RF Field Control Consideration in Beam Comissioning

EUROPEAN SPALLATION SOURCE

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Outline

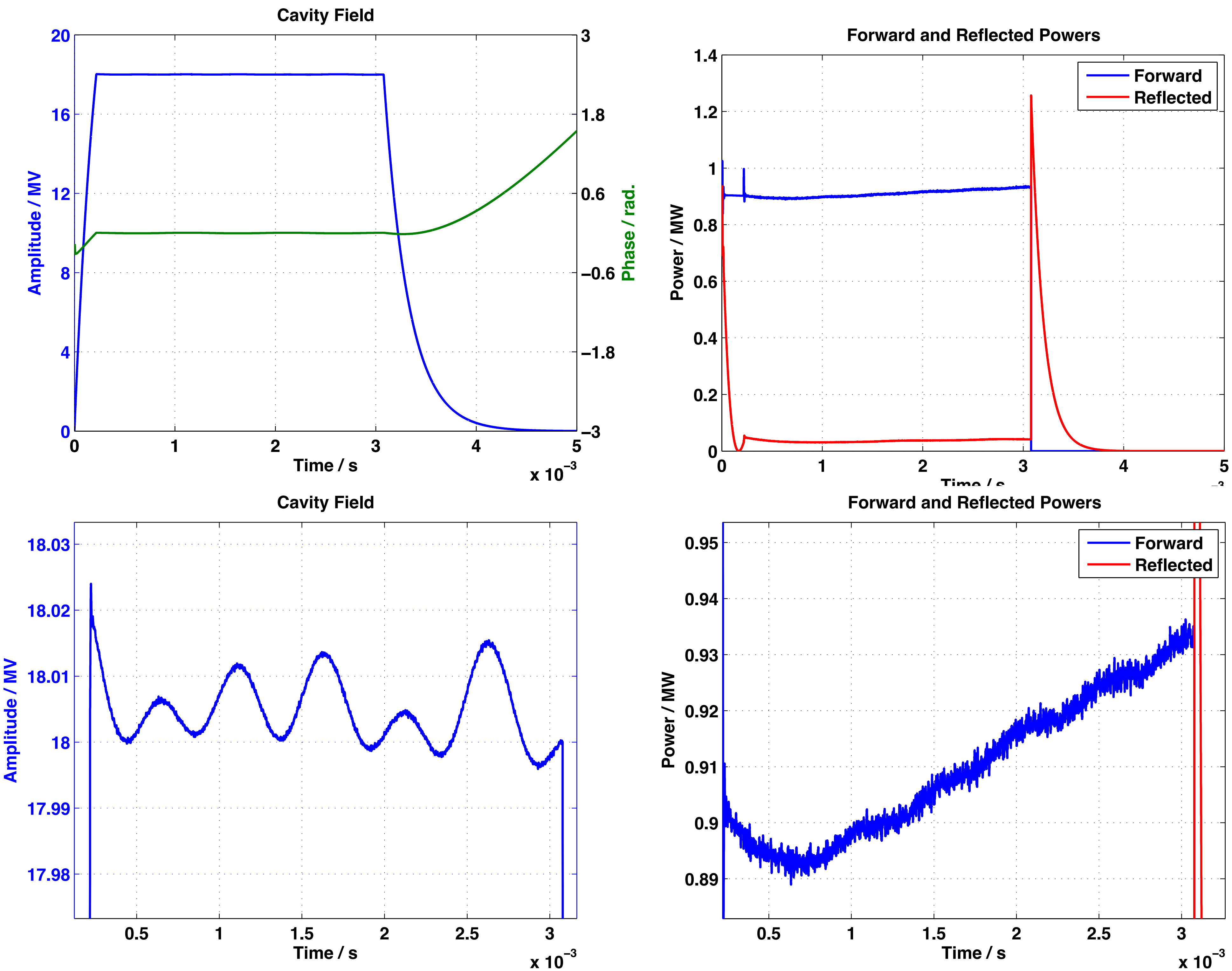
- Background
- RF control issues at beam commissioning (power overhead issue at superconducting cavities and cavity stability issue at normal conducting cavities)
- Possible solutions

Background

- Part of series of studies on power overhead reduction in RF field control
    1. Power Overhead Reduction for RF Field Control in Beam Commissioning, ESS-doc-263.
    2. Calculation on Power overhead in ESS High Beta Cavity Control, ESS-doc-244.
    3. Power Overhead Calculation for Lorentz Force Detuning, ESS-doc-184.
    4. Some Considerations on Pre-detuning for Superconducting Cavity, ESS-doc-174.
- Examine the possibilities of less than 10% power overhead (25% or more are assumed at the beginning, without detailed studies)
- Investigations already exist in other project and labs (Jparc, Desy). For instance, the goal of ILC project: 5%.
- Advantage at ESS: one cavity per klystron, most are cold linac, cavity field stability not high (1%, 1 deg.), high cavity bandwidth, powerful new technology.
- early example for RF field control (analog control) at Los Alamos in 1967. ±2 deg. phase and ±1.5% amplitude, ~200 kHz bandwidth.

