IP Orbit Feedback
Dithering

M. Masuzawa

Introduction

SuperKEKB needs to align two super-small beams in vertical and horizontal planes at the IP for good collision. And good collision conditions have to be maintained.

KEKB

y and y' :   "standard" orbital feedback based on beam-beam kick calculated from the BPM readouts located on both sides of the IP was used.

x :Beam-size (from the SR Monitor) was monitored and control by changing the horizontal bump height at the IP before crab crossing.

x :beam-beam kick after crab crossing with crab cavities.

FB rate was about 1 Hz.

Introduction

SuperKEKB needs to align two super-small beams in vertical and horizontal planes at the IP for good collision. And good collision conditions have to be maintained.

SuperKEKB

y and y' :   "standard" orbital feedback based on beam-beam kick calculated from the BPM readouts at both sides of the IP still expected to work, just needs to be faster.

⇒presentation by the monitor G (H. Ikeda).

x : Beam-beam kick will not be a sensitive parameter for monitoring collision as ξ_x is so small:

ξ_x ~ 0.0028(e+), 0.0017(e-)

⇒**Luminosity dither is being considered.**

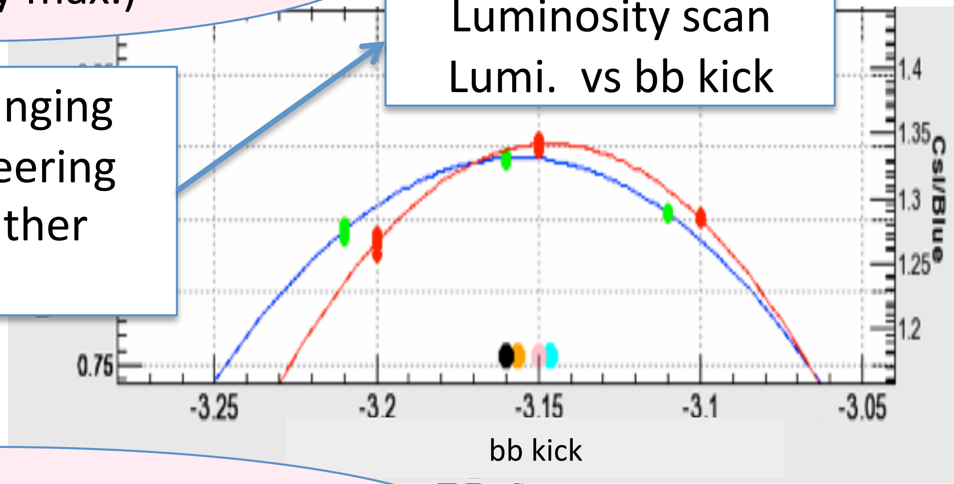
Collision FB scheme (KEKB & SuperKEKB y&y')

(1) Finding good collision (luminosity max.)

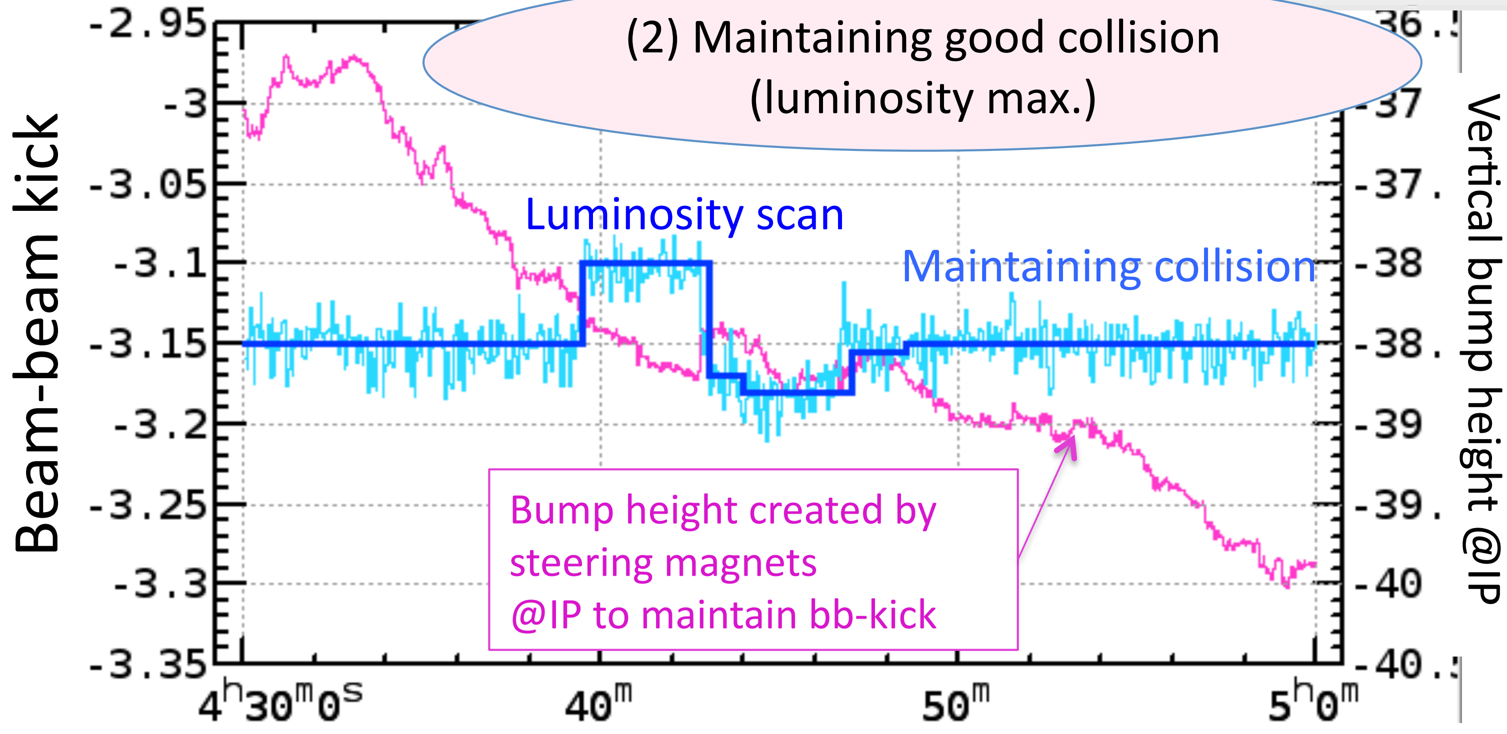
Calculate beam-beam kick (b-b deflection) using BPMs

Change bb kick by changing setting of iron-core steering magnets located on either side of the IP.

Luminosity scan Lumi. vs bb kick



(2) Maintaining good collision (luminosity max.)



Collision FB scheme (SuperKEKB x)

(1) Finding good collision
(luminosity max.)

Dithering (60~70 Hz)
by air-core coils on both sides of the IP.

