Intra-pulse feedback in pulsed RF Linacs

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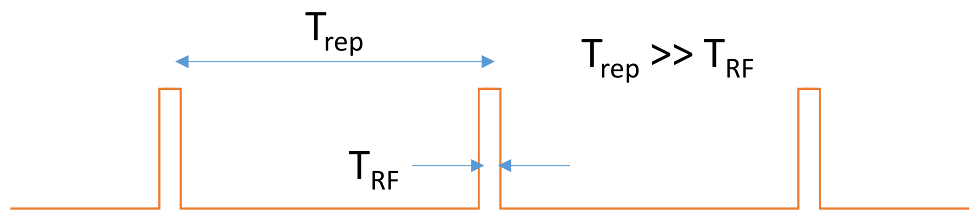
Low-Level RF Systems

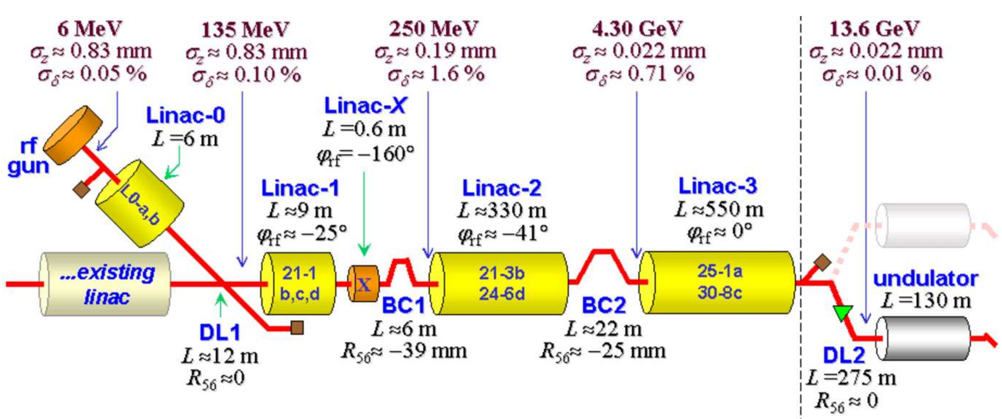
USPAS January 2017

Pulsed RF Linac

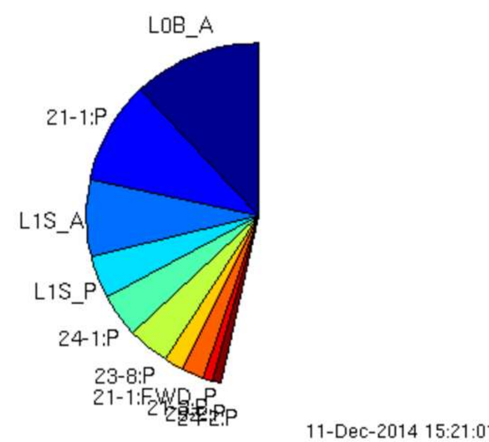


Why do I care?

- SLAC linac (LCLS, FACET): T_{rep} = 1/120 pps = 8.3 ms; T_{RF} ~ 5 µs
- Pulse-to-pulse stability dominated by RF jitter of a few stations
- Inter-pulse feedbacks exist, but open loop intra-pulse
- Experiments often limited by longitudinal jitter!



Sources for DL2 Energy Jitter (0.042%)



