Suppression of coherent synchrotron oscillation

Spring-8 accelerator division

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Motivation

- Low emittance ring
- --> small momentum compaction factor
- --> small phase fluctuation is enhanced by $1/\alpha$ in energy
- --> incease of effective energy spread

  increase of effective horizontal beam size at dispersive section

$$\frac{\varepsilon}{E} \approx -\frac{\omega_s}{\alpha}\Delta\tau$$

$$\Delta\tau = \omega_{RF} \cdot \Delta\phi$$

$$\Delta x = \eta \cdot \frac{\varepsilon}{E}$$

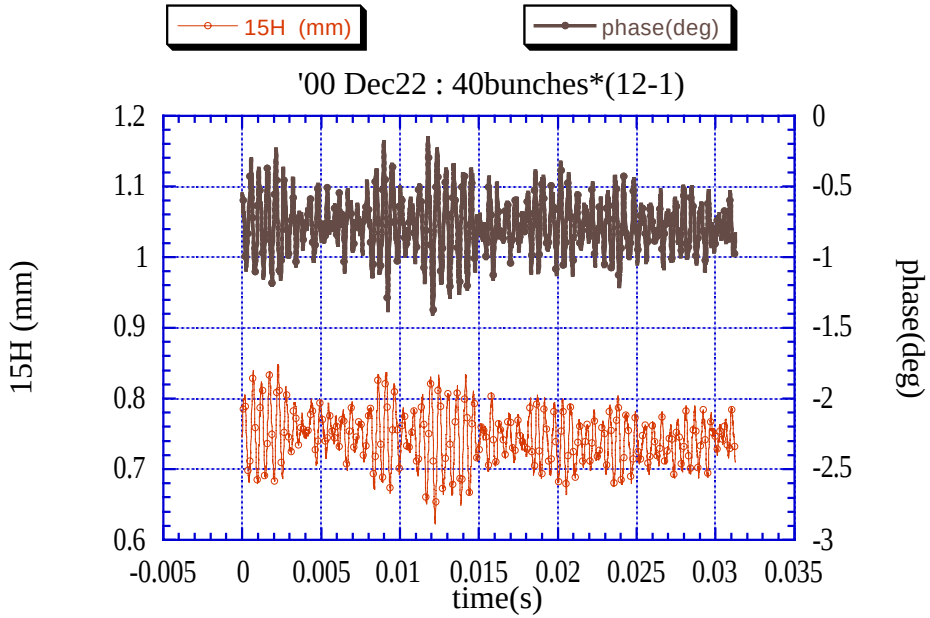
Example without feedback

$\Delta\phi \approx 0.2$ deg

$\Delta\tau \approx 1\ ps$