(2) Maintaining good collision
(luminosity max.)

Change dithering output (zeroing Lock-In amp output) by settings of iron-core steering magnets located on both sides of the IP.

Luminosity dither (similar to PEP-II) : Key components to be examined

(1) Dither frequency :
  Not faster than PEP-II dither 50~100 Hz

(2) Dithering coil design (air-core or ferrite-core) :
  Estimate of bump height & magnetic field

(3) Power supplies :
  For actuating coils

(4) Lock-in amps :
  To discriminate dither signals

(5) Vacuum duct :
  For magnetic field penetration

(6) Good luminosity signal :
  Event rate, S/N ⇒ Very critical

(1) Dither frequency

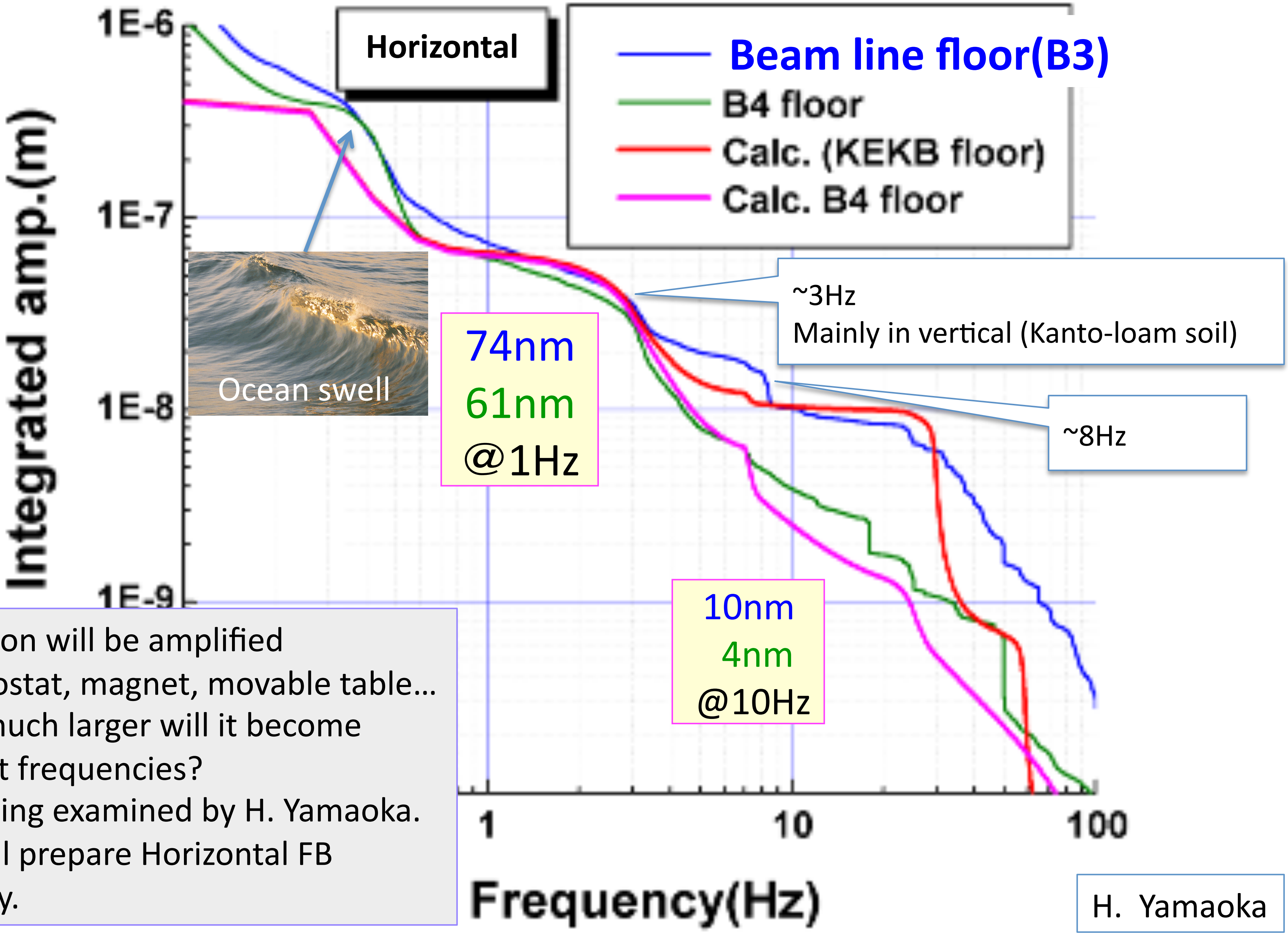
From 17th Review Committee Report:

The horizontal orbit feedback cannot use the beam-beam deflection method, since the beam beam parameter is low and there are two sources of the horizontal beam-beam kick. Instead a dithering system like at PEP-II is foreseen. The expected high ZDLM rate will allow good precision and fast response. K. Ohmi has simulated the dependence of the luminosity on the horizontal beam-beam separation. The luminosity drops rapidly for a separation larger than 5-10 micron (roughly the horizontal rms beam size). The horizontal collision feedback system need **not** be very fast, since the most important perturbation is expected to be rather slow, around 3 Hz.

Review

“perturbation is expected to be rather slow, around 3 Hz.”

Tunnel vibration near the IP



Vibration will be amplified
by cryostat, magnet, movable table…
How much larger will it become
& what frequencies?
⇒ Being examined by H. Yamaoka.
We will prepare Horizontal FB
anyway.

(1) Dither frequency

We need to pick one frequency for dithering as we will just dither in horizontal direction.

PEP-II

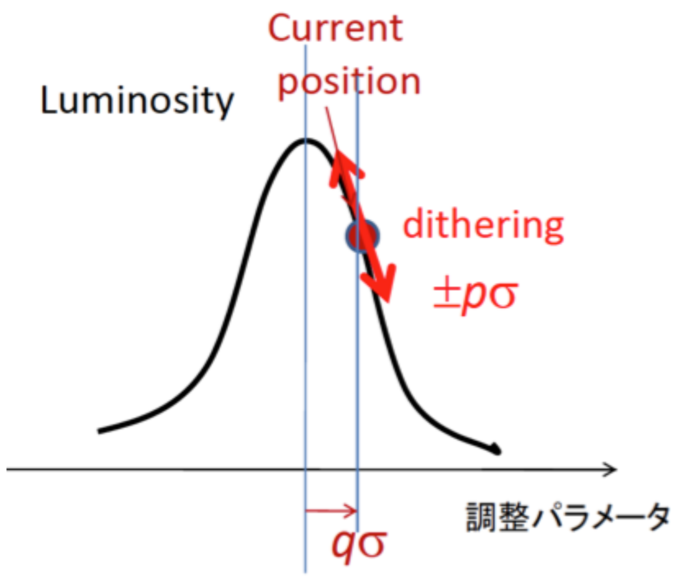
To avoid interference from the 60-Hz power line, the dithers run above 70 Hz.