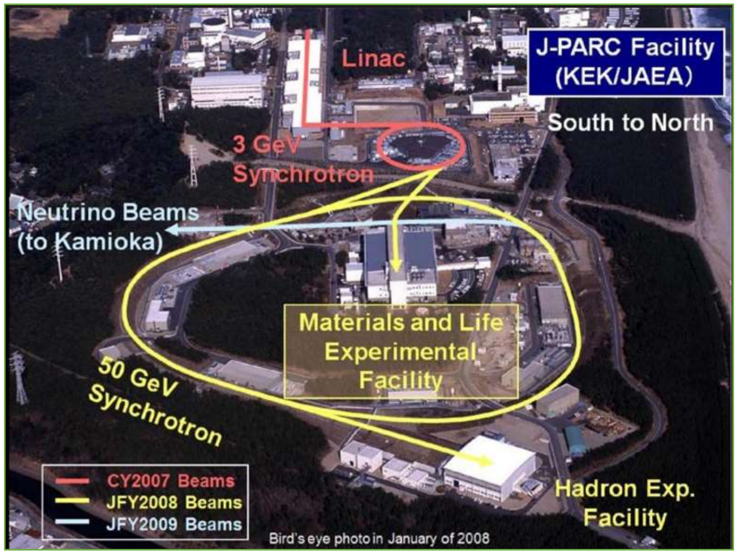
J-PARC Linac

- J-PARC Linac provides a 181-MeV proton beam to the 3-GeV rapid-cycling synchrotron (RCS)
- “the maximum RF pulse width is 620 μs … repetition is 25 pps”

WEPMN039 Proceedings of PAC07, Albuquerque, New Mexico, USA

PERFORMANCE OF J-PARC LINAC RF SYSTEM

T. Kobayashi#, E. Chishiro, T. Hori, H. Suzuki, M. Yamazaki, JAEA, Tokai, Naka, Ibaraki, Japan
S. Anami, Z. Fang, Y. Fukui, M. Kawamura, S. Michizono, K. Nanmo, S. Yamaguchi,
KEK, Tsukuba, Ibaraki, Japan



J-PARC Linac RF System

- "… keep the cavity field stability within ±1% in amplitude and ±1° in phase…"
- "… main factors of the instability are the voltage sag and the pulse-to-pulse fluctuation of the klystron DC power supply, the temperature drift and the beam loading."