$\frac{\varepsilon}{E} \approx 1 \cdot 10^{-4}$

$\Delta x \approx 35\ \mu m\ @\ \eta = 400 mm$



c.f. energy spread ~ 1.e-3

horizontal beam size(rms) ~ 0.38mm

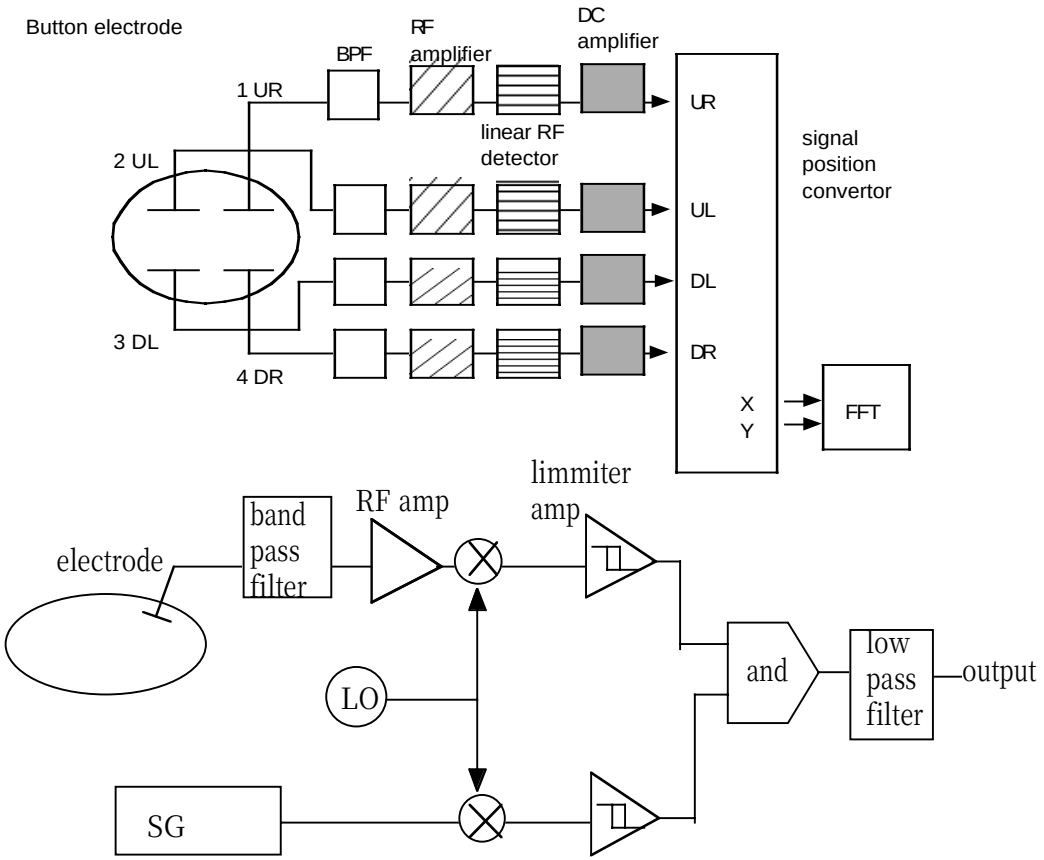
Measurement of energy & phase

- Energy

horizontal position at dispersive section

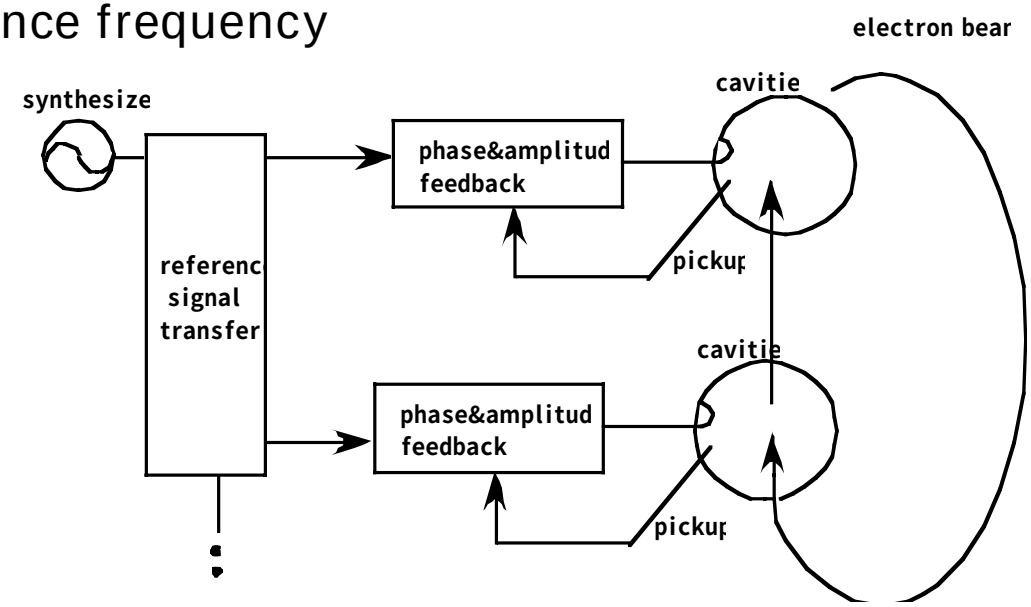
- Phase

difference between RF reference and pick-up signal



Source of noise in RF voltage

- phase noise of signal generator (synthesizer)
- transmission lines of reference signal
- At each station
  - noise in voltage control circuit
  - noise in phase lock loop
  - ripple at klystron power supply
  - change of cavity resonance frequency
  - etc