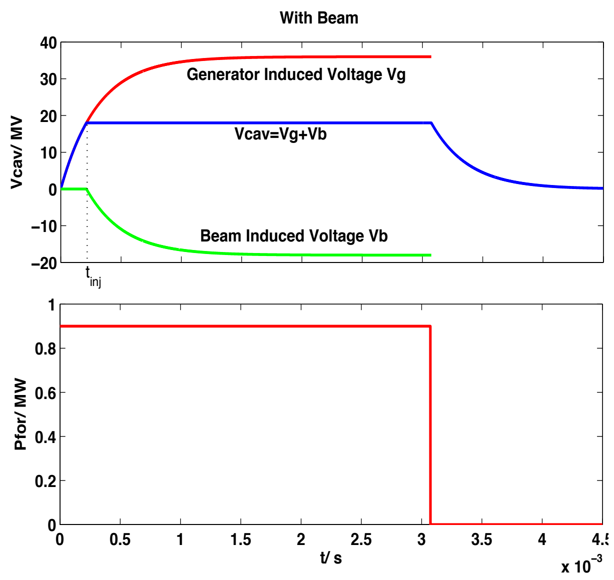
Overhead for error compensation

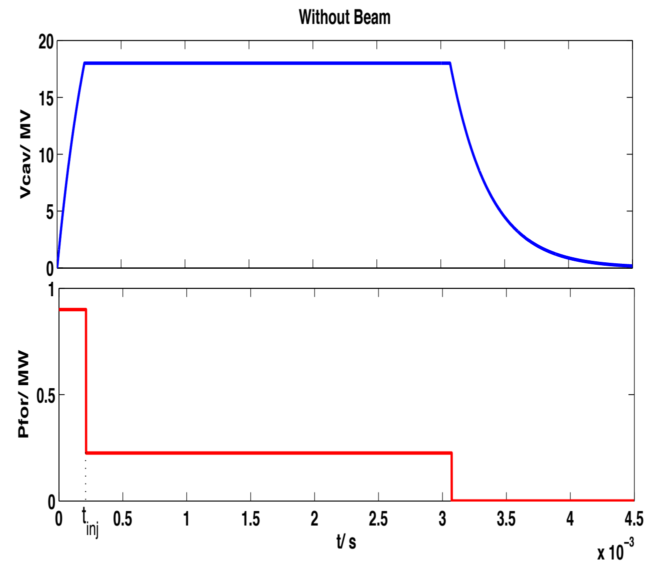
- Klystron cathode voltage ripple: 1%, 1kHz
- Beam fluctuation: droop: 2% random noise: 2%
  - Ql variation: -30%
- Lorentz force detuning: K=1Hz/MV, τ_m=1ms
  - Feedback Loop gain: 50 Loop delay: 2us
- Feedforward for LFD
- Set point adjust
- Pre-detuning for sync. phase and LFD



Overhead at beam commissioning

- Situation are more complicated when it comes to the beam commissioning
- Deal with different beam modes with different beam current, pulse length, arrive time.
- Perturbation to the cavity field caused by beam loading is significant and results in considerable power overshoot under feedback control

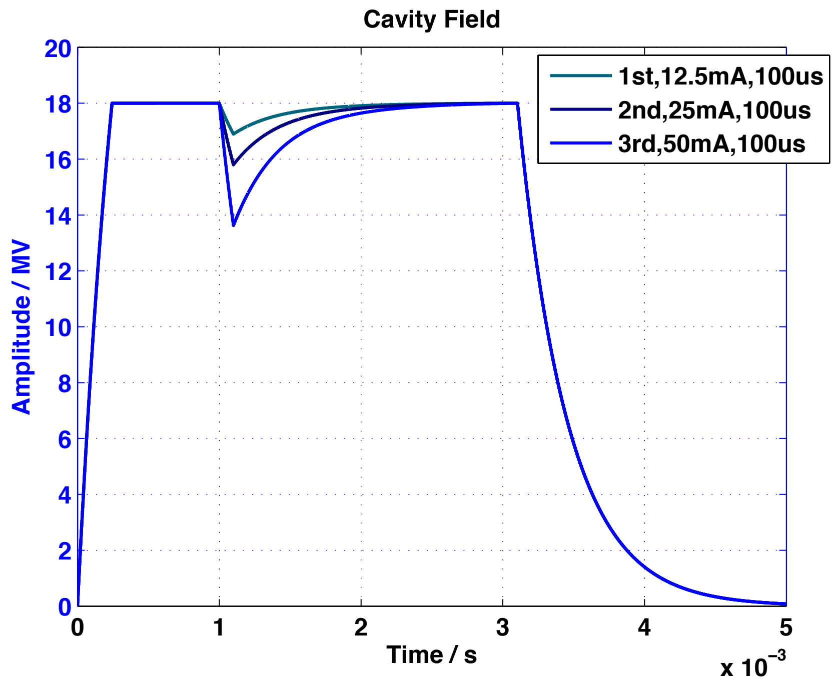


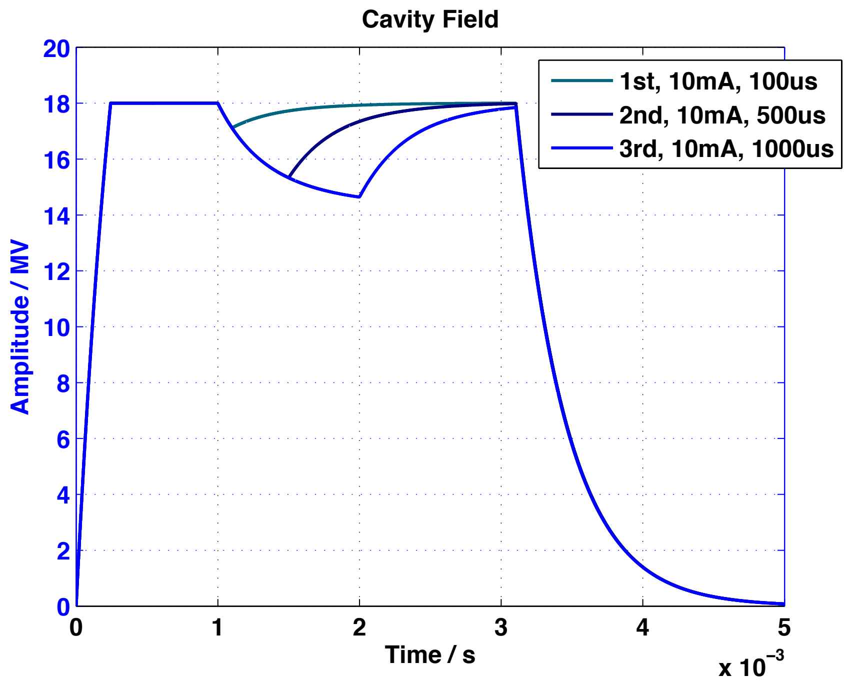


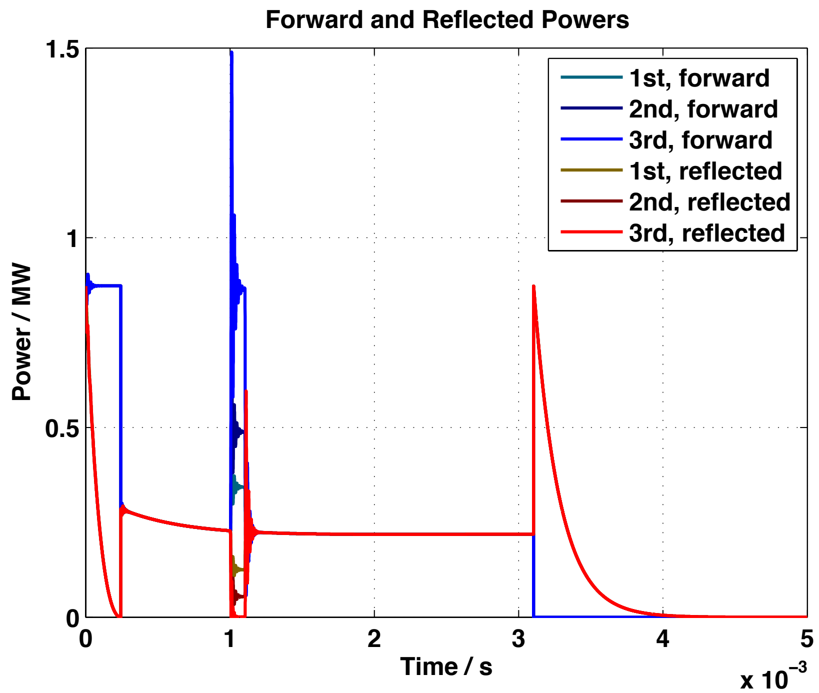
$$V_b = \frac{\omega_{1/2} R_L \cdot I_b}{\omega_{1/2} - j\Delta\omega}\left(1 - e^{-(\omega_{1/2} - j\Delta\omega)t}\right)$$

