RF control for crab cavity

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KEKB review committee

Beam-loading on crab cavity

K. Akai et al, EPAC96, p.2118.

2.2 Vector relations

In the following, a positron beam ($q > 0, I_b > 0$) is considered. (An electron beam can be treated similarly.) Figure 1 shows a vector relation for the crabbing mode. In this figure, $V_{\perp g}$ is the generator voltage, $V_{\perp gr}$ the generator voltage on resonance, α_L the angle between $V_{\perp gr}$ and $V_{\perp c}$, and ϕ_c the angle of $V_{\perp c}$ with respect to the beam. It is similar to that for the accelerating mode, except for the beam-induced voltage, $V_{\perp br}$ and $V_{\perp b}$. The phase of $V_{\perp br}$ with respect to the bunch phase is 90 or 270 degrees, according to $\Delta x < 0$ or $\Delta x > 0$ (180 degrees for the accelerating mode). Furthermore, the amplitude of $V_{\perp br}$ is dependent on Δx.

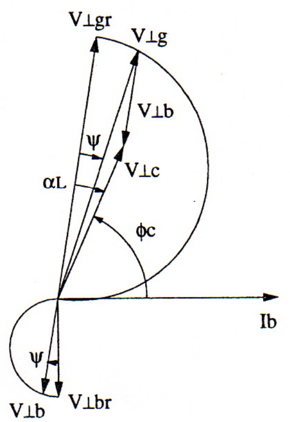


Figure 1: Vector relation for the crabbing mode ($\Delta x > 0$).

From the vector relation we obtain

$$\tan\alpha_L = \frac{\tan\psi - Y\cos\phi_c}{1 + Y\sin\phi_c}, \quad (6)$$

$$|V_{\perp gr}|\cos\alpha_L = |V_{\perp c}|(1 + Y\sin\phi_c), \quad (7)$$

where $Y \equiv \pm |V_{\perp br}/V_{\perp c}|$ (positive sign for $\Delta x > 0$ and negative sign for $\Delta x < 0$).

Since $|V_{\perp gr}|$ is related to the input power (P_g) as

$$|V_{\perp gr}| = \frac{2\sqrt{\beta}}{1+\beta}\sqrt{\bar{R}_\perp P_g}, \quad (8)$$

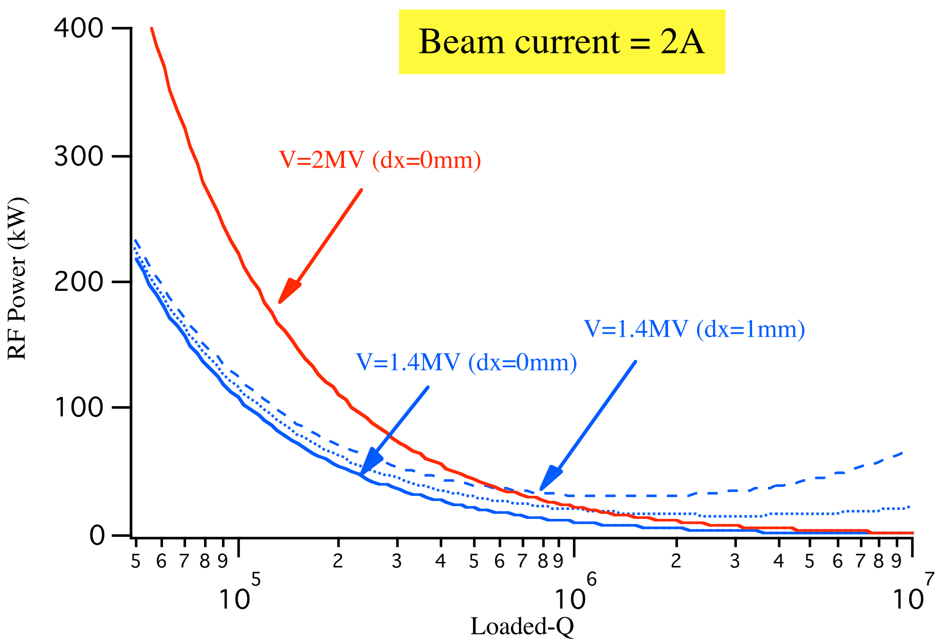
the required power to maintain the crabbing voltage is obtained from Eqs. 4, 7 and 8 as