Ripple of Vk of klystron PS

- Change of Vk

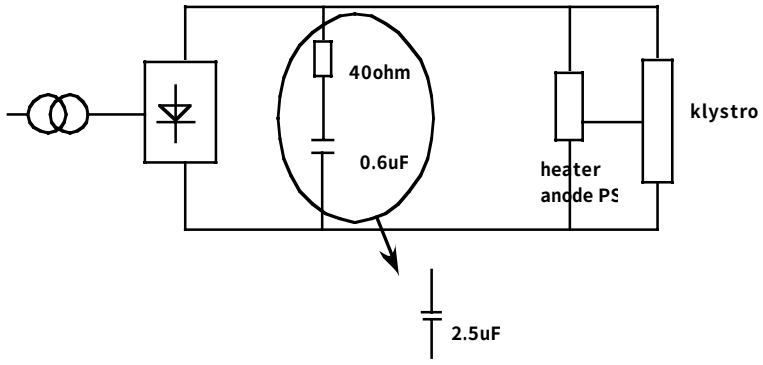
-> change of beam velocity

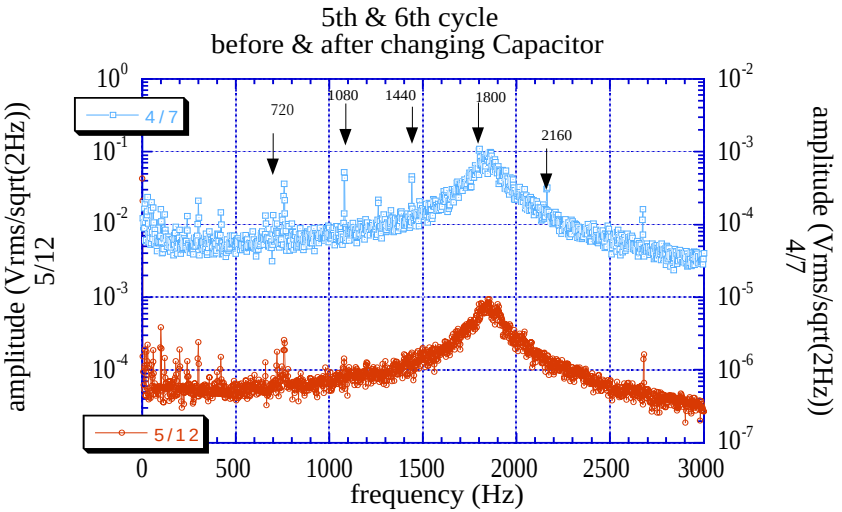
-> change in

RF output phase

- Use large capacitor

in smoothing circuit

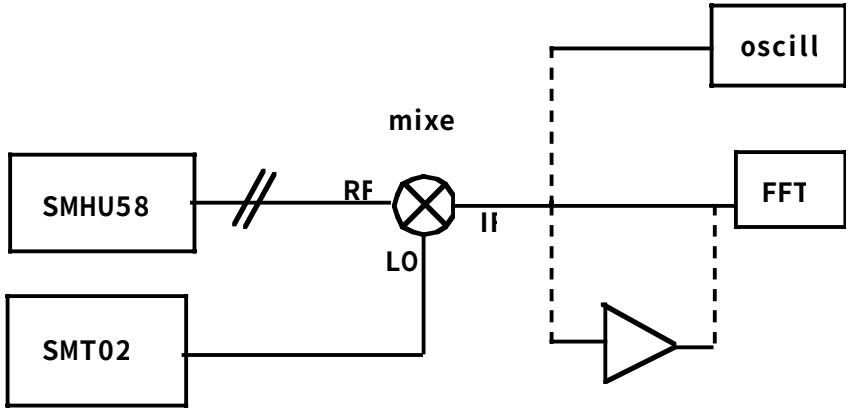


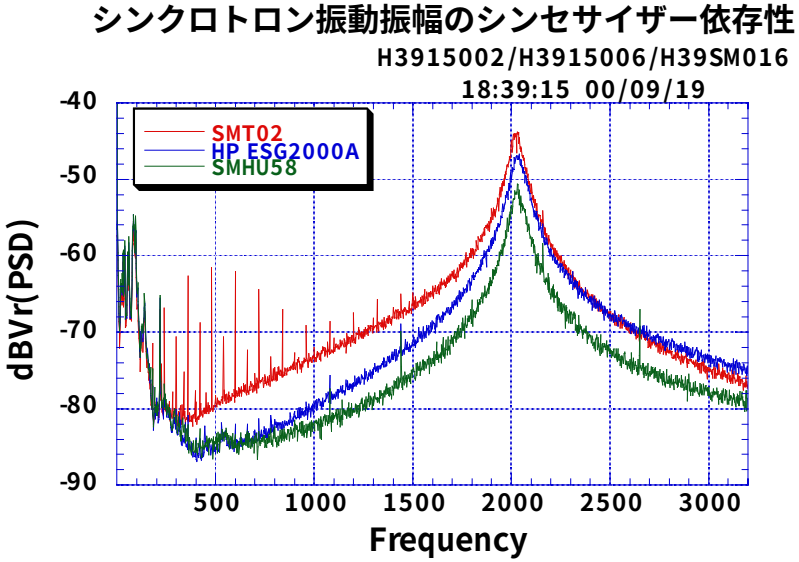


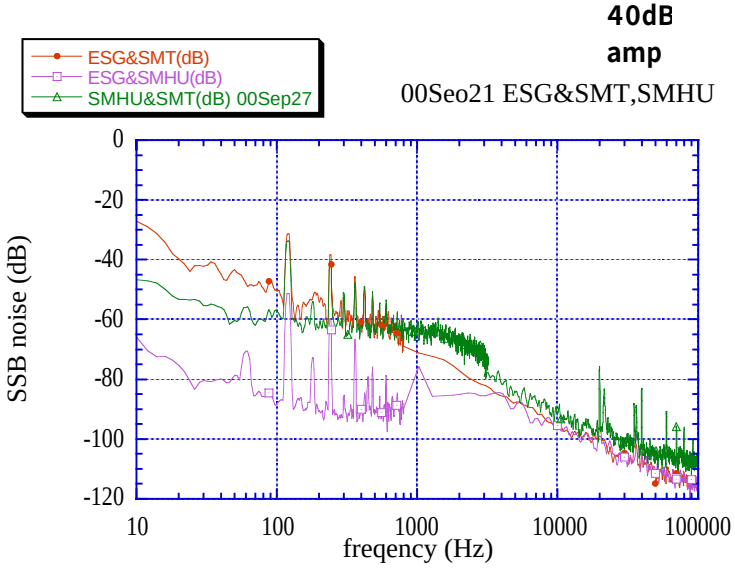
- reduction of harmonics of 360Hz
- still remain broad peak

Phase noise in synthesizer

- Select model with low phase noise







Synchrotron oscillation

$$\frac{d\tau}{dt} = -\alpha\delta$$

$$\frac{d\delta}{dt} = \frac{e\,V}{E\,T}\sin\left(\omega_{RF}\,\tau + \phi_s + \psi\right) - \frac{U + D\,E\,\delta}{E\,T}$$