Our power line runs at 50 Hz…

So 50 ~ 100Hz?

(2)Dithering coil design (air core or ferrite core) Estimate of bump height and magnetic field

When two beams overlap, the luminosity drops on either side of the peak, giving modulation at $2\omega_x$.
Off center, there is additional modulation at the fundamental.

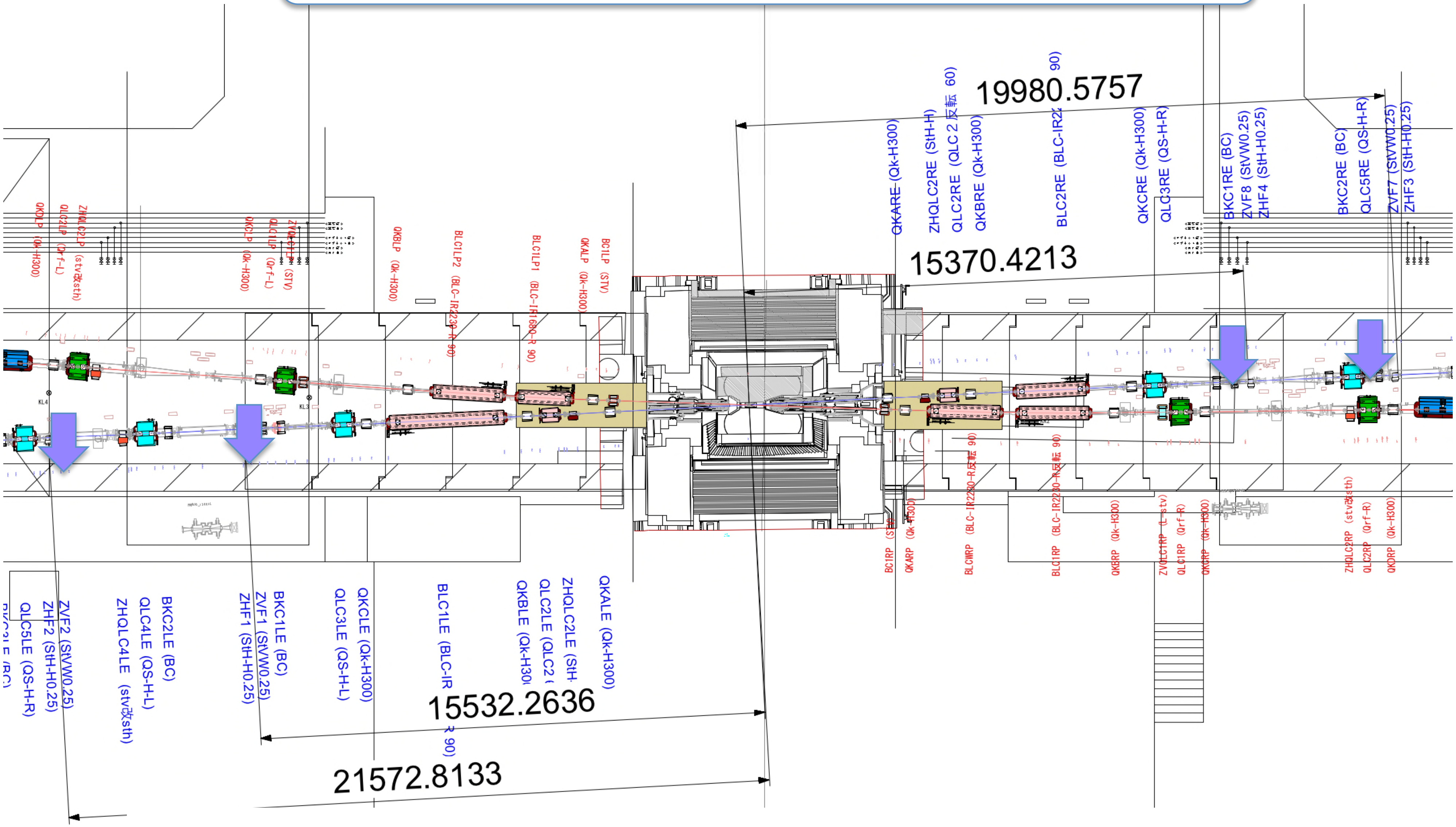


Dithering simulation by S.Uehara
Max. dithering amplitude, which corresponds to 10 % drop of the peak luminosity should be prepared.

Beam-beam simulation by K. Ohmi
This corresponds to a horizontal bump height of ~7μm.

We will prepare coils, which can make a ±10μm horizontal dithering bump at the IP.
⇒Max. kick angle (estimated by Y. Funakoshi)) of ±10μrad, if coils are placed near the slow “iBump” horizontal steering magnets.

Dithering coil locations



Four locations, two on each side of the IP, in HER.

Does it make more sense to have dithering coils in LER?

Will be investigated.

Dithering coil design
Air-core type

Coil design will be done soon.
Wire size, # of turns, inductance, resistance, power consumption and so on.

Dithering coil design
Ferrite-core type

What SuperB proposed:
Dither coils will be curved "saddle" coils with a cos(θ) current distribution and an outer ferrite cylinder to act as a shield and flux return.
Provides much better shielding and efficiency than the open Helmholtz coil design used in PEP-II.

This is interesting.
Will be looked into.

Coil–pair parameters

Calculated values

	B_0 / I (G/A)	L_{eff} (m)	R (Ohms)	L (mH)
horizontal kick ± 50 m	2.89	0.178	0.546	5.36
vertical kick ± 50 m	2.89	0.245	0.546	5.36
horizontal kick ± 30 m	2.92	0.177	0.546	5.36
vertical kick ± 30 m	2.52	0.248	0.546	5.25

calculated single-coil inductance is 2.48 mH (compare 1.54 mH measured)
calculated inductance is used in tables that follow

We will need to make a table like this.

Coil design and performance
Fast dither review

Steve Gierman
Oct. 19, 2005

Required voltage V_0 (100 Hz)

dither amplitudes →		Δx = 40 μm	Δy = 5 μm	Δy′ = 100 μrad
horizontal kick	bsep1L	5.66	-0.21	-1.38
	bsep2L	4.61	0.20	0.92
	bsep2R	4.59	-0.53	0.93
	bsep1R	5.65	0.38	-1.63
vertical kick	bsep1L	5.25	-18.13	-3.97
	bsep2L	-1.50	5.29	-4.17
	bsep2R	2.12	5.61	3.87
	bsep1R	-5.69	-17.35	4.38

We will need to make a table like this.

(3)Power supplies for actuating dither coils

Digital Meters
Model BOP 20-5D (top) and BOP 72-6D (bottom)
100, 200 and 400 Watt Linear High-Speed Amplifiers

PEP-II
a bipolar voltage-controlled current source capable of delivering up to 20 A at 20 V (Kepco BOP 20-20M) was used.