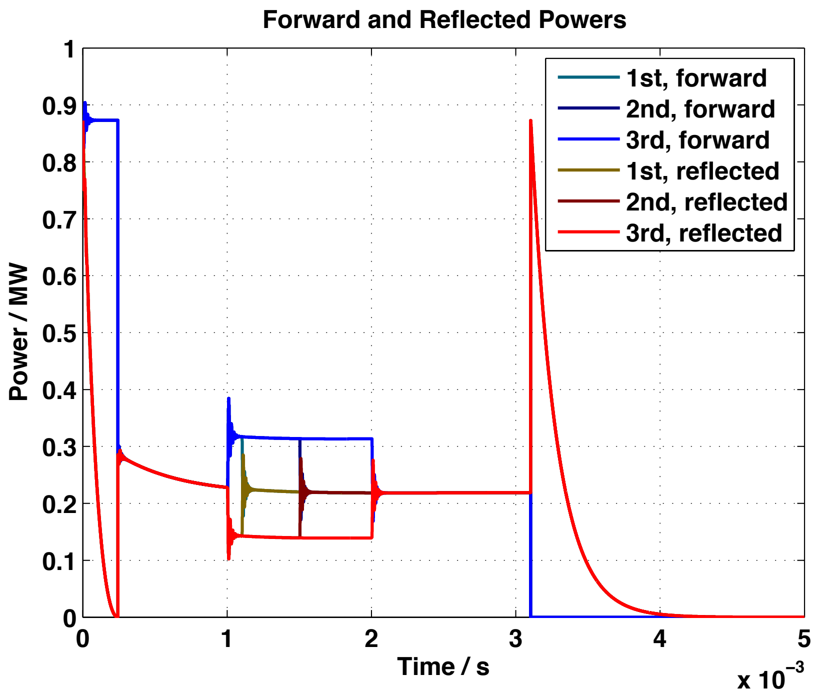
Overhead at beam commissioning

- Behaviors are different among different beam modes
- peak power depends on the error when system transient response reaches its first overshoot peak, limited by system bandwidth. $P = error \cdot G$