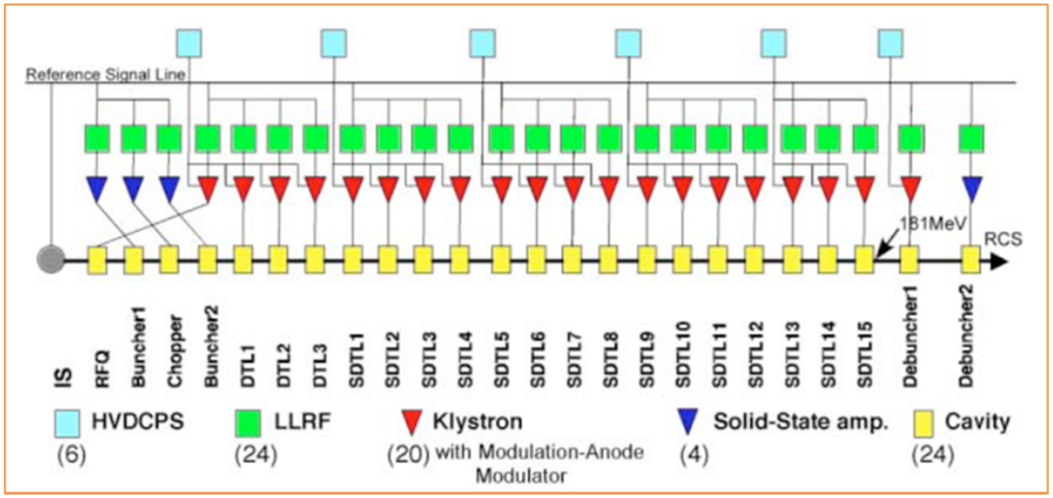


Table 1: Main parameters of the HVDCPS

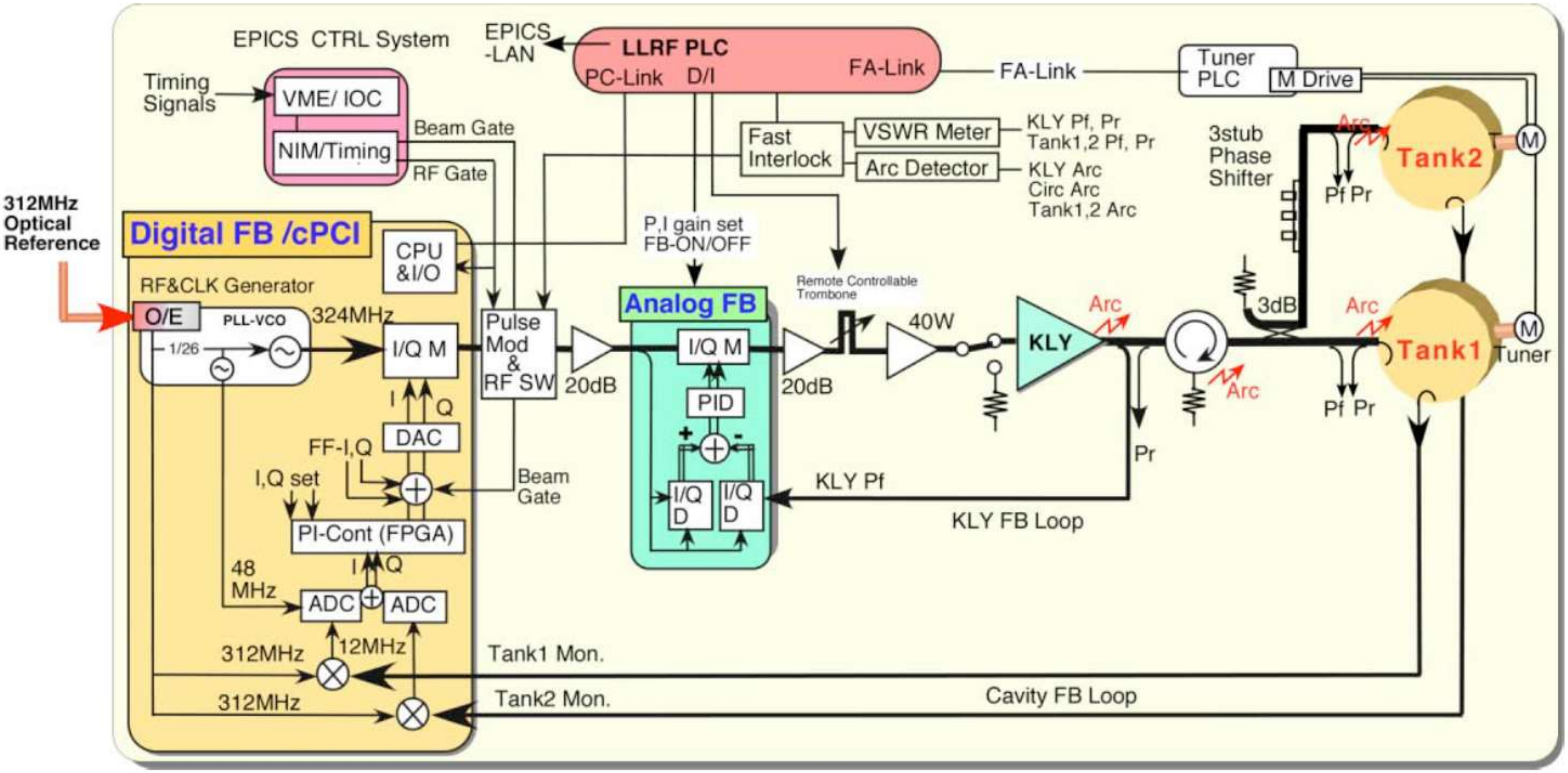
DC voltage output	110 kV (incl. sag drop voltage)
Pulse width	700 μsec
Pulse repetition rate	50 Hz (Max)
Voltage sag	< 5%

Table 2: Main parameters of the 324-MHz klystron

Peak Power	2.5 (max. 3.0) MW
Pulse Width	650 μs
Repetition	50 Hz (25 Hz)
m-Perveance	1.37 A/V $^{3/2}$
Gain	50 dB
Efficiency	55 %
Beam Voltage	105 (max. 110) kV
Beam Current	45 (max. 50) A
Mounting Position	Horizontal