RF Power

$$P_g = \frac{(1+\beta)^2}{4\beta\bar{R}_\perp} \times \left\{\frac{1}{\cos\alpha_L}\left(|V_{\perp c}| + \frac{I_b\bar{R}_\perp}{1+\beta}k\Delta x\sin\phi_c\right)\right\}^2. \quad (9)$$

Kick voltage *Beam offset (dx)*

Required power vs Loaded-Q



- Should be taken into account:
  - Available RF power
  - Not to be too sensitive to beam orbit change
  - Higher voltage than normal operation can be applied for conditioning cavity.
- Q_L=1~3 x10^5 seems a good choice.
  - RF power of 200 kW is sufficient.
  - Orbit change by 0.5mm is tolerable.

Tolerance_Timing (RF phase)

- Timing error (RF phase error) gives rise to horizontal displacement at the IP.

$$c\Delta t \leq A\sigma_x^* / \phi_{cross}$$

Please delete "A"

  - Here, ϕ_{cross} is the half crossing angle.
  - A is the ratio of allowed offset to horizontal beam size, σ_x*. A.
    The value A should be determined from beam-beam view point.

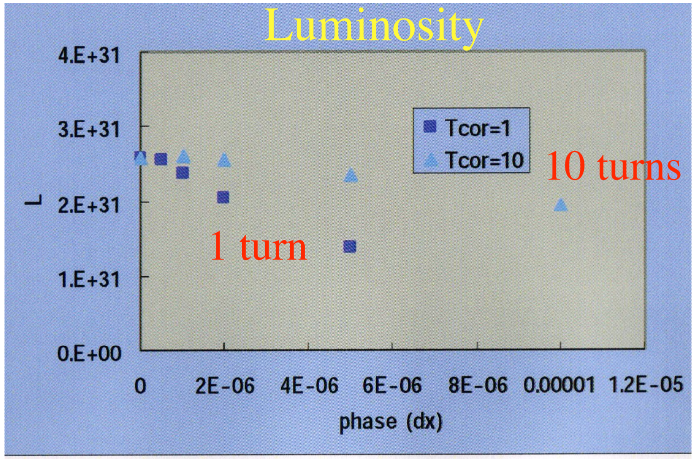
	KEKB	Super-KEKB	LC
σ_x*	100μm	70μm	0.24μm
A (assumed)	0.05?	~0.05?	~0.2?
ϕ_{cross}	+/- 11mrad	+/- 15mrad	+/- 3.5mrad
Δt	1.5 ps	0.8 ps	0.05 ps

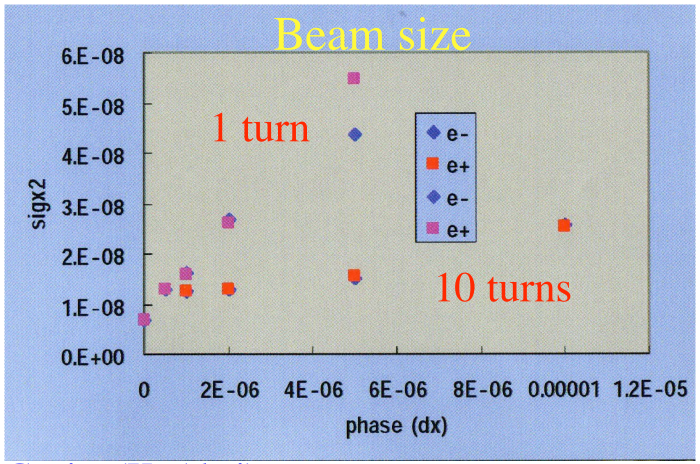
1.5 ps → 0.27 deg (509MHz)

Effect on the beam-beam performance of RF phase jitter

- Luminosity and beam size as functions of dx.
- Correlation time of the jitter, 1 or 10 turns, is important.
  - For correlation time of 10 turns, 5 microns is allowed.
  - For correlation time of 1 turn, tolerance is only 1 micron.