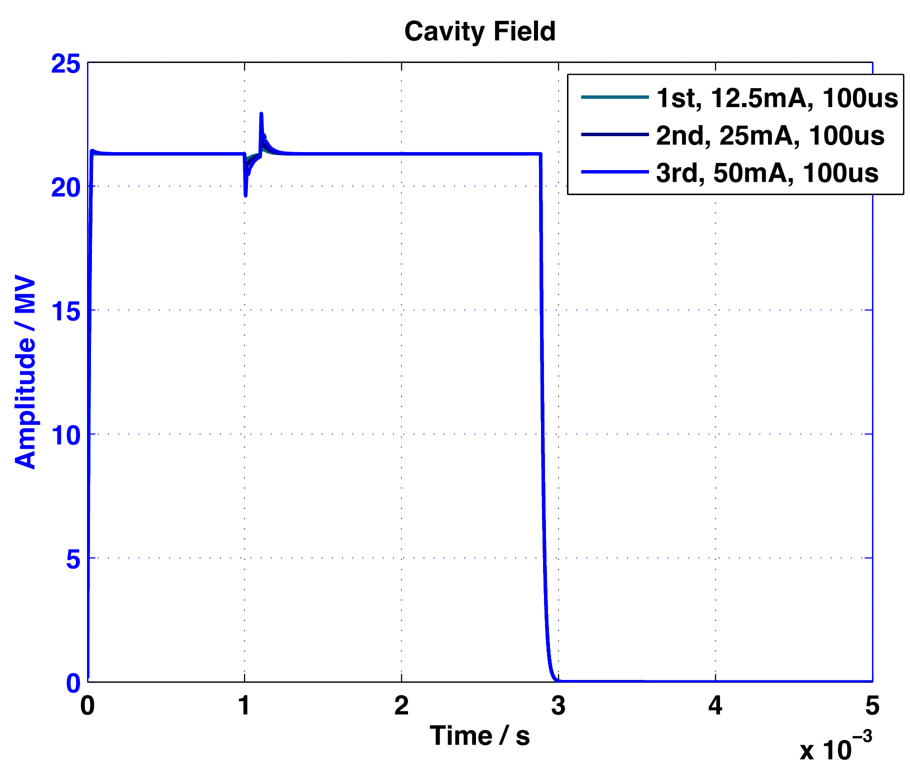


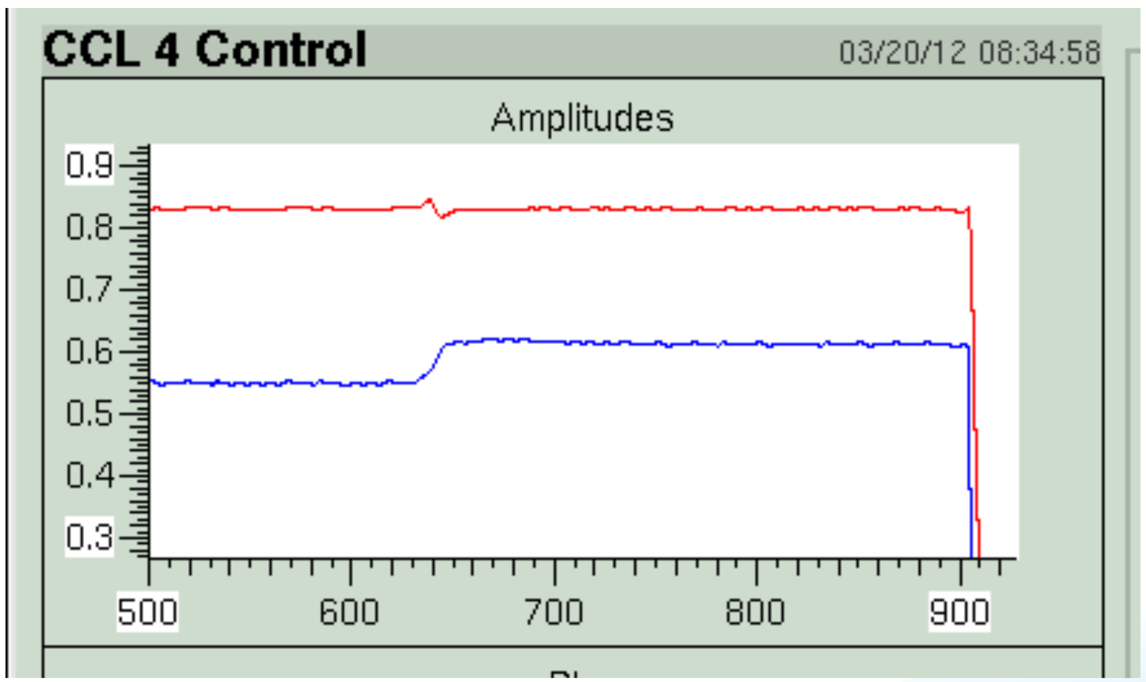




Worse at normal conducting cavity

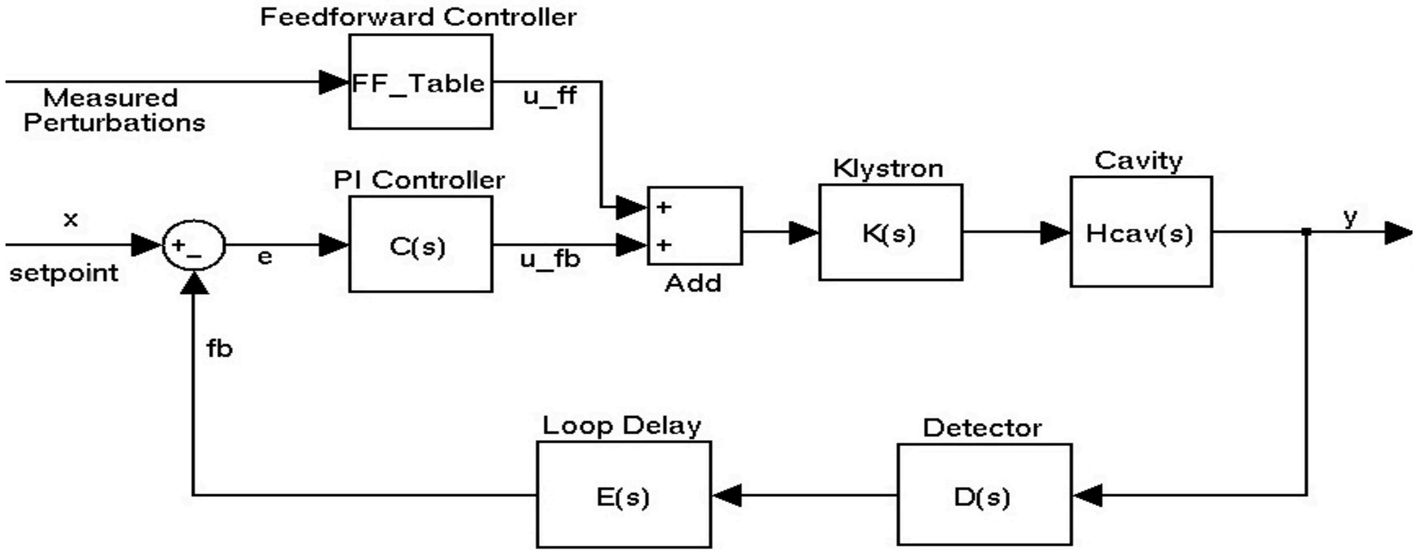
- Normal conducting cavities (RFQ, DTL) have much lower Ql, ~ factor of 30.
- Control is much more difficult due to low loop gain (~2, compared to 50 in superconducting cavity)
- Beam loading is a very high frequency perturbations, and cannot be well compensated by integral controller