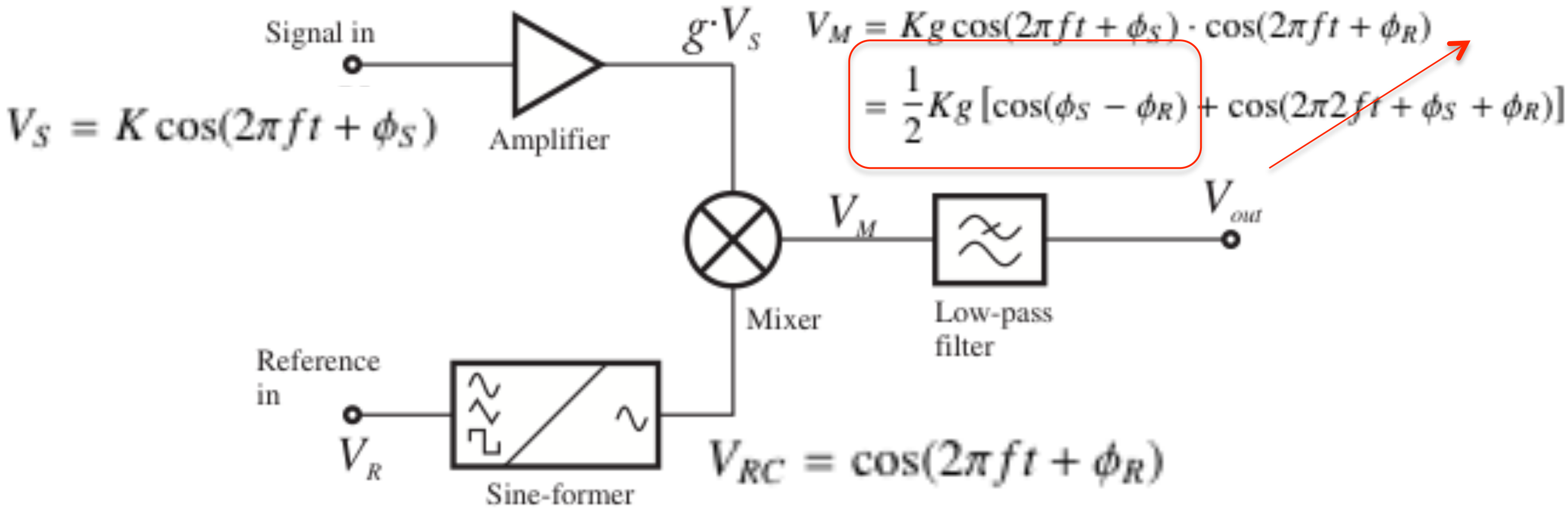
Our power supplies have similar specifications
As Kepco BOP 20-20M.

BOP DYNAMIC SPECIFICATIONS

MODEL	BANDWIDTH (d-c to f_{-3dB}) KHz (minimum) Mode		RISE & FALL TIME 10%-90% μsec (maximum) Mode		LARGE SIGNAL FREQUENCY (min) RESPONSE, KHz Mode	
	V	I	V	I	V	I
100 WATT						
BOP 20-5M	18	12	20	30	17	13
BOP 50-2M	18	12	20	30	17	13
BOP 100-1M	18	11	17	22	18	11
200 WATT						
BOP 20-10M	18	6	20	60	17	7
BOP 36-6M	16	13	20	27	15	14
BOP 50-4M	23	14	14	25	15	11
BOP 72-3M	20	15	18	26	17	12
BOP 100-2M	22	15	18	26	17	12
BOP 200-1M	4.0	2.5	110	150	4.0	2.5
400 WATT						
BOP 20-20M	9.5	10	35	35	8	10

仕様／形名		BWS18-15	BWS40-7.5
最大出電圧（V）		±18	±40
最大出力電流（A）		±15	±7.5
ロード レギュレーション	CV	0.01%±1mV 以内	0.01%±2mV 以内
	CC	0.01%±5mA 以内	
増幅度 (AMPモード)	CV	0～3.6V/V	0～8V/V
	CC	0～3A/V	0～1.5A/V
リップル (r.m.s)	CV	1mV以下	
	CC	1.5mA以下	0.5mA以下
周波数特性 $^{+0}_{-3}$dB	CV	DC～15kHz	DC～20kHz
	CC	DC～10kHz	
最大入力電力(約VA)		750	750
寸法本体（最大値）	(W)mm	425(439)	
	(H)mm	147(164)	
	(D)mm	450（530）	
重量（約）kg		26	

(4)Lock-in amps
To discriminate dither signals



(4)Lock-in amps
To discriminate dither signals

X_0 : Offset of two beams.

$$x = x_0 + \tilde{x}\cos\omega_x t$$

$$\Sigma_x^2 = \sigma_{x+}^{*2} + \sigma_{x-}^{*2}$$

$$L(x) = L_0 \exp\left[-\frac{x^2}{2\Sigma_x^2}\right]$$

$$= L_0\left[1 - \frac{x_0\tilde{x}}{\Sigma_x^2}\cos\omega_x t - \frac{\tilde{x}^2}{2\Sigma_x^2}\cos^2\omega_x t\right]\exp\left[-\frac{x_0{}^2}{2\Sigma_x^2}\right]$$

Lock-in amp
&low-pass filter

$$V_x = C_L L_0 \frac{x_0\tilde{x}}{\sqrt{2}\Sigma_x^2}\exp\left[-\frac{x_0{}^2}{2\Sigma_x^2}\right]$$

V_x is useful because
(1) proportional to the offset x_0
(2) and goes to zero when the luminosity is maximized.

PEP-II

SRS 830 Digital Lock-In Amplifier

- Same model used for the tune trackers.
- Built-in sine-wave source (or accepts external sine).
- Quadrature measurement: amplitude and phase shift.
- Digital mixer and narrow low-pass filter to isolate signal component at the reference frequency.
  - Synchronous filter to suppress 2nd and higher harmonics.
  - Optionally, can measure the Nth harmonic for Σ studies.
- EPICS control (written for tune trackers) using GPIB.
  - Want it for occasional use to set range, frequency, filtering.
- BNC outputs for amplitude and phase.
  - For the feedback loop, send these to a SAM and avoid GPIB.

We will need to get a Lock-In Amp. and play with it.