Simulation by Ohmi and Tawada





Source of phase error and cure

- Phase drift due to temperature change, etc.
  - Slow. If the error is measured, it can be easily compensated by feedback control of a phase shifter.
  - CCC (continuous closed orbit correction system) can show single kick caused by crab cavity.
- Other possible errors
  - Since $Q_L \sim 2x10^5$ and h=5120, the correlation time for most of possible errors will be larger than 10 turns. Then, a displacement of 5 microns is allowed, corresponding to a phase error of 0.27 degree. This is feasible with conventional control system.

Transient to abort gap

K. Akai et al, EPAC98, p.1749.

- Depends on operating parameters.
  - accerating Vc and Q_L, beam current, gap length.
- Mostly compensated.
  - Same direction in both rings.
- How about residual?
  - Although modulation period is 1 turn, correlation time for each bunch is NOT 1 turn, but determined by Q_L of accelerating cavities.
  - Then +/- 7 microns is not disastrous. However, still marginal for the 10 turn correlation.
  - Consequently, variable range for current ratio e+/e- will be limitted to reduce the residual.

Table 2: Bunch position shift due to 5% gap in both rings.

	LER	HER
Current [A]	2.6	1.1
Phase modulation (p-p) [deg]	3.5	2.7
Δ z (p-p) [mm]	5.7	4.4
Δ x at CP (p-p) [mm]	0.063	0.049
Δ z (relative) † [mm]	± 0.3	
Δ x (relative) †† [mm]	± 0.007	

† $(\Delta z_{\mathrm{her}} - \Delta z_{\mathrm{ler}})/4$ and †† $(\Delta x_{\mathrm{her}} - \Delta x_{\mathrm{ler}})/2$