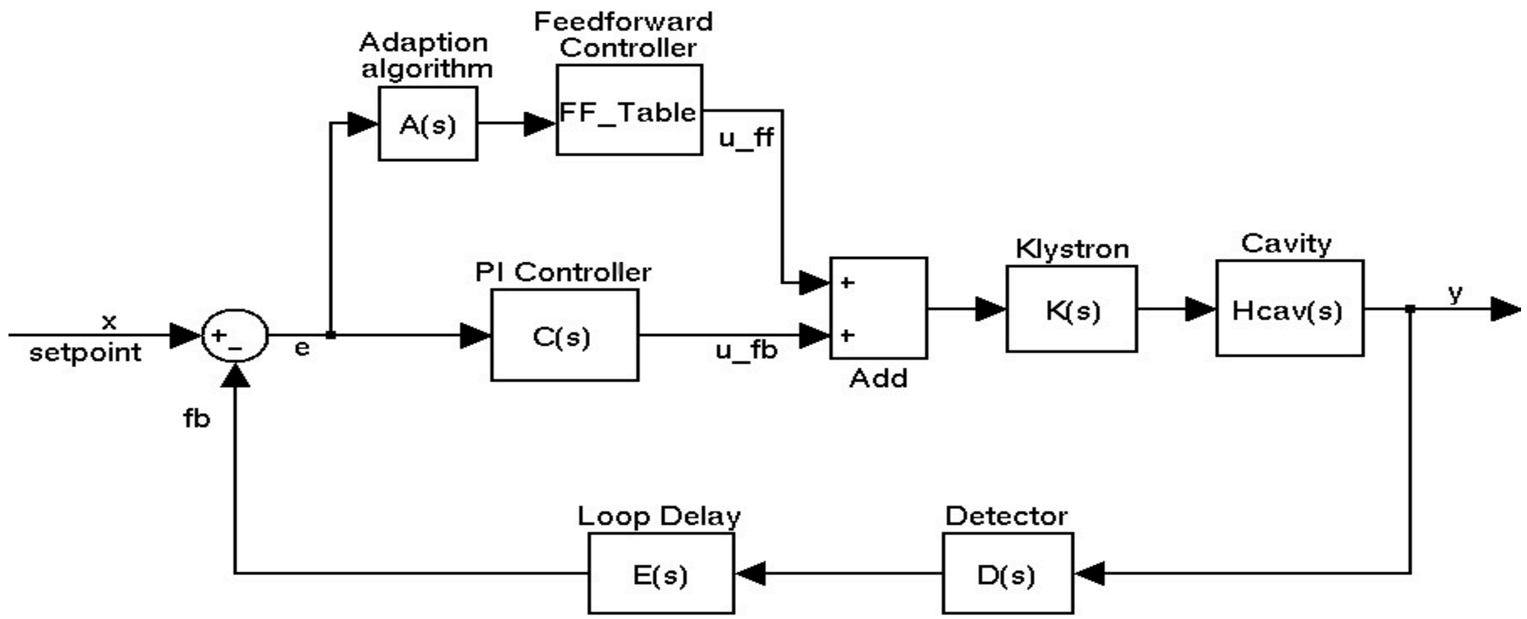




from presentation of J. Galambos

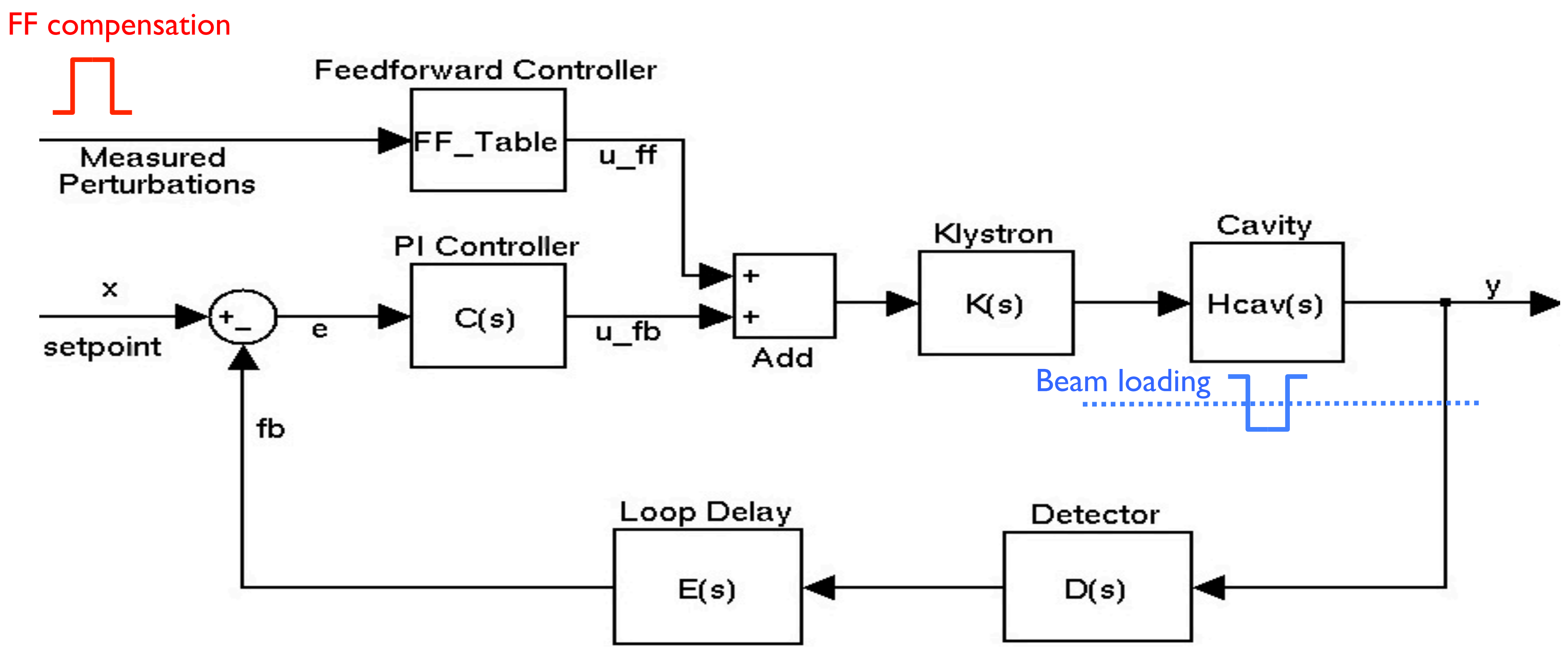
FeedForward vs. Adaptive FeedForward



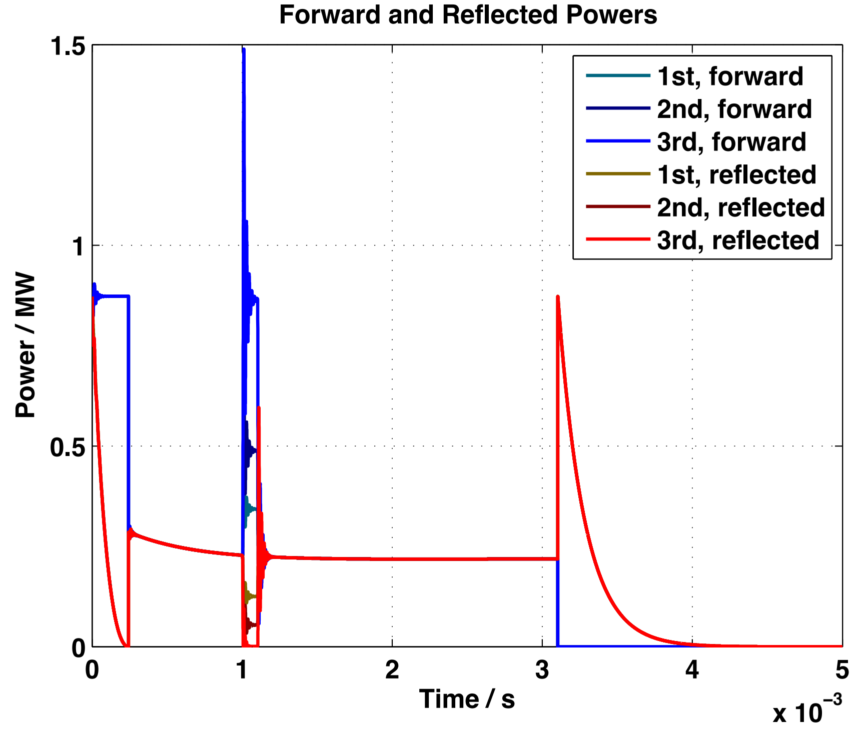


Solution: Individual FF compensation

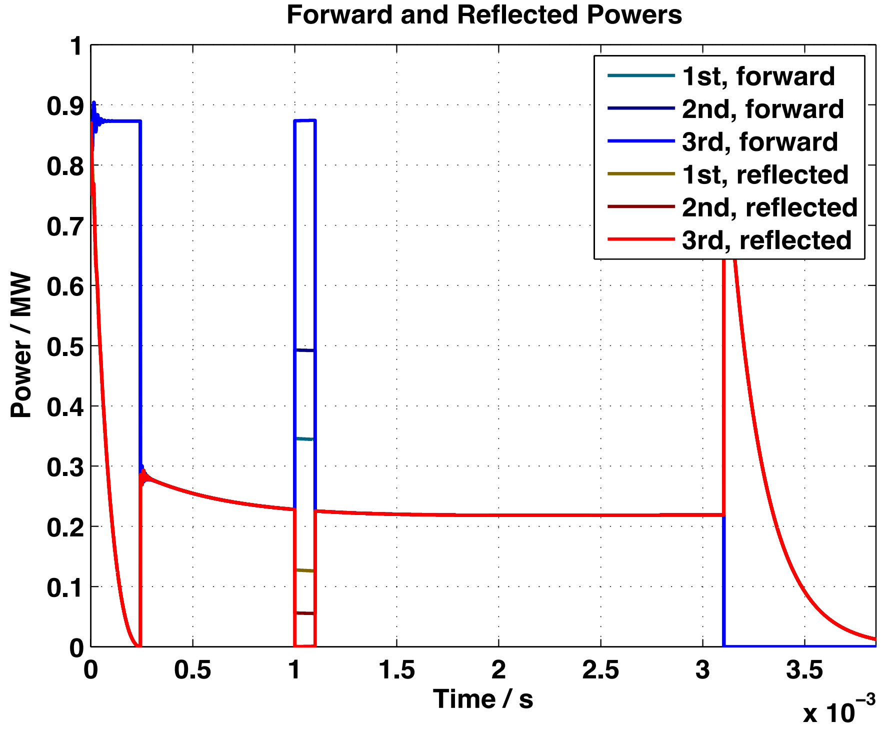
- Individual FF(feedforward)compensation for each beam modes, by knowing its peak current, pulse length, arrival time.