$$\frac{d^2\tau}{dt^2} + 2\alpha_e\frac{d\tau}{dt} + \omega_{sy}^2\tau = \omega_n\psi$$

$$\alpha_e = \frac{D}{2T} \qquad \omega_{sy}^2 = \frac{\alpha\,e\,V\,\omega_{RF}\cos\phi_s}{ET} \qquad \omega_n = \frac{\omega_{sy}^2}{\omega_{RF}}$$

Phase Modulation type external force $\psi = \theta\, e^{i\omega t}$

$$\tau_0 = \frac{\omega_n\,\theta}{\left(\omega_s{}^2 - \omega^2\right) + 2\,\alpha_e\omega\,i}$$

$$\delta_0 = \frac{-\,i\,\omega_{sy}}{\alpha}\tau_0$$

Frequency Modulation type external force $\psi = \int \theta\, e^{i\omega t}\, dt$

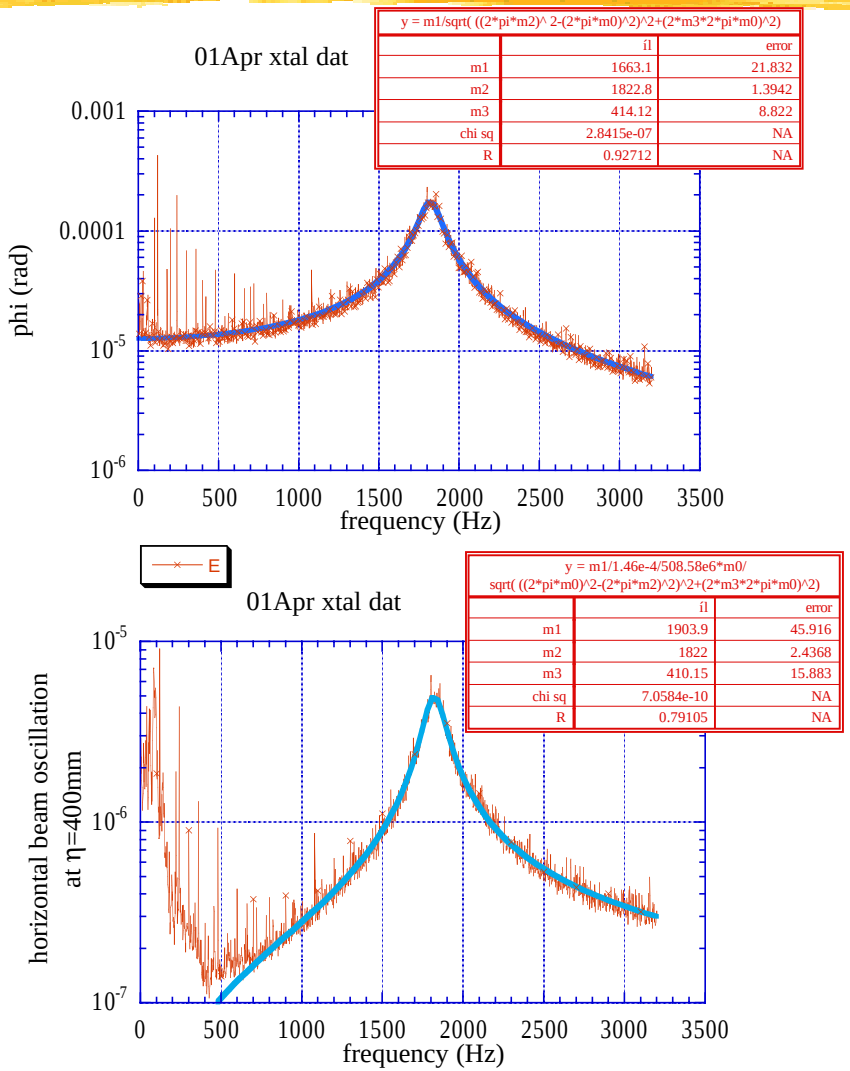
$$-\omega^2\,\tau_0 + 2\alpha_e i\,\omega\,\tau_0 + \omega_{sy}^2\tau_0 = \omega_n\frac{\theta}{i\,\omega}$$