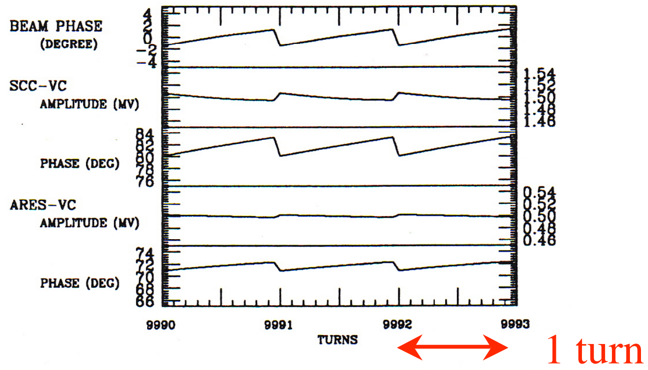
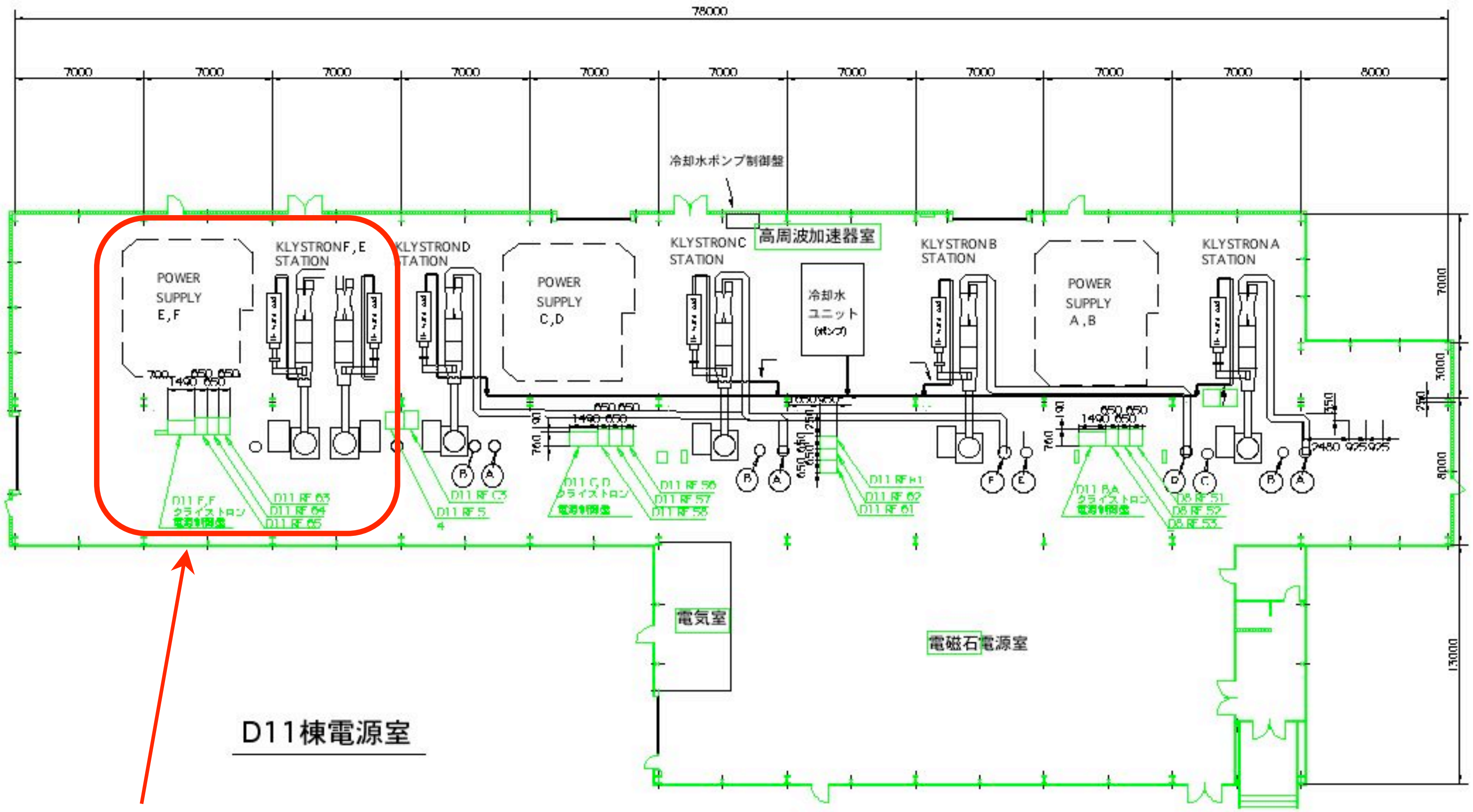


Figure 3: Transient response of the hybrid system in HER to a 5% gap.