Feedback only

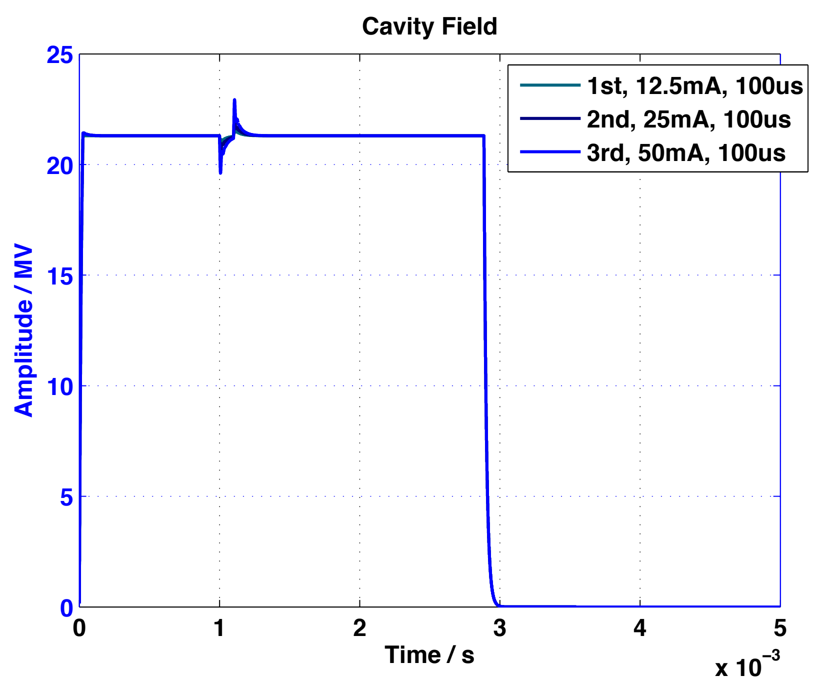


Feedback + Feedforward

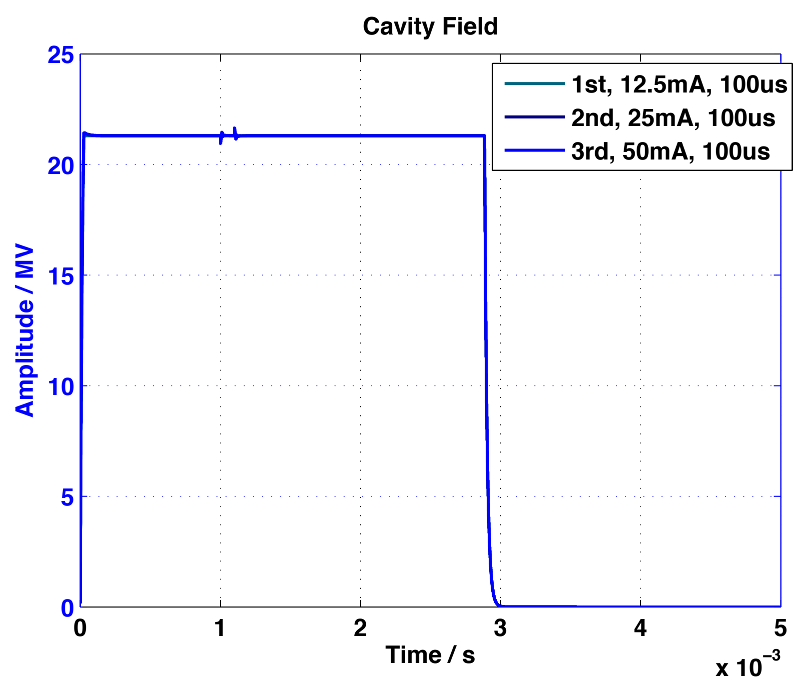


Performance under errors

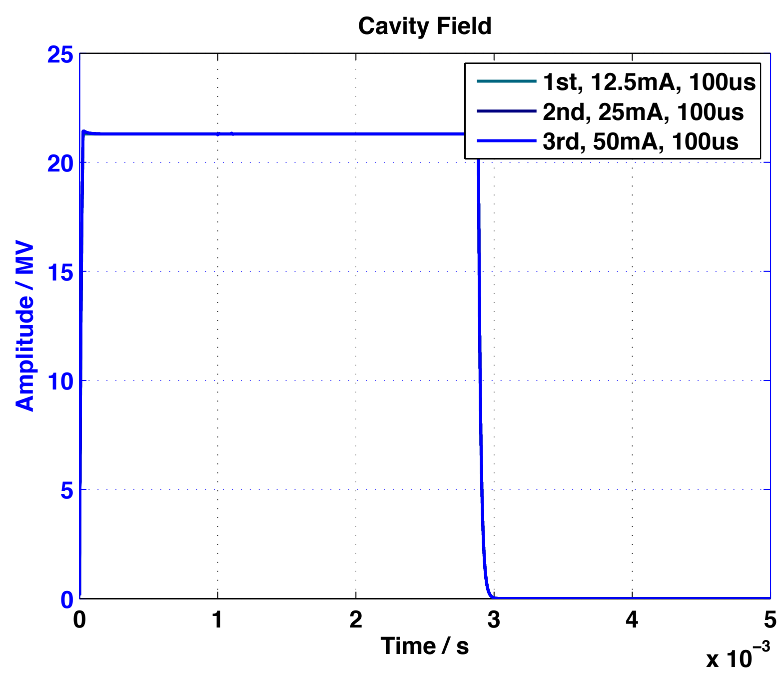
- Beam current fluctuation, random noise
- Beam arrival time jitter (better performance achieved when arrival time jitter <100ns)