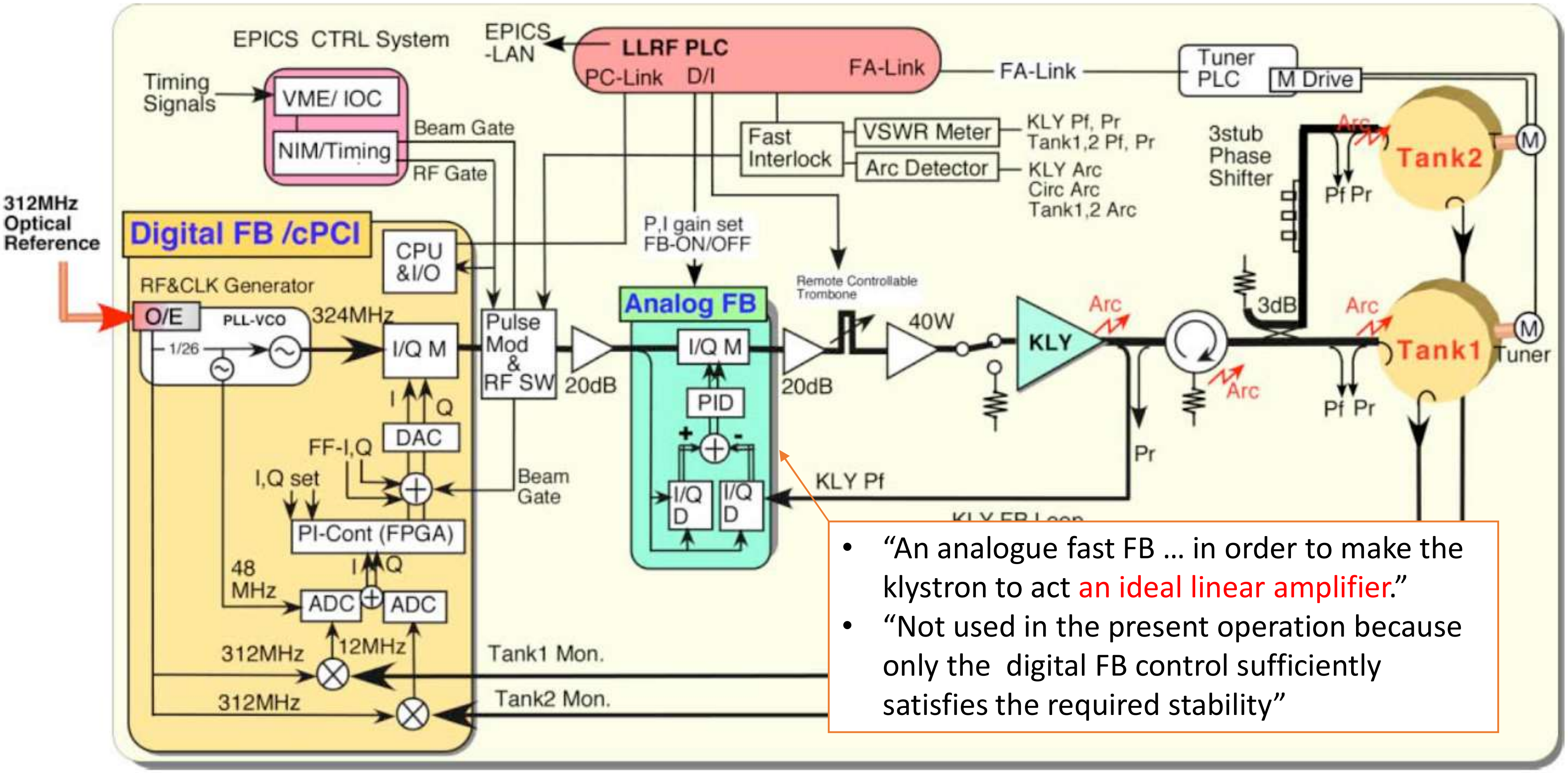
J-PARC Station LLRF

T_{rep} = 20 ms; T_{RF} = 700 µs



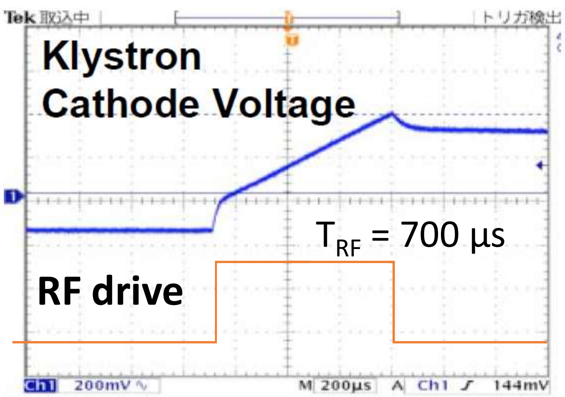
J-PARC Station LLRF

T_{rep} = 20 ms; T_{RF} = 700 µs



- “An analogue fast FB … in order to make the klystron to act an ideal linear amplifier.”
- “Not used in the present operation because only the digital FB control sufficiently satisfies the required stability”