$$\tau_0 = \frac{\frac{\omega_n}{\omega}\,\theta}{\left(\omega_s{}^2 - \omega^2\right) + 2\,\alpha_e\omega\,i}$$

$$\delta_0 = \frac{-\,i\,\omega_{sy}}{\alpha}\tau_0$$

Phase and energy oscillation

- calculation with PM type external force
- ϕ good except spike
- E good at >500Hz



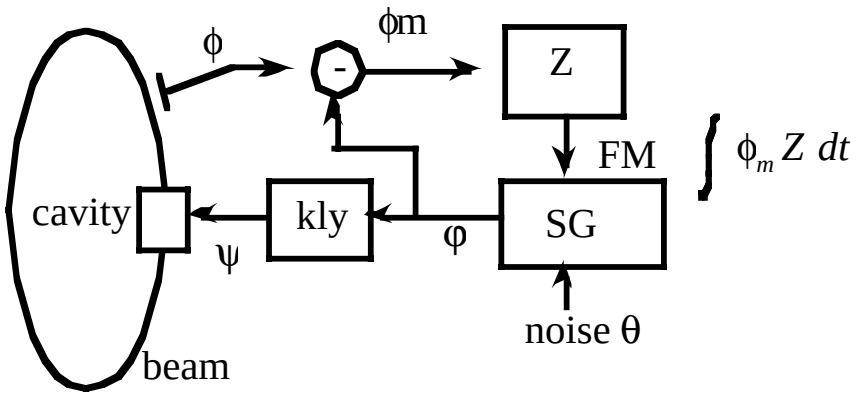
	íl	error
m1	1663.1	21.832
m2	1822.8	1.3942
m3	414.12	8.822
chi sq	2.8415e-07	NA
R	0.92712	NA

	íl	error
m1	1903.9	45.916
m2	1822	2.4368
m3	410.15	15.883
chi sq	7.0584e-10	NA
R	0.79105	NA

Feedback (Frequency Modulation to SG)

ϕm :measured beam phase

Z : loop gain



$$\psi = \theta\, e^{i\omega t} + \int \phi_{m0} e^{i\omega t} Z\, dt$$

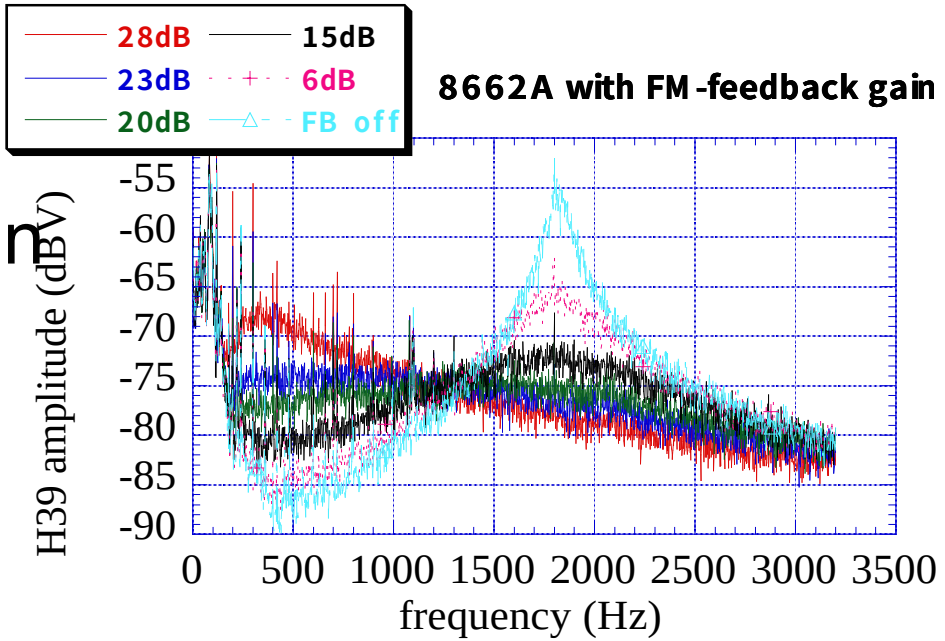
$$-\omega^2 \tau_0 + 2\alpha_e i\, \omega\, \tau_0 + \omega_{sy}^2 \tau_0 = \omega_n \left[\theta + Z \left\{ \frac{\tau_0\, \omega_{RF} - \theta}{i\, \omega} \right\} \right]$$

$$\tau_0 = \frac{\omega_n \left(\theta - \frac{Z\, \theta}{i\, \omega} \right)}{\left(\omega_s{}^2 - \omega^2 \right) + \left(2\, \alpha_e \omega\, i - \frac{\omega_n\, \omega_{rf}\, Z}{i\, \omega} \right)}$$