RF stations for crab cavities

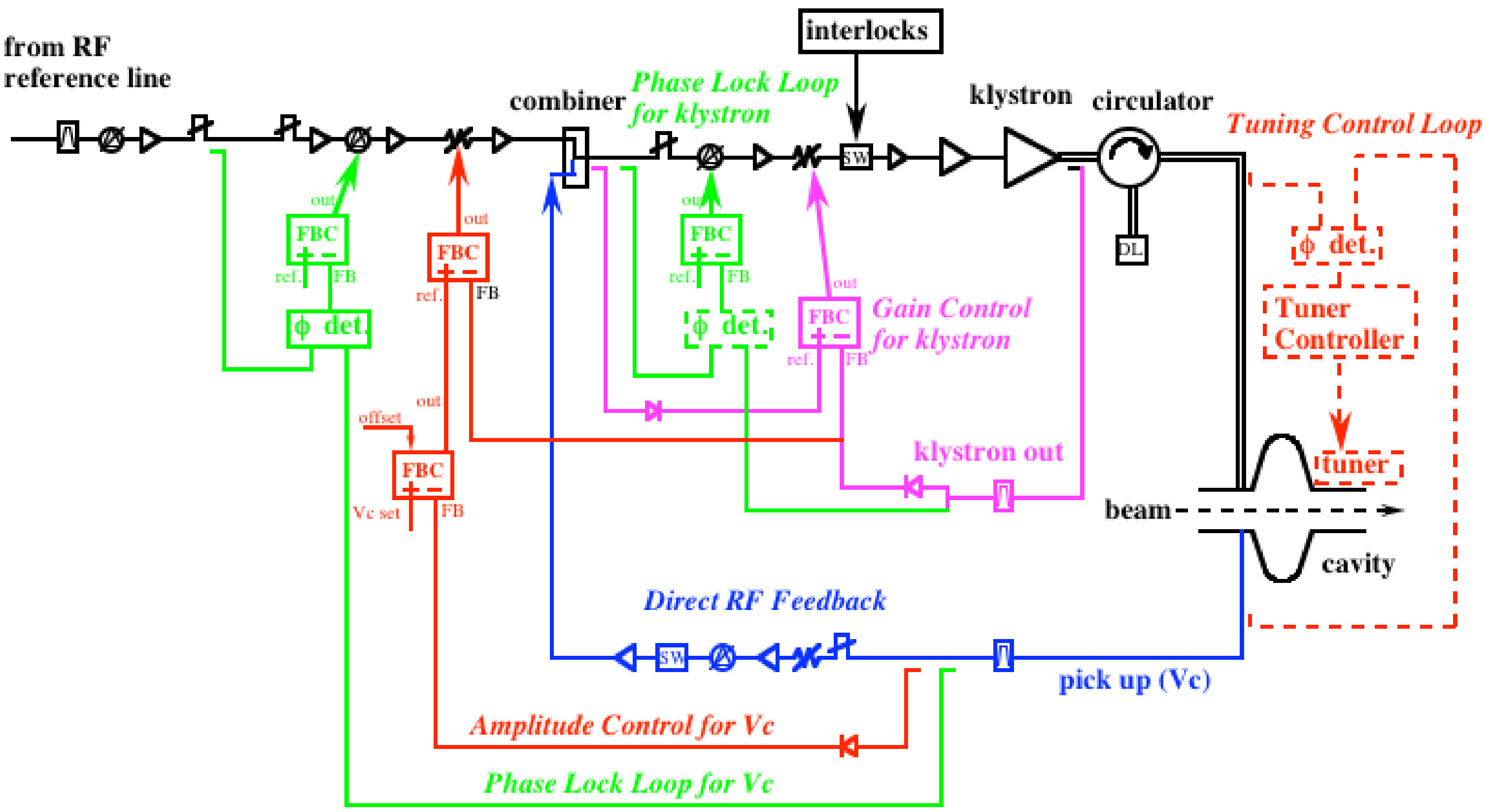
- Two RF units are being constructed in D11.
  - D11-E is for the LER crab cavity.
  - D11-F is for HER, although the cavity will be located in D10 tunnel.
  - Required power is 200 kW, much lower than existing stations for accelerating cavities.
- High power components with reduced cost.
  - Two reused klystrons have been conditioned up to 600 kW, enough for crab cavities.
  - A spare power supply for one klystron was moved from D2 and will be modified to drive two klystrons.
  - Circulators, dummy loads, and waveguides are being fabricated.
- Control system
  - Mostly similar to that for the SC accelerating cavities.
  - Required accuracy for phase control is about 0.2 degree.