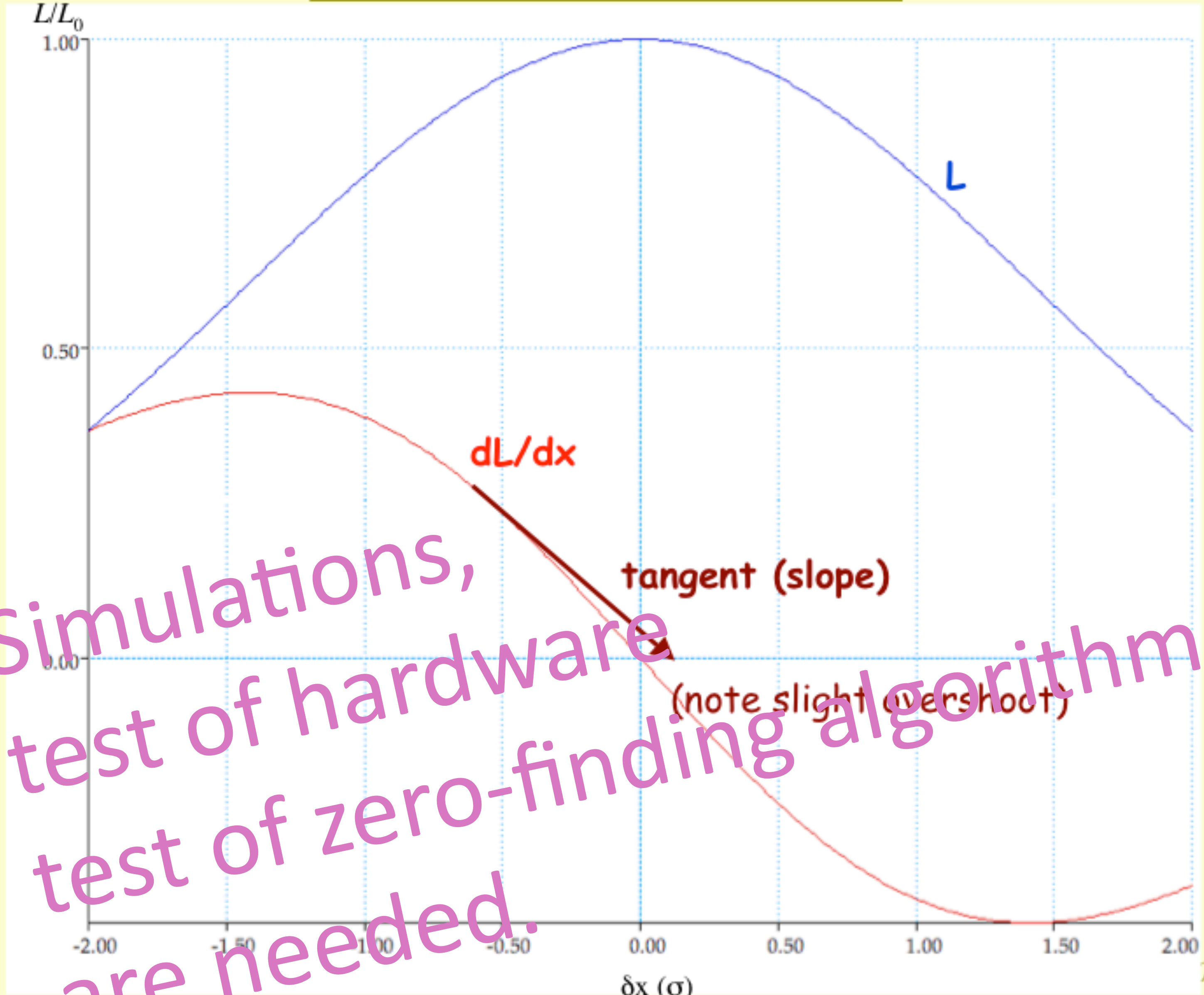
Alan Fisher
2005-10-19

Basic Idea

- Lock-In amplifier will give signal ∝ dL/dx
  - will become 0 at perfect alignment of beams
- Newton search to zero out this signal
- 3 planes (x,y,y') independently run
  - each cycle implements all 3 moves together
- Algorithm is independent of 2- or 3-frequency system
- Avoid using other information
  - beam-currents, L
  - "not a religion"

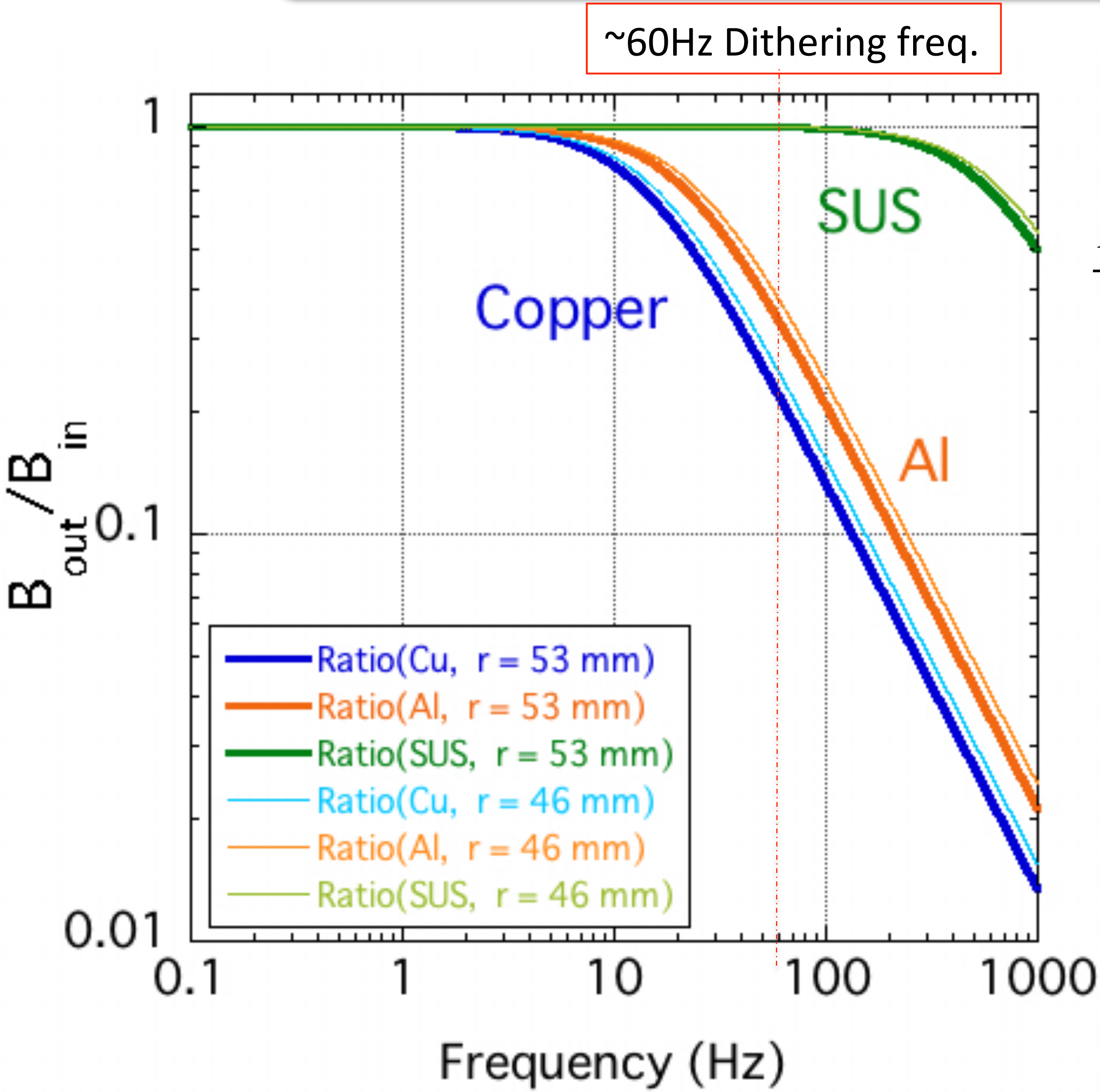
Simulations,
test of hardware
test of zero-finding algorithm
are needed.