Digital feedback



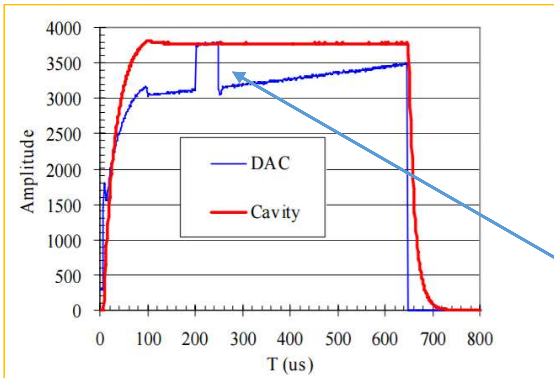
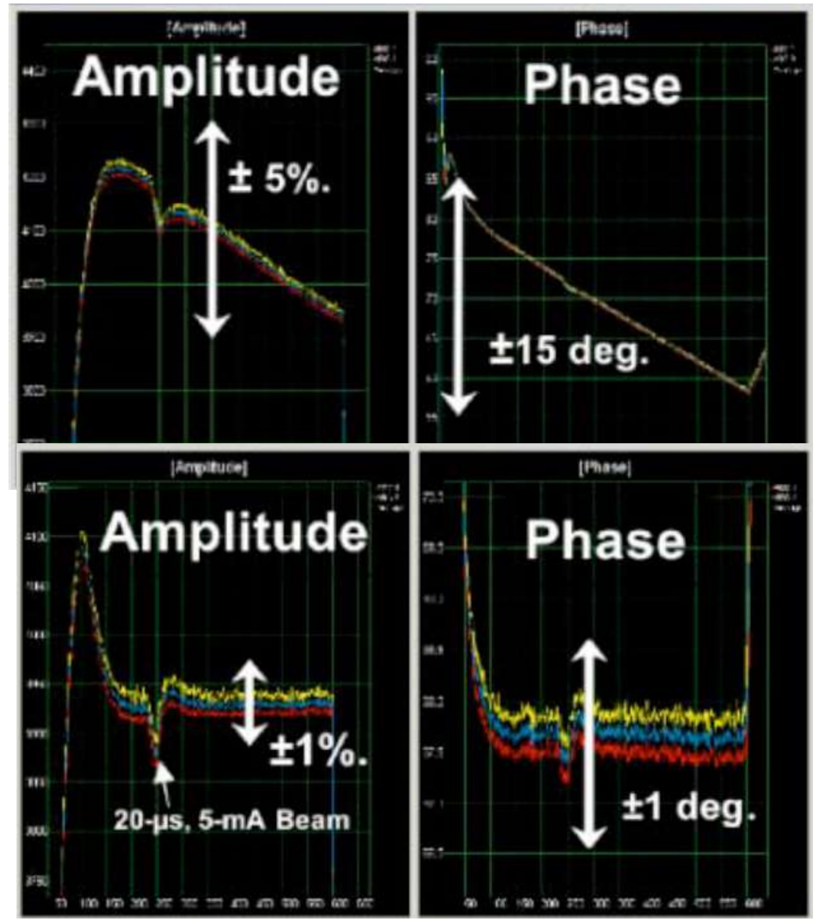


Figure 6: Amplitudes of the cavity and DAC outputs at SDTL3 with beam feedforward compensation.

3% voltage sag drives 30-deg phase excursion

Open Loop

Closed Loop



Beam loading corrected by feedforward

Analog feedback on cavity signal

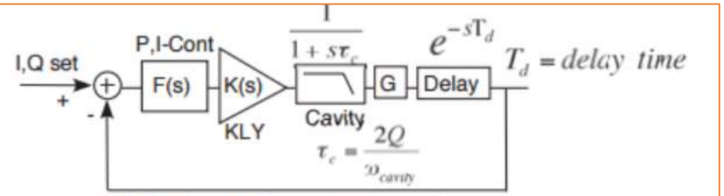
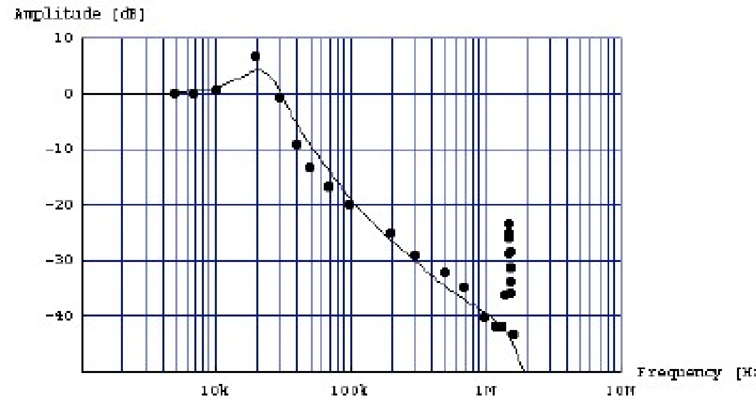