Layout of D11 klystron gallery



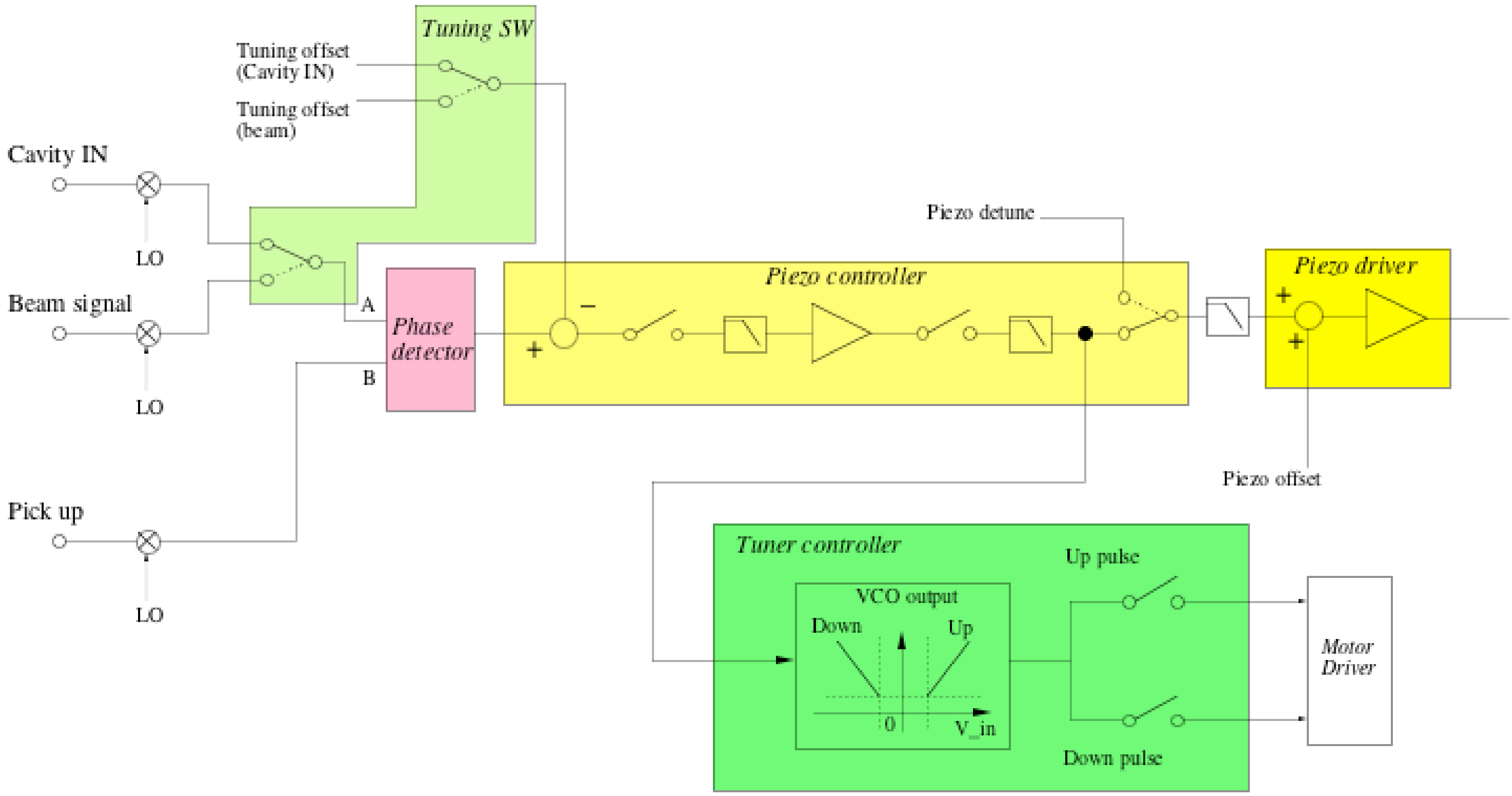
Two RF high power stations are being built for crab cavities.

Low-level RF for KEKB Superconducting cavity



RF system for crab cavity will be similar.