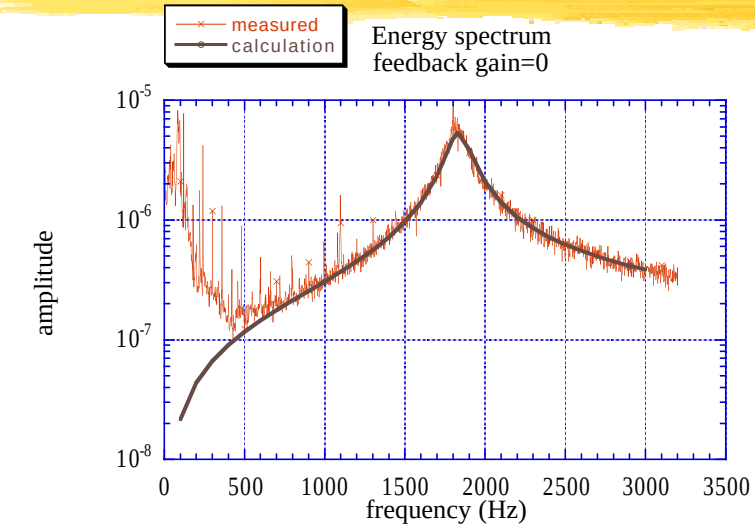
$$\delta_0 = \frac{-\, i\, \frac{\omega\, \omega_n}{\alpha} \left(\theta - \frac{Z\, \theta}{i\, \omega} \right)}{\left(\omega_s{}^2 - \omega^2 \right) + \left(2\, \alpha_e \omega\, i - \frac{\omega_n\, \omega_{rf}\, Z}{i\, \omega} \right)}$$