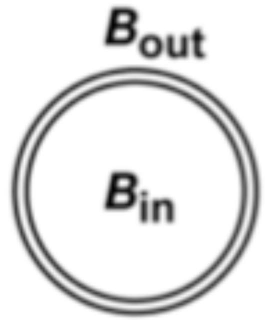
Newton Search



Simulations,
test of hardware
test of zero-finding algorithm
are needed.

(5)Vacuum duct
For field penetration



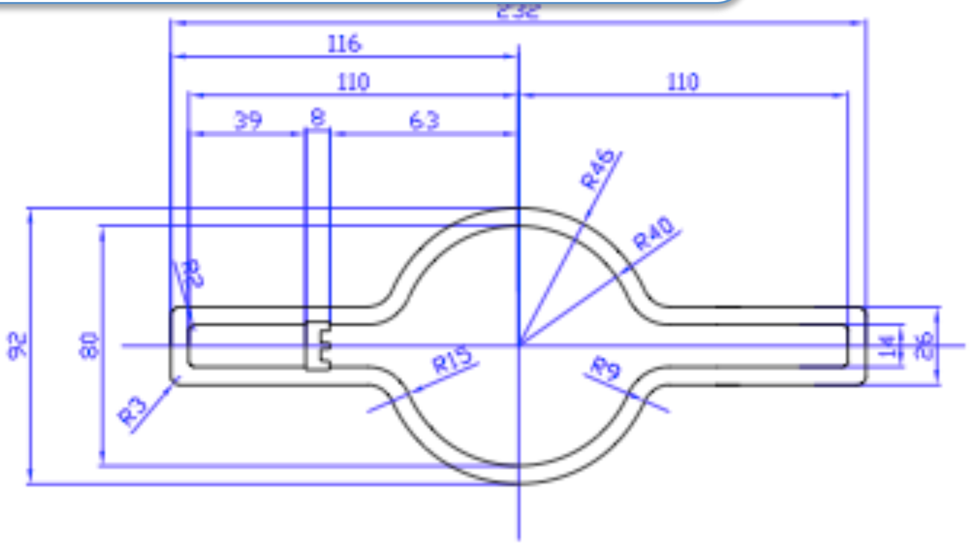


$$\frac{B_{out}}{B_{in}} = \frac{1}{\sqrt{1 + \left[\frac{\mu_0}{2}\frac{bt}{\rho}\omega\right]^2}}$$

b: Outer radius of the duct
t: Thickness of the duct
6mm
ρ: conductivity
ω: Angular frequency

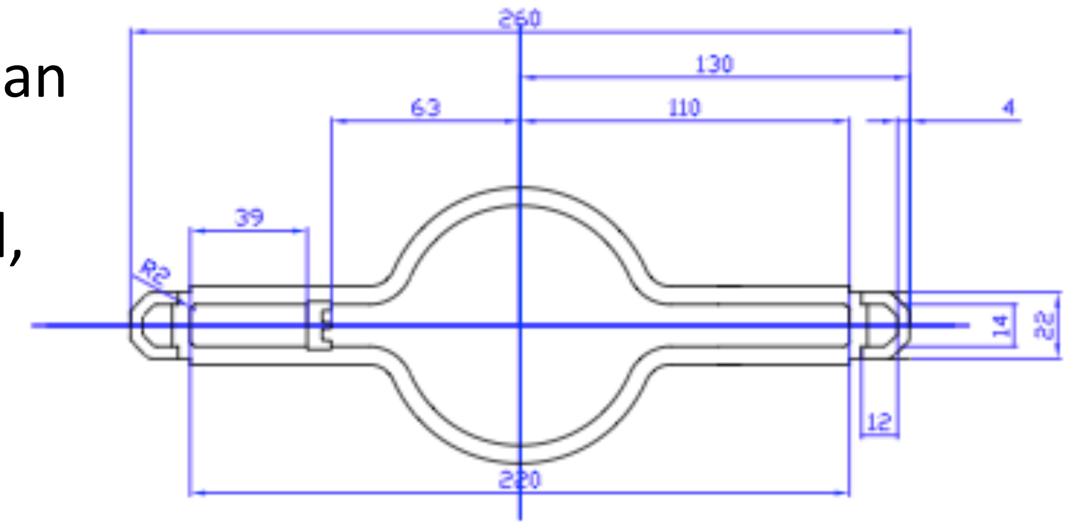
A.W. Chao and M. Tigner, Editors, Handbook of
Accelerator Physics and Engineering, Second printing, World Scienti
fic, Singapore (1998), p. 264.

(5)Vacuum duct
For field penetration



Current design
Copper
6 mm thick

We will have to
make a request to Suetsugu-san
to change the duct material
from Copper to stainless steel,
where iBump & dithering
magnets are located.



HER LC f80x220 Cross Section

Y. Suetsugu

(6) Good luminosity signal (S/N)

Fast luminosity monitor by S. Uehara.

How clean is the signal?

Very important.

Concept of the Lock-In Scheme

- Continuous sinusoidal dither of the beam at the IP.
- ~~Simultaneous~~ dithers for x, ~~y, and y'. Two methods available:~~
  - Use ~~three different~~ frequencies—ω_x, ~~ω_y, and $\omega_{y'}$~~
  - ~~Drive x with $X_d \cos\omega_{xy} t$ and y with $Y_d \sin\omega_{xy} t$ at one frequency, while y' uses $\omega_{y'}$~~
- One lock-in amp per dither frequency detects the magnitude and phase of the luminosity's response.
  - Lock-in magnitude at drive frequency disappears when beam is centered (while signal at even harmonics should climb).
  - ~~The xy combination dither circles the luminosity peak.~~
  - Lock-in phase indicates the direction beam must move to increase luminosity.
- Excite the ~~4 xy~~ air-core coil set~~s~~ with coefficients that give desired kicks.
- Measure ~~all 3~~ dithers, then send one ~~combined~~ correction to DC correctors.
- 1-Hz cycle: 0.3 sec for measurement, 0.7 sec for moving DC correctors.