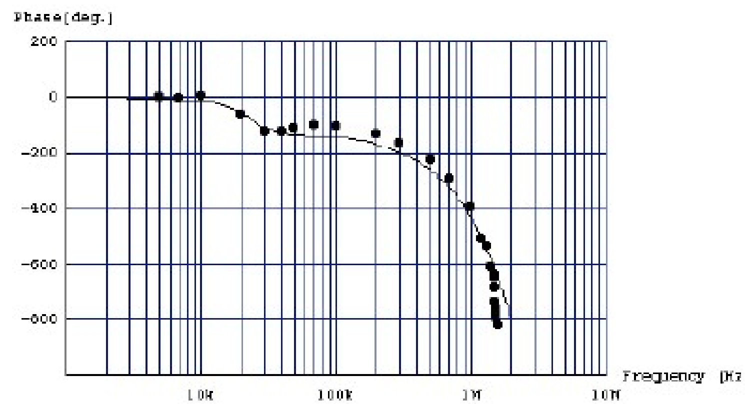
図５：FB制御系のブロックモデル

τ_i = 95 μs
τ_C = 22 μs
$\tau_k = 9.9\mathrm{x}10^{-8}$
$\alpha = 1.2\mathrm{x}10^{-14}$
T_d = 0.8 μs



$$F(s) = Kg \cdot \left(K_p + \frac{K_i}{1+s\tau_i}\right) \qquad K(s) = \frac{1}{1+s\tau_k - \alpha s^2}$$

$$H(s) = \frac{A(s)}{1+A(s)}, \qquad A(s) = G \cdot F(s) \cdot K(s) \cdot \frac{1}{1+s\tau_c} \cdot e^{-sT_d}$$



T_d limits the feedback response at high ω

Performance Study of Low-Level RF Analog Feedback Control System for J-PARC Linac
T. Kobayashi et al, Proceedings of 2nd Annual Meeting of Particle Accelerator Society of Japan

What about a faster time scale?

