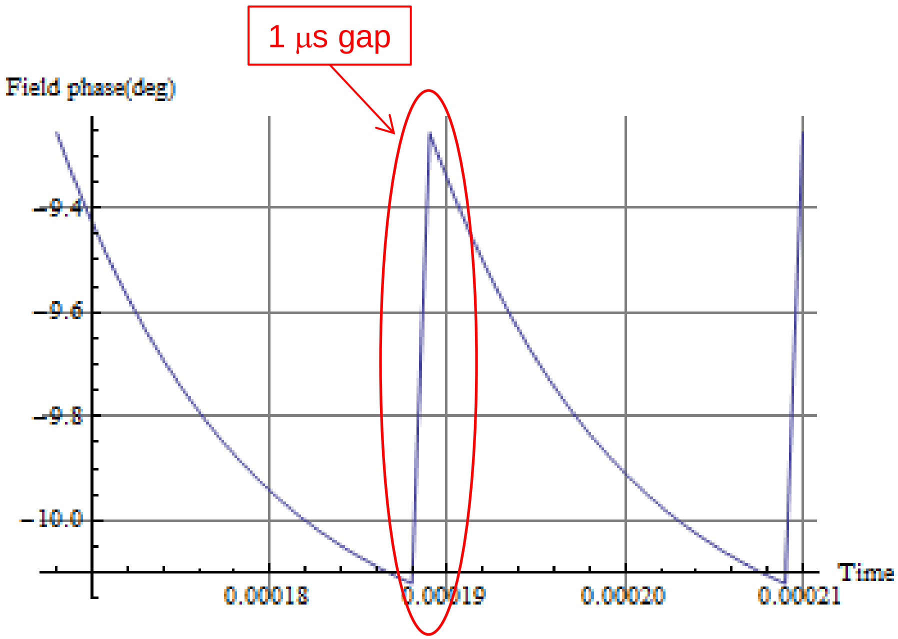
Example DTL1

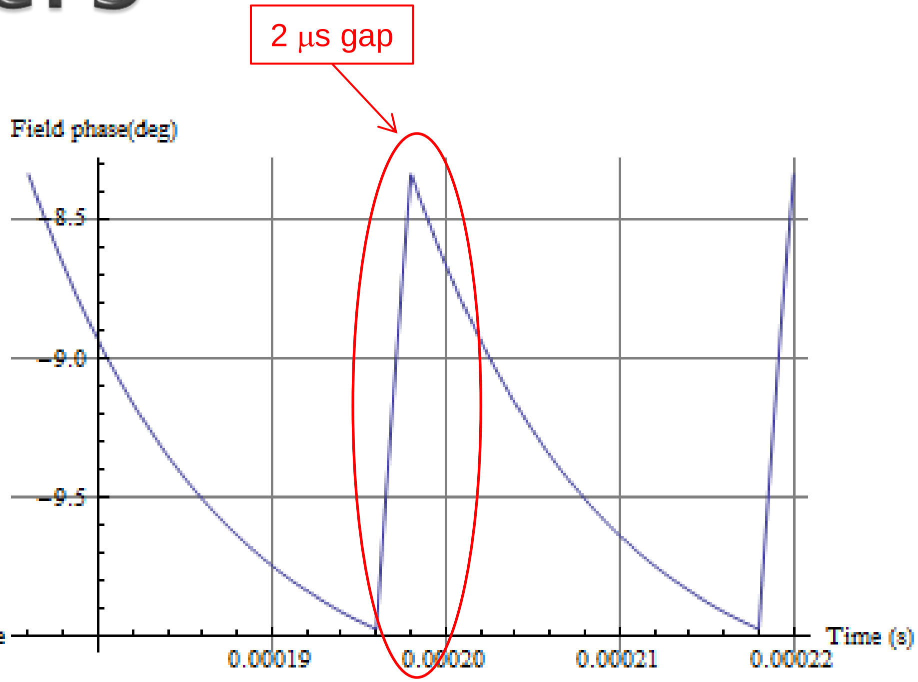




- Effect of a 1 μs and 2 μs gap in the DTL1 voltage (10 MV), without regulation: The voltage increases by ~ 2% and 4% respectively. 40 mA DC beam current.