Without FF compensation
Error: ±7%



Arrival time jitter: 1us
Field error: ±1.6%

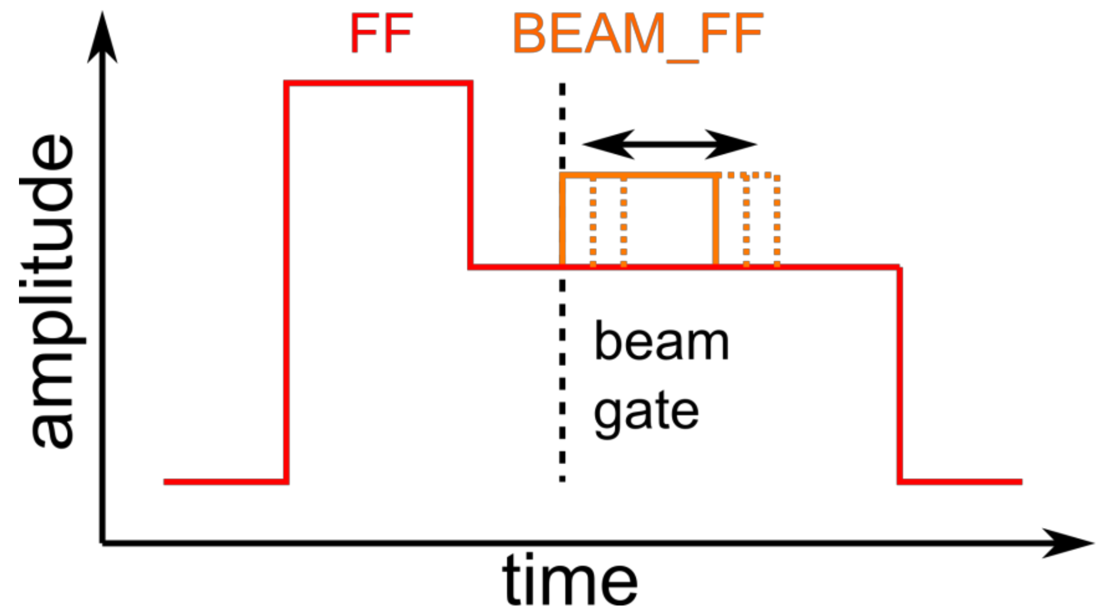


Arrival time jitter: 0.1us
Field error: ±0.18%

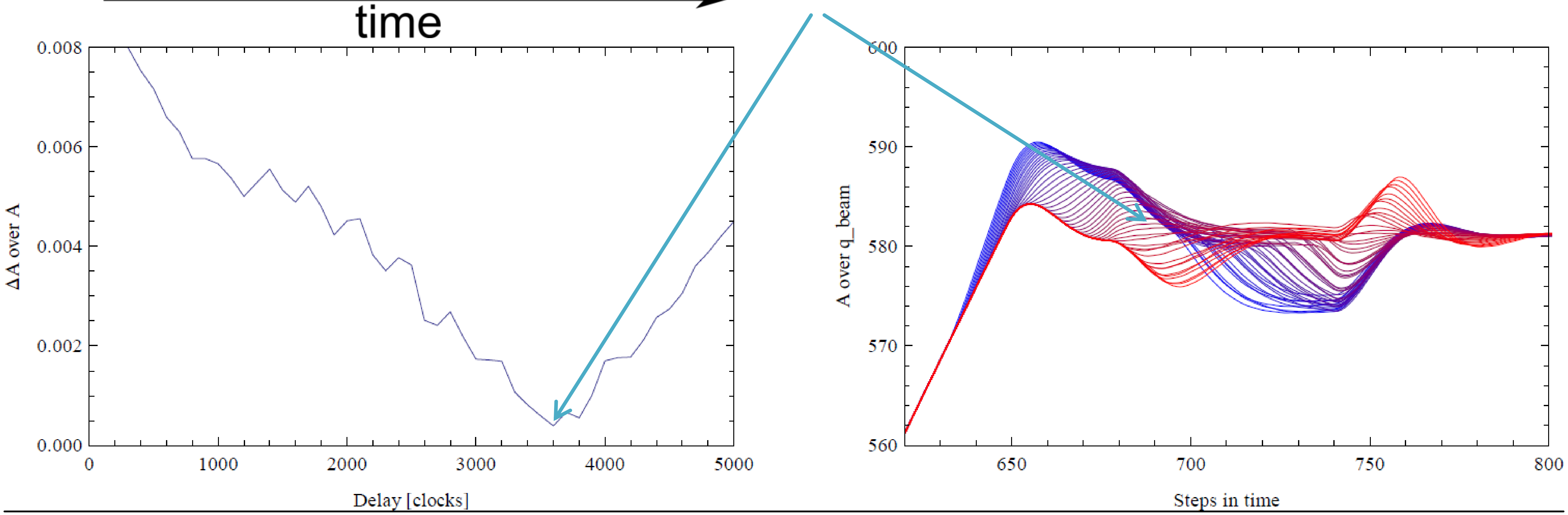
Slide from Mathieu OMET, KEK

Beam Compensation

Beam gate delay scan @ 3 mA beam, 10000 bunches



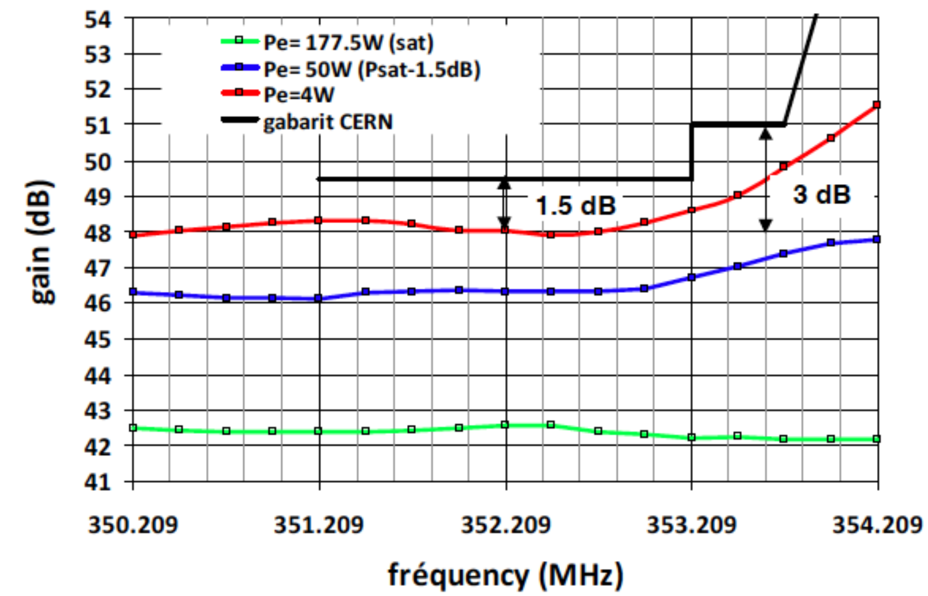
Scan optimum		w/o beam
Beam gate delay	3600	-
Beam FF Ampl.	7000	-
ΔA/A (filter channel beam gate)	0.05%	0.009%

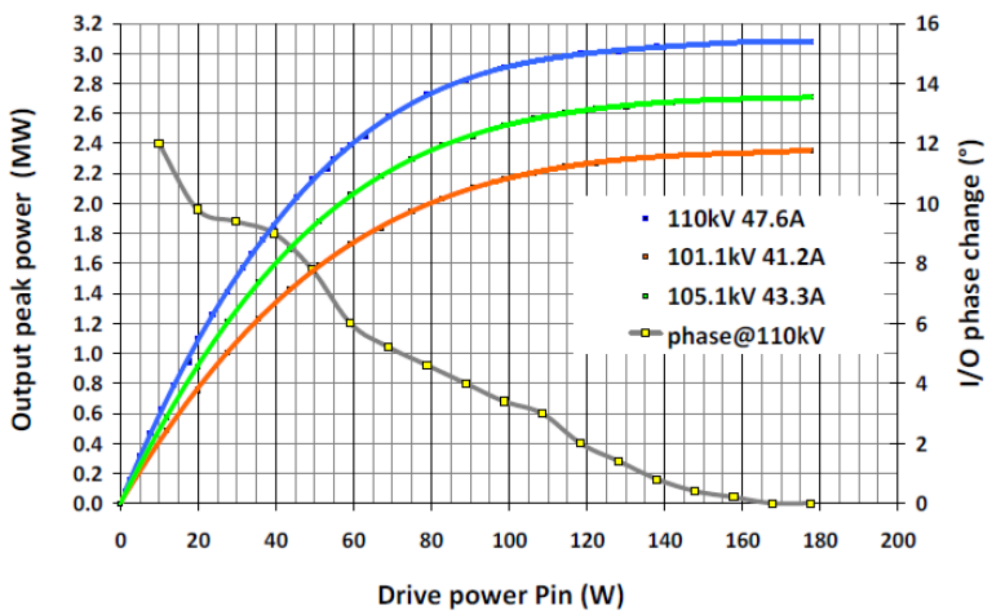


Klystron linearization

- Amplitude Linearization
- Phase compensation:

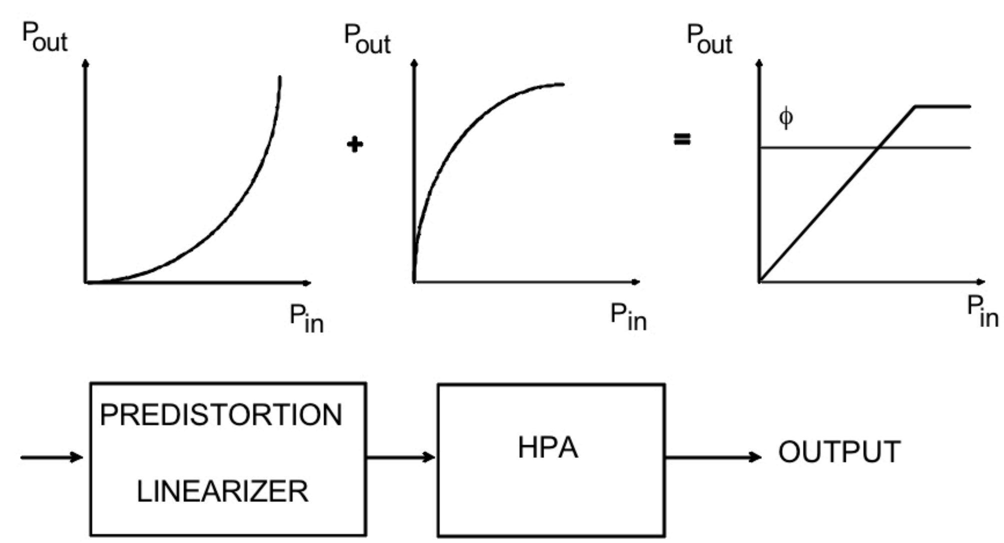
Out put phase varies a lot with cathode errors.
Changes with operation condition and environment change





THALES

- 352MHz, 1.5ms, 50Hz, 3.1MW



Conclusion

- Behaviors of Different beam mode loading are different in the cavity, peak current change are more concerned by cavity control.
- Power overhead issue becomes severe for higher peak current beam under feedback. Situation gets worse for normal conducting cavity field stability
- Individual compensation for each beam modes seems promising, with powerful modern technologies. Output limiter with klystron linearization expects to be another big contribution for overhead reduction
- To deal with such new challenges, LLRF prototype hardware will employ 10 input channel (2.5 times as SNS), ~1000 times bigger memory, and faster CPU, communication…
- 10% power overhead investigation continues…

Thank you for the attention!