Block diagram of tuning control system for KEKB-SCC



RF system construction for Crab cavity

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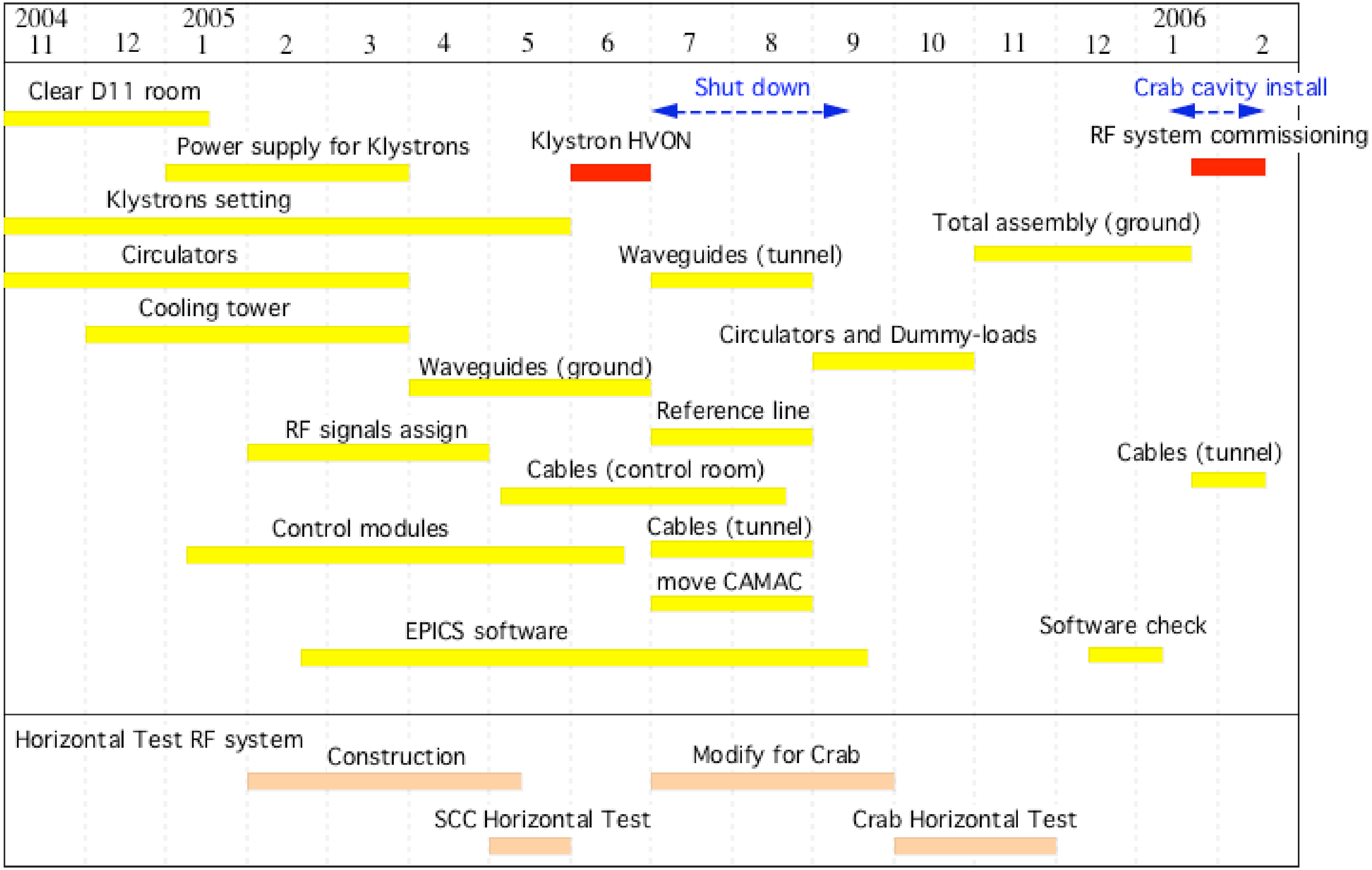
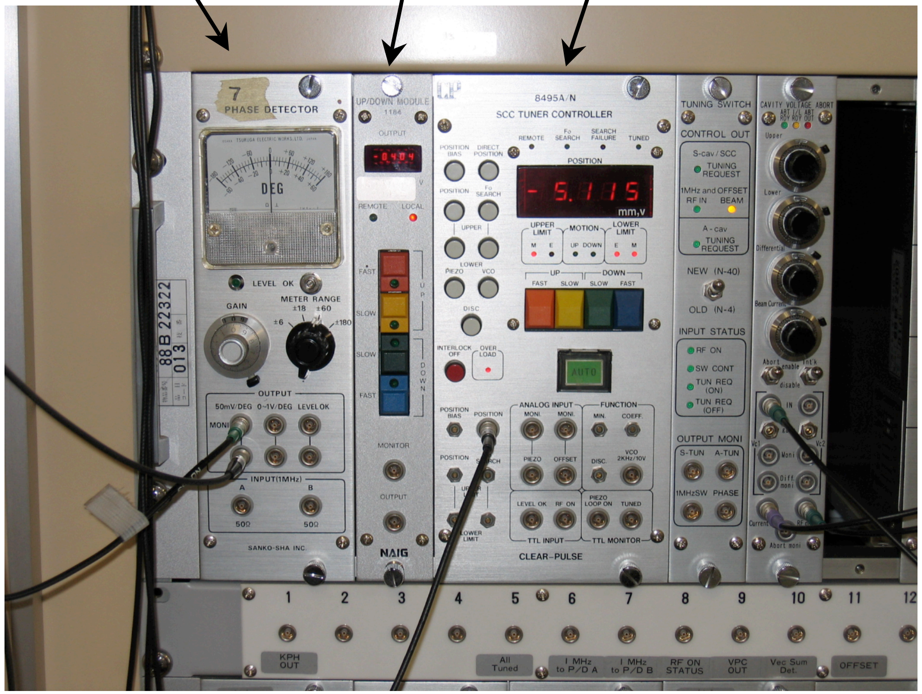