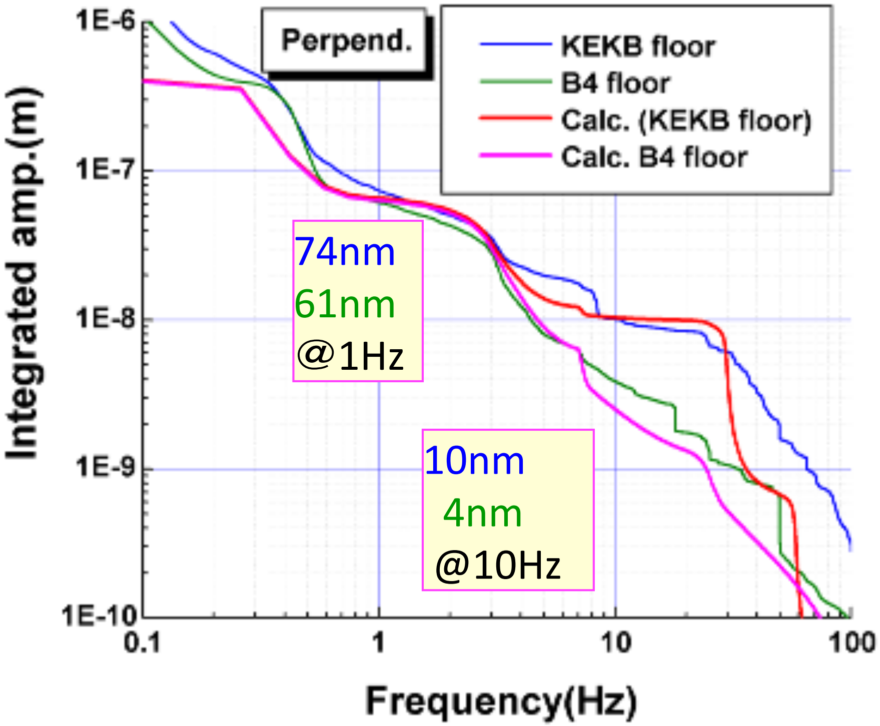
Is 1 Hz fast enough?

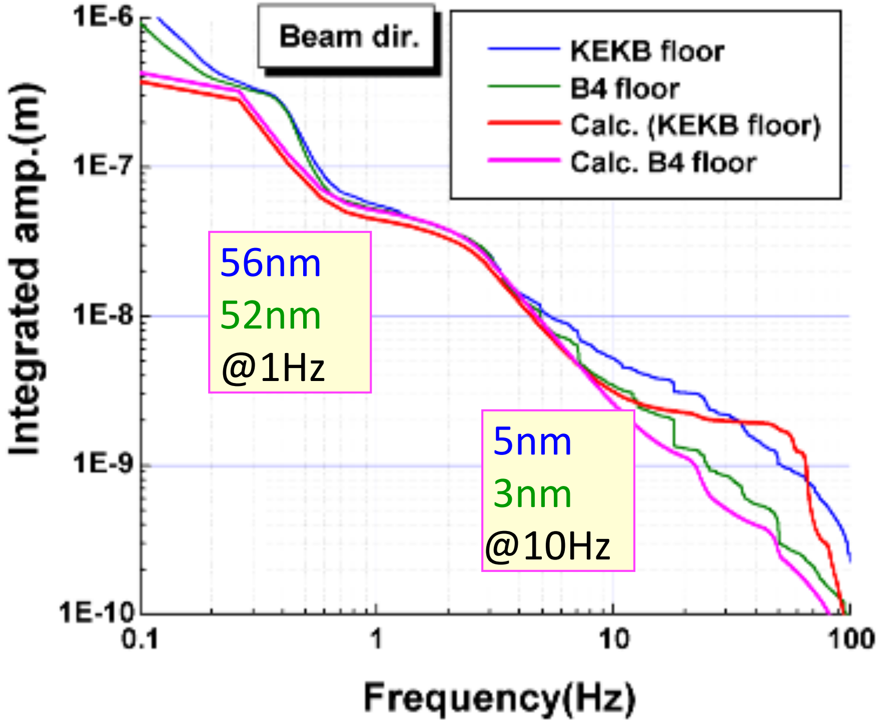
Alan Fisher
2005-10-19

Dithering Summary : To-do list

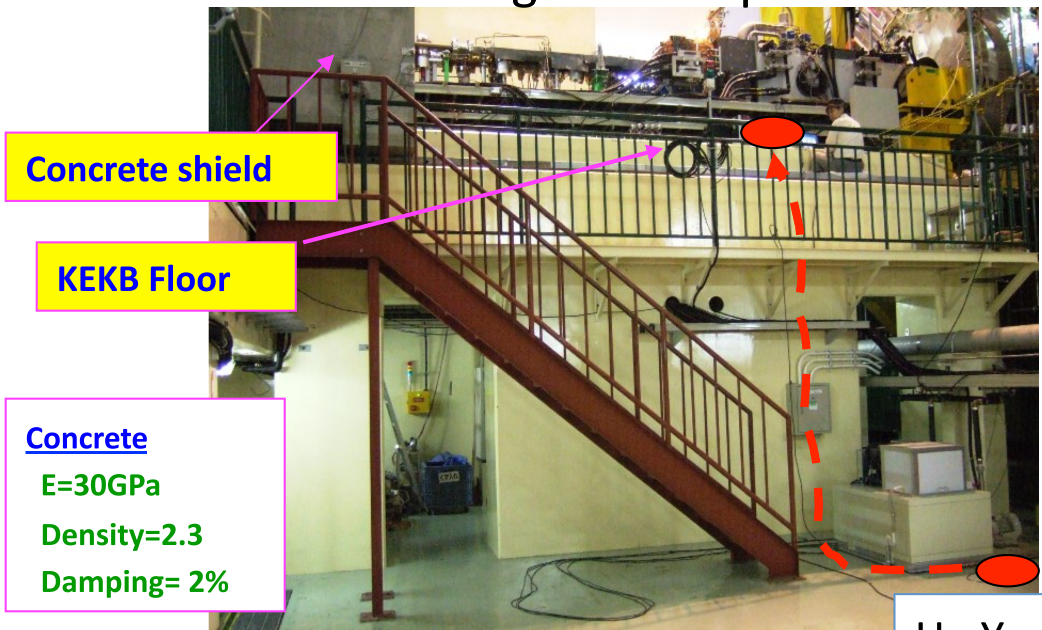
- Locations of the dithering coils (and iBump (orbit control) steering magnets) need to be finalized and a request to the vacuum group needs to be placed very soon. Stainless steel vacuum ducts are preferred. Or find locations where ducts are thinner (bellows)?
- Horizontal only?
- Specifications for coils and power supplies need to be finalized and the coils (air-core or ferrite core) need to designed.
- Power supplies need to be purchased. (or re-use the old KEKB iBump power supplies.)
- Specifications for Lock-In amps need to be decided. Can we borrow one from SLAC? Or purchase one?
- Continuing work on fast luminosity monitor by S. Uehara -- collaboration with LAL is ongoing.
- Signal/noise, zero-finding algorithm simulation work is needed.
- Steering magnets for changing the collision orbit needs to be designed. Setting rate?
- Collaboration with SLAC is highly appreciated.