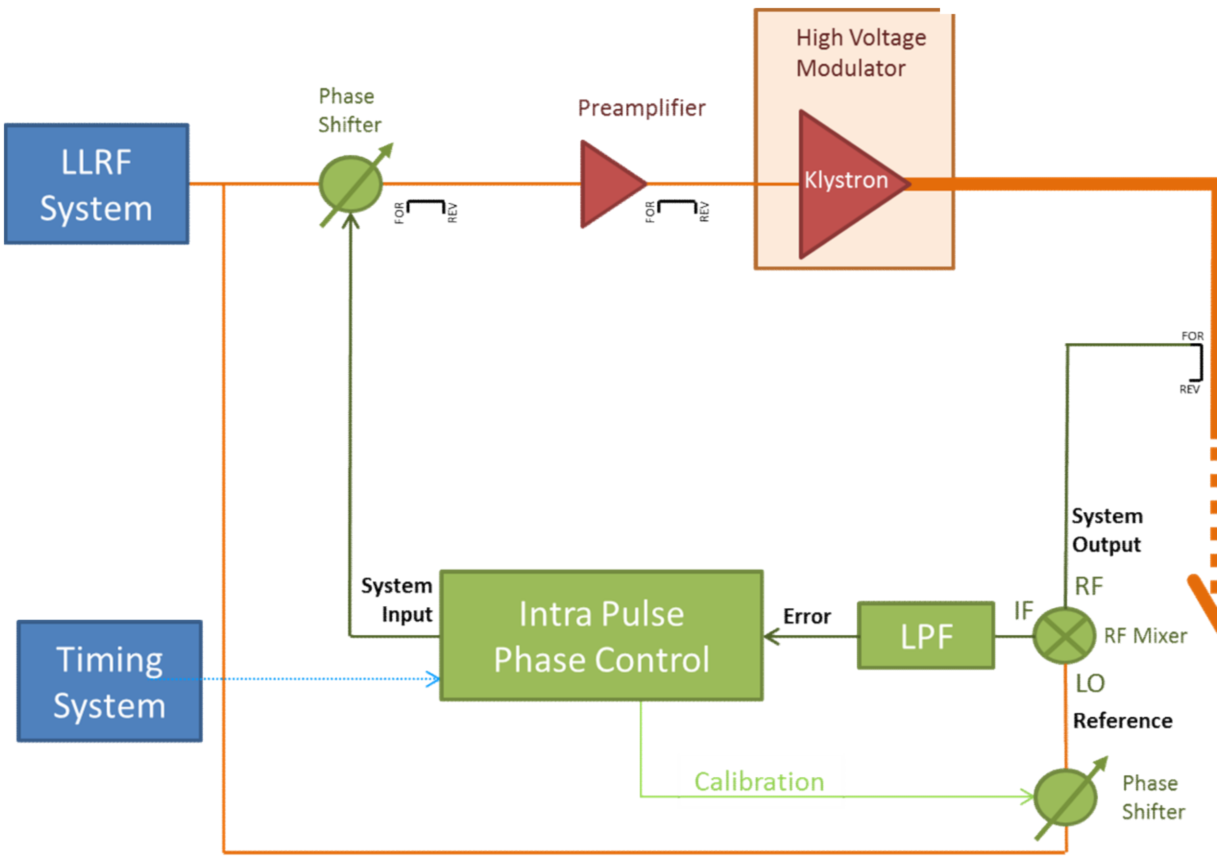
SwissFEL at PSI

3 µs RF pulse, HV modulator

Analog PI controller

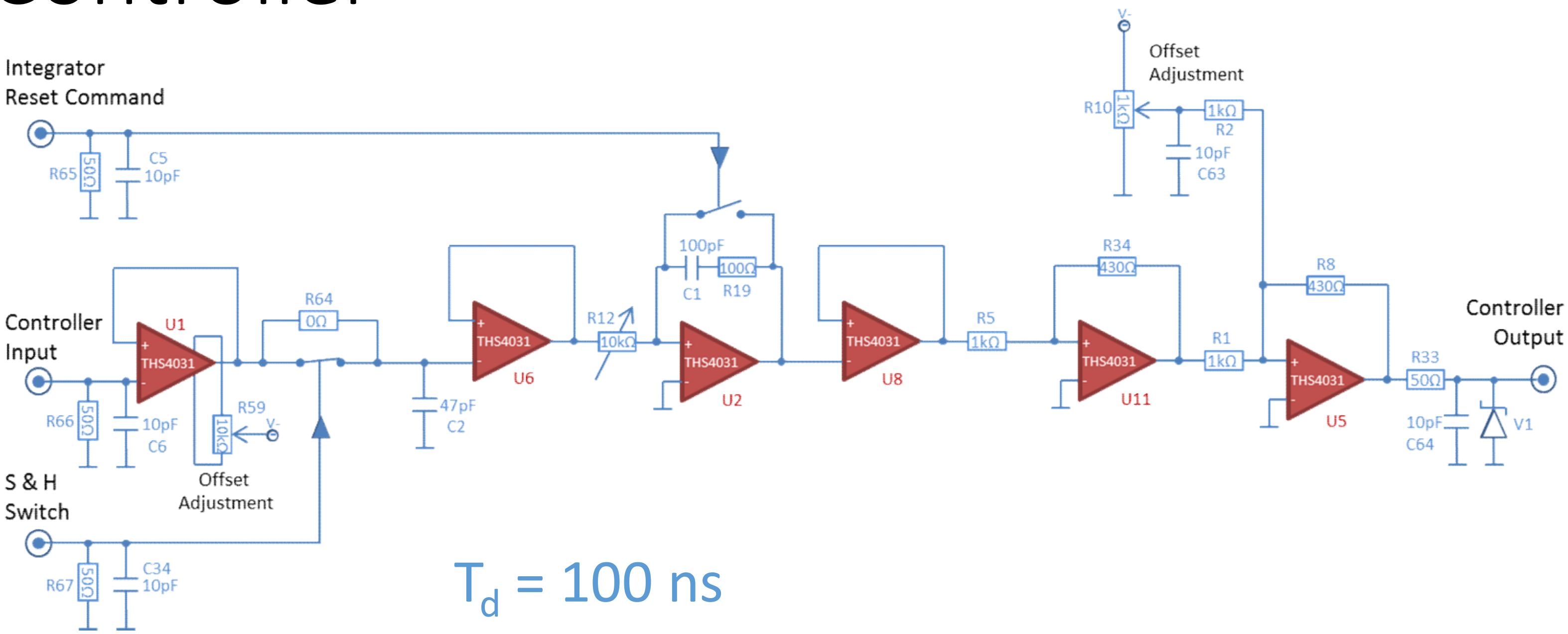
T_d = 100 ns

"In the lab test a control bandwidth of 1MHz has been measured"



Intra Pulse Phase Control
M. Bronnimann, PSI, LLRF Workshop 2015

PI Controller

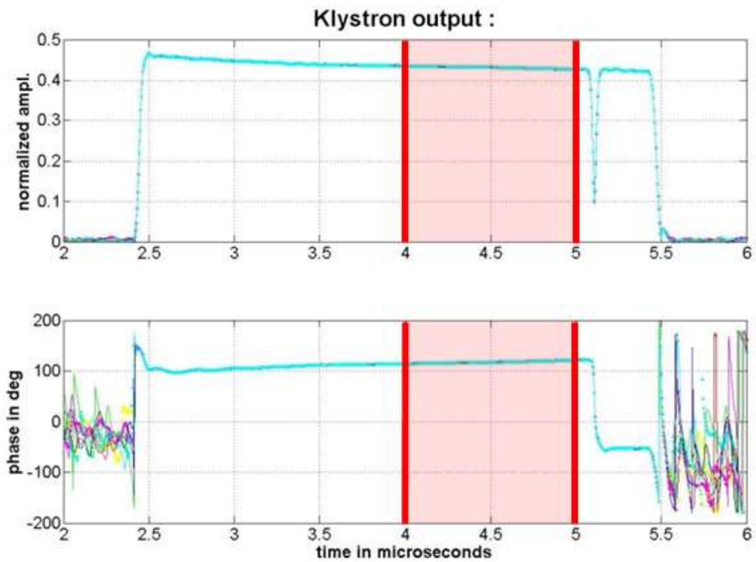


T_d = 100 ns