Tuner contoller

Phase detector

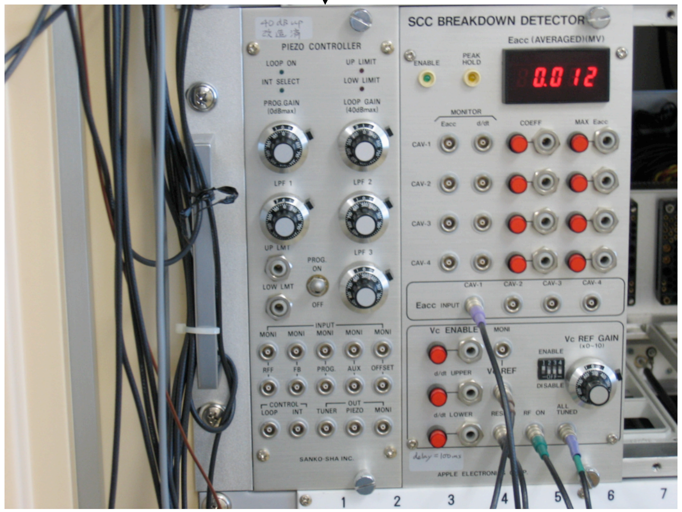
Tuning offset

Tuner controller

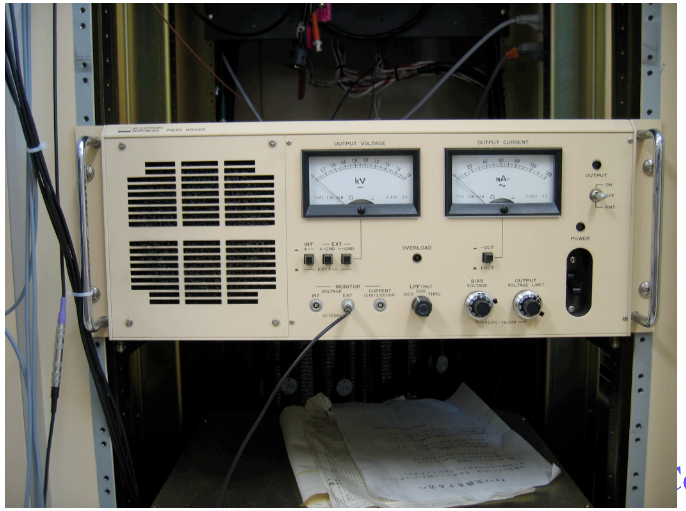


- Auto up/down based on phase detector signal.
- Manual up/down
- Stop by mechanical switch, electrical limit, or piezo overload
- Display tuner position
- F0 search

Piezo controller and Piezo driver



- Piezo controller:
  - Gain 60dB max
  - LPF 3 stages



- Piezo driver
  - Gain = 200
  - Output 0～1600V
  - Current 100mA max