Example Buncher3

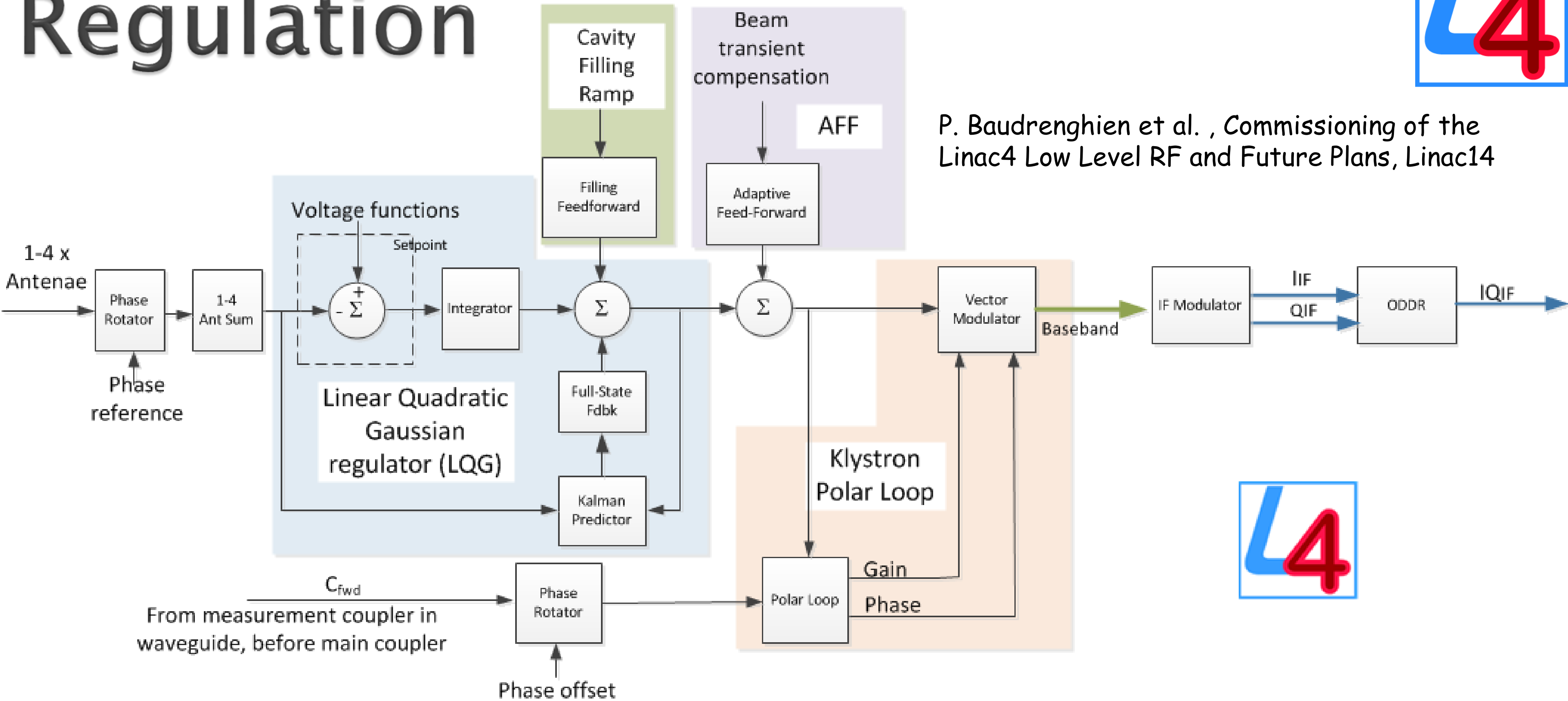




- Effect of a 1 μs and 2 μs gap in the Buncher, without regulation (150 kV): The phase drifts by ~ 0.8 deg. and 1.6 deg. respectively. 40 mA DC beam current.