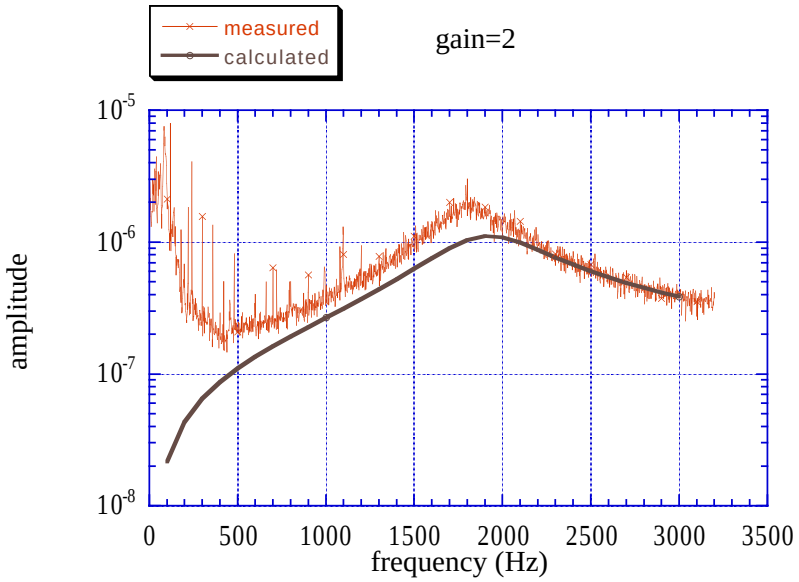
Result : gain dependence

- Measure energy oscillation with different loop gain



Calculation and measurement





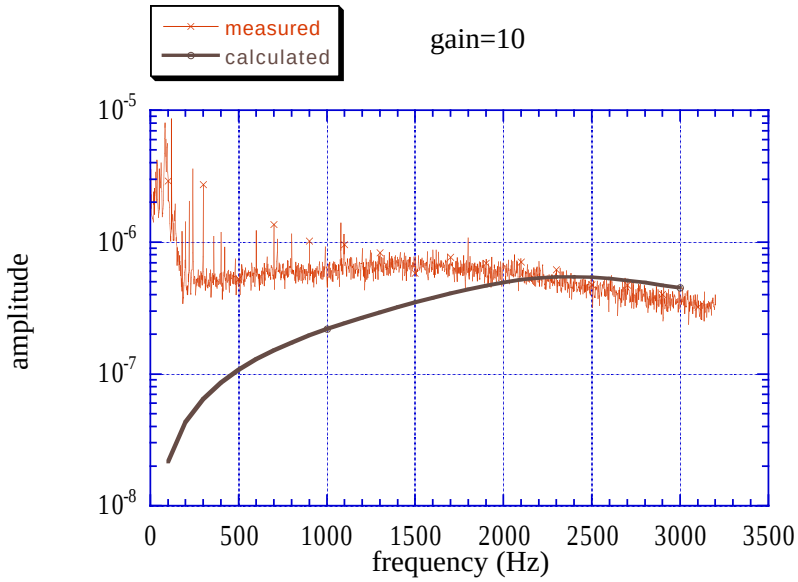
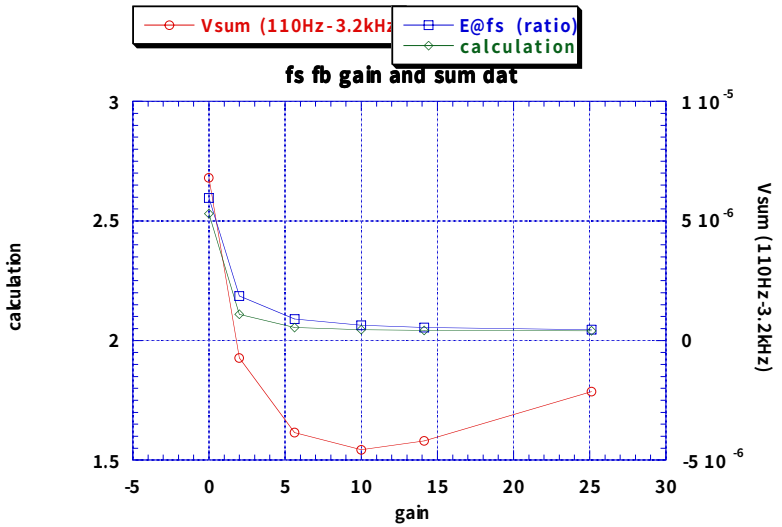