spare

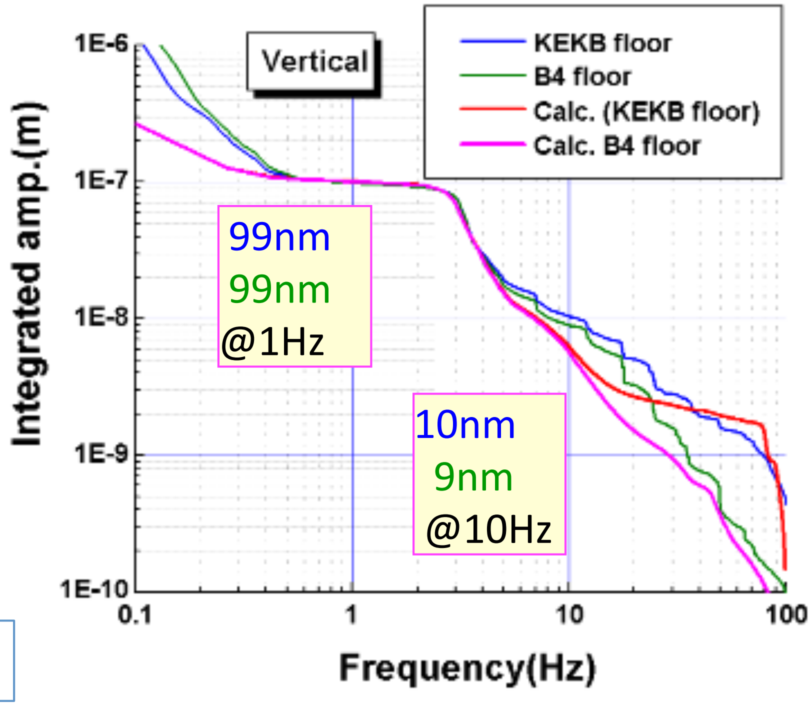




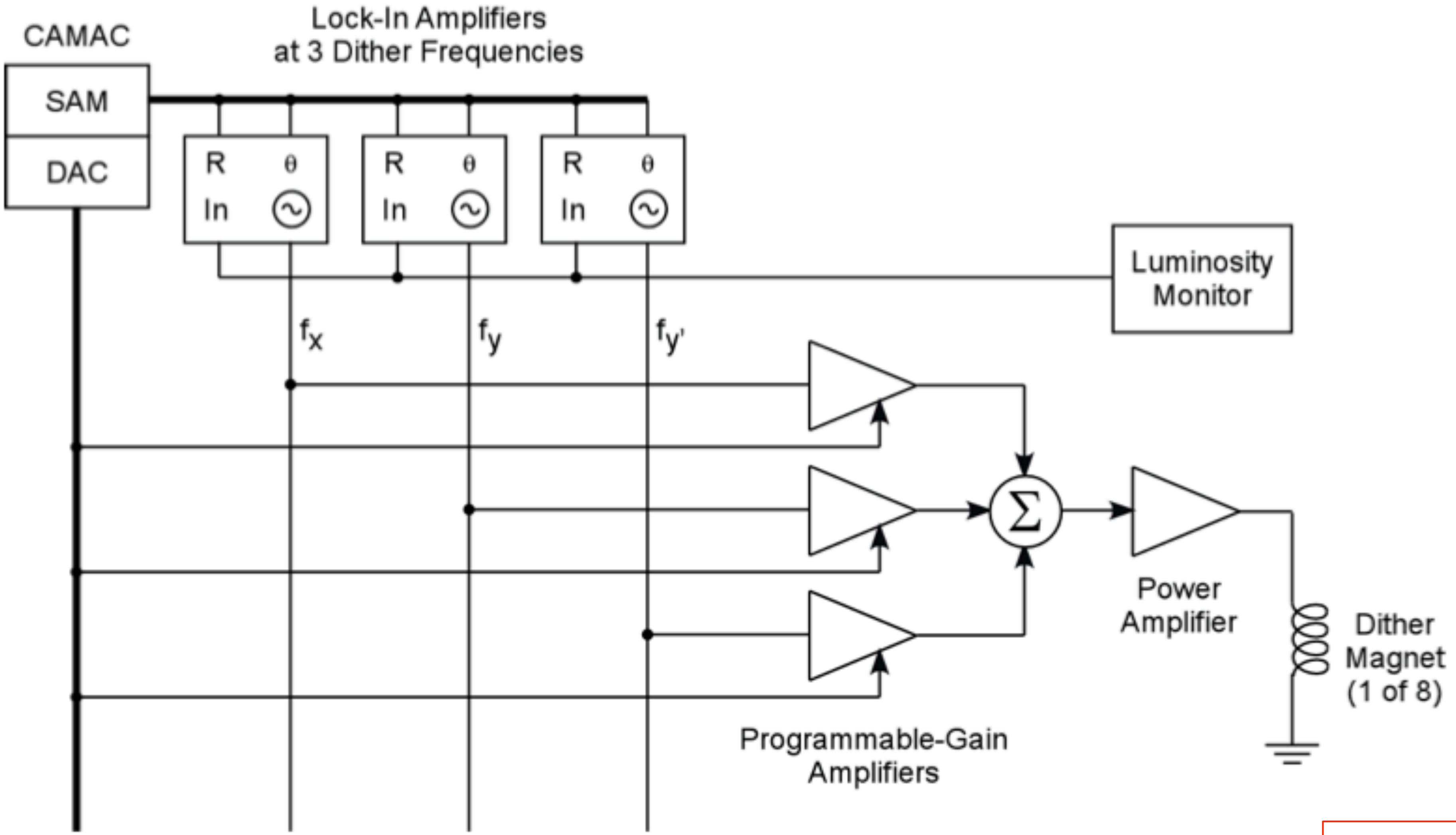
Integrated amplitude



H. Yamaoka



Conceptual Sketch



Alan Fisher
2005-10-19

Project Scope for SLAC work (tentative, to be agreed upon between SLAC & KEK)

- IR Feedback Investigate an IR feedback scheme that will maintain stable collisions at high luminosity
  - Perform analytic work and simulations of such a system, as appropriate, in communication with KEK
  - Generate requirements for the luminosity monitor(s) and other diagnostics to be used in the feedback
  - Generate requirements for the beam-control elements (steering magnets)
  - Propose hardware implementation compatible with extant KEK infrastructure.

Y. Funakoshi