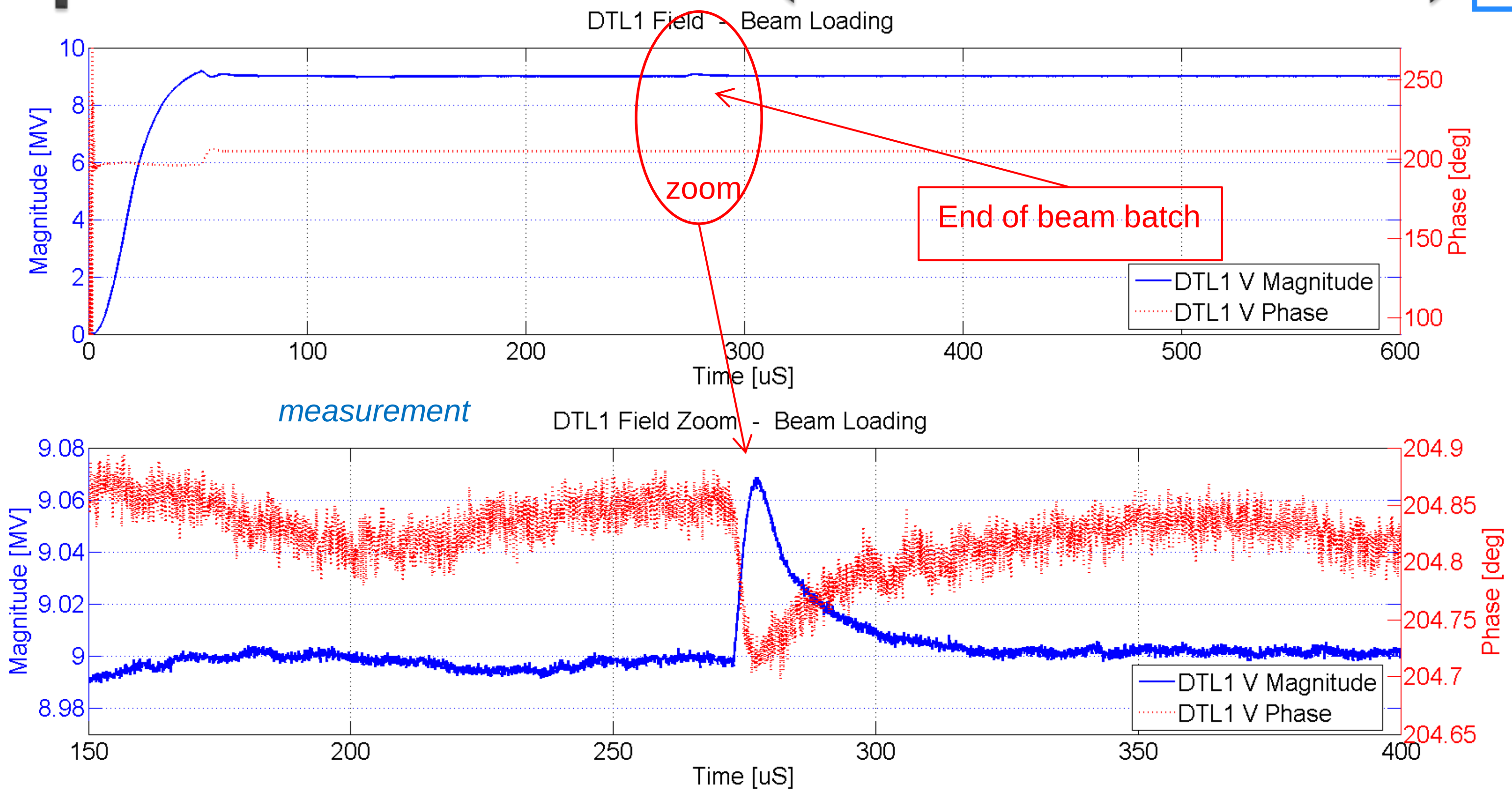
Regulation

P. Baudrenghien et al. , Commissioning of the Linac4 Low Level RF and Future Plans, Linac14



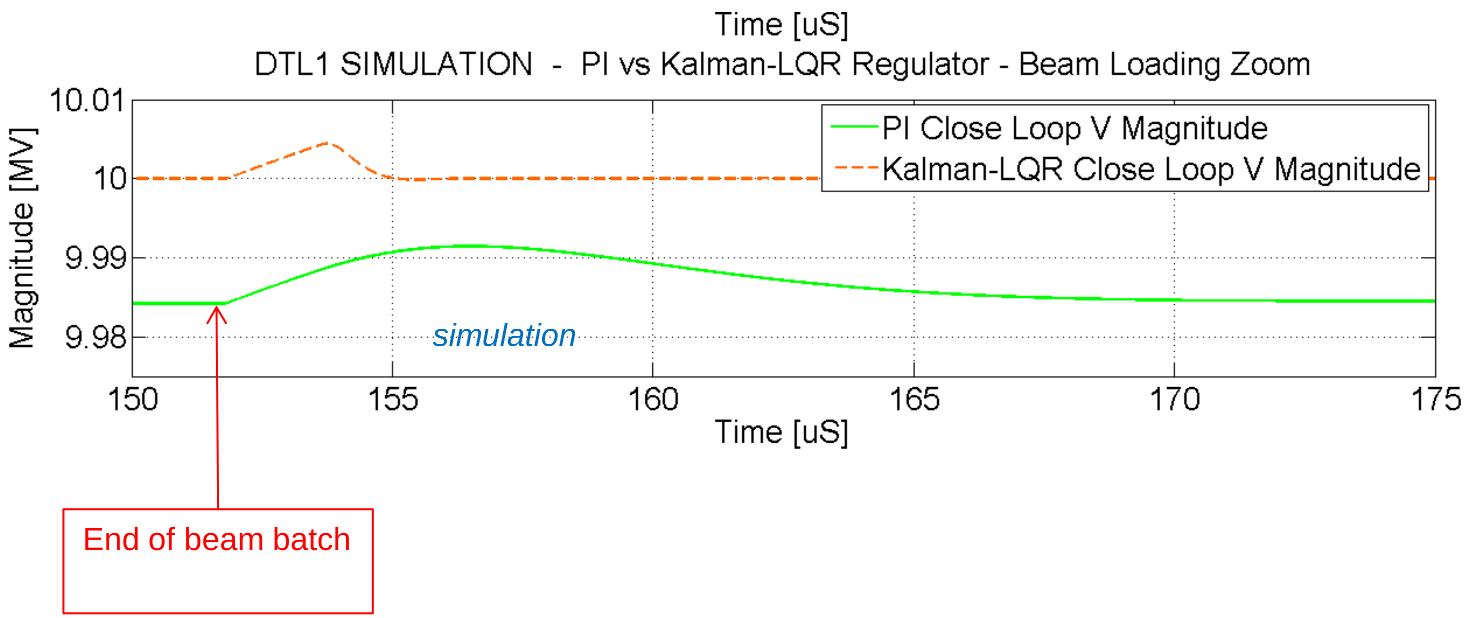
- We can reduce the effect of the beam gaps by
  - Feedback: Compare the Antenna signal with the desired value and correct the generator drive accordingly
  - Feedforward: Adjust the drive in anticipation of the beam gaps, from prior knowledge, PU measurements or observations of the previous cycles.

Simple Feedback (PI controller)



- Using a simple feedback, the sharp end of a 6 mA DC beam batch (gap of infinite length) results in 0.8 % voltage transient
- Scaling to 40 mA DC we would get 5 % voltage transient.

Improved Feedback (LQG)

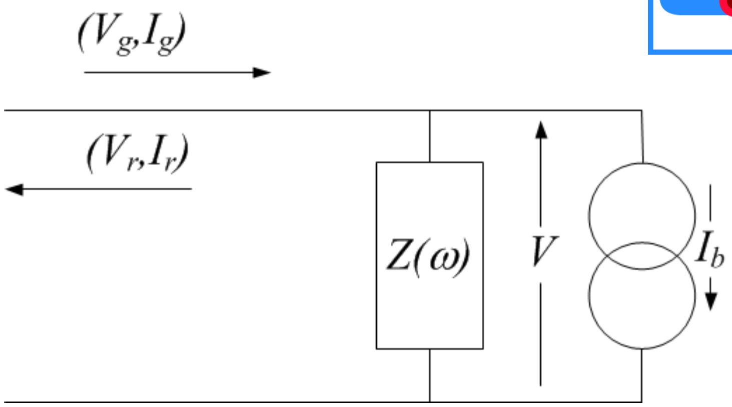


- With an improved feedback (Linear Quadratic Regulator, LQG) the transient does not exceed the 1 μs case for any gap length.

Feedforward

Keep constant

$$\begin{cases} \dfrac{dv_I(t)}{dt} + \dfrac{\omega}{2Q_L} v_I(t) + \Delta\omega\, v_Q(t) = \omega R/Q \left[i_{gI}(t) - \dfrac{i_{bI}(t)}{2} \right] \\ \dfrac{dv_Q(t)}{dt} + \dfrac{\omega}{2Q_L} v_Q(t) - \Delta\omega\, v_I(t) = \omega R/Q \left[i_{gQ}(t) - \dfrac{i_{bQ}(t)}{2} \right] \end{cases}$$



- The cavity field will be constant if we modulate the generator current to track the beam current modulation
- No need for very fast tracking. The error is smoothed by the slow cavity response
- The modulation of the generator current can be driven by
  - Observations of the previous cycles
  - Knowledge of the beam pattern. Easy as the LLRF is also piloting the choppers.

Conclusions

- With the LQG regulator, the transient beam loading will be compensated after ~1 μs, **independently** of the gap length
- With additional feedforward the resulting amplitude and phase transients will be reduced below the 2% and 1 degree (caused by a 1 μs gap without regulation), for **any** gap length.

Thank you…