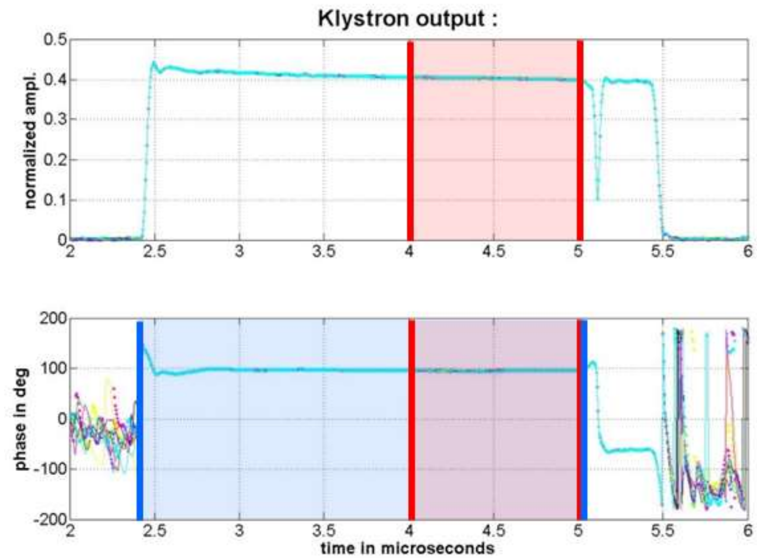
"In the lab test a control bandwidth of 1MHz has been measured"

Intra pulse phase correction

Without IPPC



With IPPC, HMC929 and serial PI controller



measurement	Intra pulse phase stv. dev. in degree	P2p phase jitter in degree
Without IPPC	2.01	0.046
IPPC in open loop	2.03	0.047
IPPC in closed loop	0.37	0.017