Figure of merit

Integrated value of spectrum

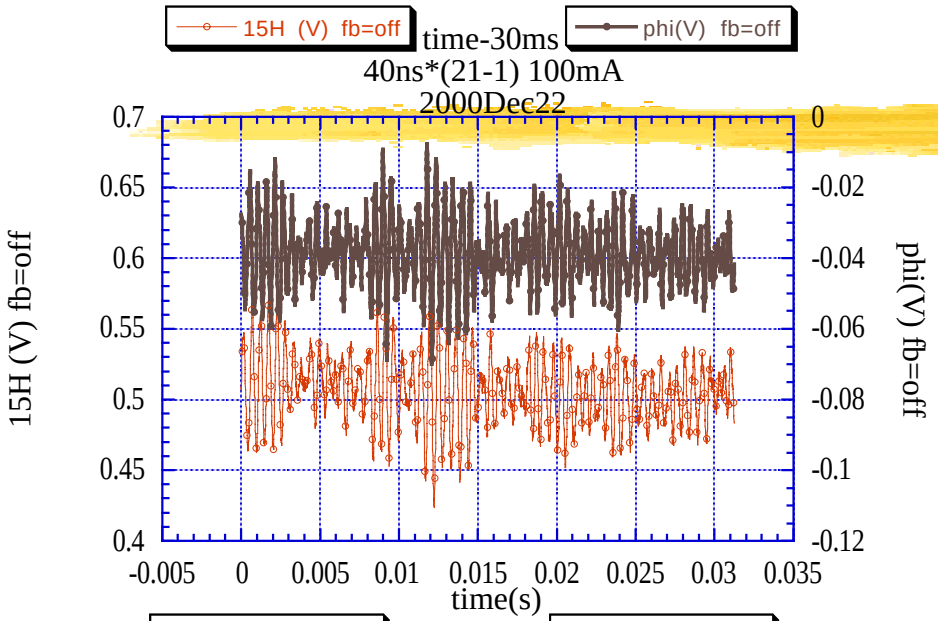
Peak amplitude at fs

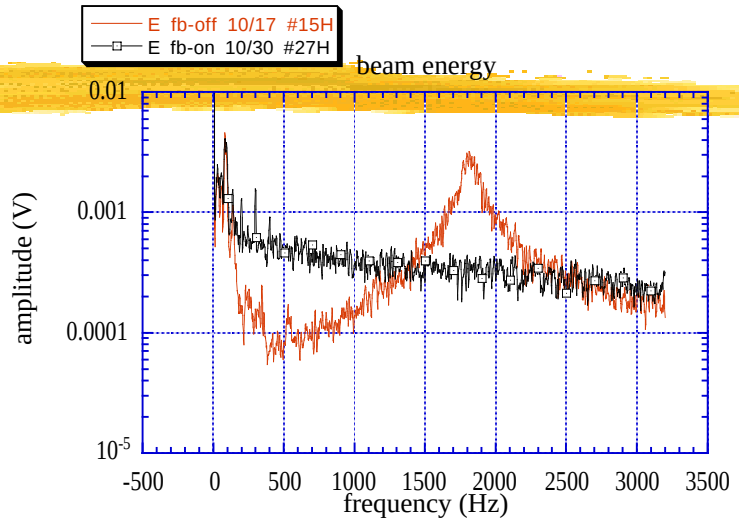
Gain of *10 is good

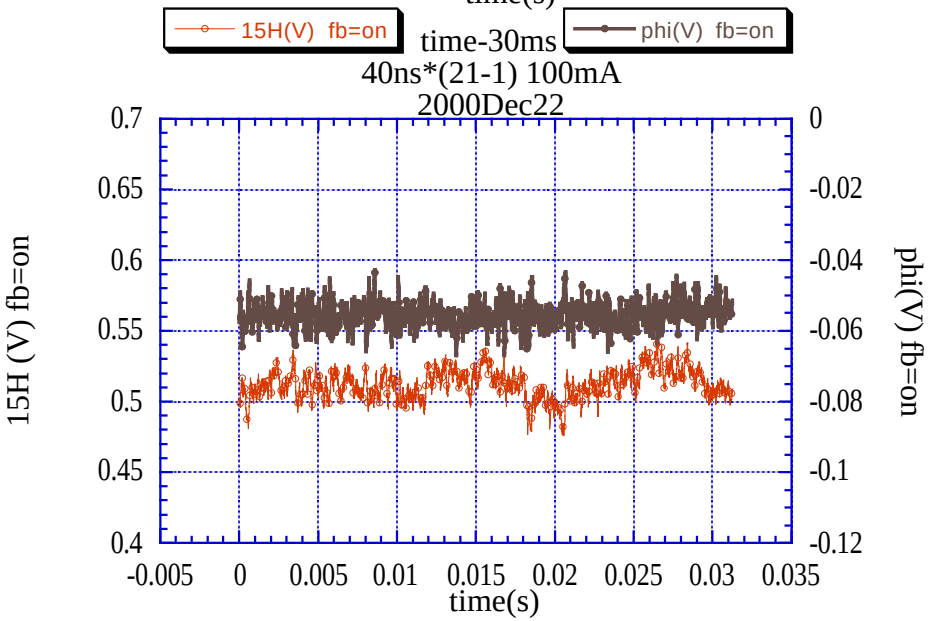


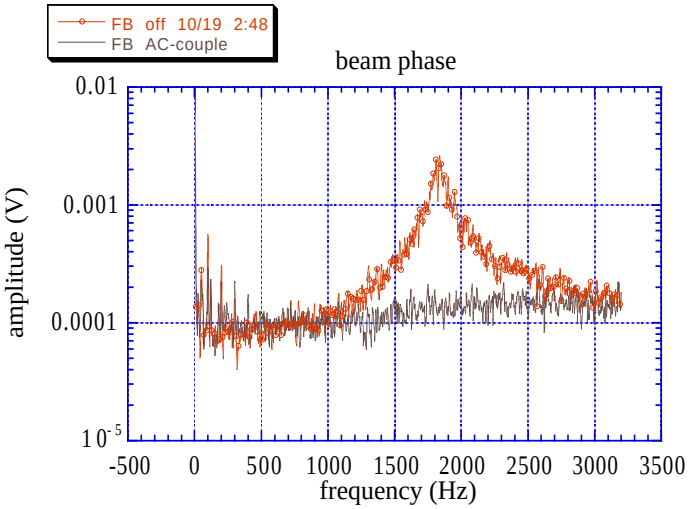
Conclusion

- Using FM feedback to synthesizer of RF reference
- we could reduce the coherent synchrotron oscillation amplitude to 1/20 in frequency domatin
- This feedback is in operation from 2000 October at SR user time


15H (V) fb=off
phi(V) fb=off
time-30ms
40ns*(21-1) 100mA
2000Dec22
15H (V) fb=off
phi(V) fb=off
time(s)


E fb-off 10/17 #15H
E fb-on 10/30 #27H
beam energy
amplitude (V)
frequency (Hz)


15H(V) fb=on
phi(V) fb=on
time-30ms
40ns*(21-1) 100mA
2000Dec22
15H (V) fb=on
phi(V) fb=on
time(s)


FB off 10/19 2:48
FB AC-couple
beam phase
amplitude (V)
frequency (Hz)

Next step

- Futher reduction of oscillation amplitude below 500Hz

  -> low noise phase detector

  ->check other RF components