Beam Diagnostics

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1. Introduction

Parameters of SuperKEKB related to beam diagnostics

	HER	LER	Related monitors
Energy (GeV)	7.007	4.000	
Current (A)	2.6	3.6	BPM, FB, SRM
Number of bunches	2500	2500	FB, SRM
Single bunch current (mA)	1.04	1.44	BPM, FB, SRM
Bunch separation (ns)	4	4	BPM, FB, SRM
Bunch length (mm)	5	6	FB, SRM
Emittance (nm)	4.3	3.2	BPM, FB, SRM
x-y Coupling (%)	0.24	0.27	BPM, FB, SRM
Vertical beam size at IP (nm)	56	48	BPM, FB
Transverse damping time (ms)	53	43	FB
Vacuum chamber	reuse of KEKB chambers	ante-chamber	BPM, SRM

Much smaller beam size and larger beam current than those at KEKB.

BPM : Beam position monitor

FB : Bunch feedback

SRM : Synchrotron radiation monitor

Main ring diagnostics

System	Quantity		Comments
	LER	HER	
Beam position monitor (BPM)	452	475	Closed orbit correction, slow/fast orbit feedback, iBump feedback, optics correction
Displacement sensor	100*	100*	Displacement between a sextupole and a BPM
Transverse bunch by bunch feedback	1	1	Suppress beam instabilities, kick a pilot bunch
Longitudinal bunch by bunch feedback	1	-	Suppress beam instabilities
Visible light monitor	1	1	Transverse/longitudinal bunch profile, transverse beam size
X-ray light monitor	1	1	Precise beam size
Beamstrahlung monitor	1	1	Beam information at IP
Gated measurement	1	1	Tune, position and phase of each bunch
Tune monitor	1	1	
Loss monitor	300*	300*	300 PINs in each ring, additional 100 ion chambers common to LER and HER
DCCT	1	1	Reuse of KEKB system with modification of a circuit
Bunch current/fill pattern monitor	1	1	

Items marked by orange are new in SuperKEKB.

A luminosity monitor will be prepared by the Belle II group.

* Tentative number

2. Beam Position Monitor

2.1 Consideration on system design

A. Tentative specification

- Precise slow measurement

  Optics measurement at low beam current, slow orbit feedback

  Resolution : ~ 2μm, repetition rate : ~0.25Hz

- Orbit measurement for fast iBump feedback

  To Maintain stable beam collision

  Resolution : ~ 1μm, repetition rate : ~1kHz

- Turn by turn orbit measurement

  Optics measurement during physics by kicking a pilot bunch

  Resolution : 50 to 100μm

- Orbit measurement for fast orbit stabilizing feedback

  To avoid vertical emittance growth

  Resolution : ~ 3μm, repetition rate : ~1kHz

B. Assumption for system consideration

1) LER vacuum chambers are replaced by ante-chambers.

Narrowband detectors of KEKB can not be used because cutoff frequency of the ante-chamber is below their detection frequency.

2) Most HER vacuum chambers in KEKB are reused.

The narrowband detectors of KEKB will be used.

3) The number of turn by turn BPMs are three per betatron wave length.

4) BPMs for fast orbit feedback are placed around IR region.

The number of the BPMs is not large, e.g. about 30 per ring.

This condition, which was presented at an optics meeting last September, led to the change of design of BPM system.

C. Other factors affecting system consideration

1) Larger beam currents than those in KEKB

Large signal power to a detector, poor electrical contact of an electrode and a cable and movement of BPM due to thermal deformation of a chamber.

2) Maximal use of present narrowband detection system to save the cost.

D. Plan of BPM system

1) Introduction of new detectors

- Narrowband detector for 509 MHz detection

  The detector is a 509MHz version of a KEKB detector.

  One detector covers four BPMs by multiplexing signals.
  The VXI system in KEKB can be used.
  } Cost reduction

- Turn-by-turn detector with a fast gate
- Mediumband detector for orbit stabilizing feedback
- Special detector for iBump feedback

2) Use of new button electrode

Button with small diameter, pin type inner conductor

3) Use of displacement sensors to measure the movement of BPM due to thermal deformation of a chamber.

About 200 displacement sensors are already installed in KEKB to measure the movement of BPMs from nearby sextupoles (resolution < 0.2μm, range 0.5 to 2.5mm).

Need to develop special sensors near rotatable sextupoles for local chromaticity correction and at QC2s in cryostats.

Full BPM system

Type	Function	Resolution (tentative)	Repetition (tentative)	The number of units
Narrowband of KEKB	closed orbit correction, maintain orbit against slow drift, optics measurement	2μm	0.25Hz	115 (already we have.)
New narrowband	as above	2μm	0.25Hz	110
Turn by turn	optics measurement during collision	50 - 100μm	100kHz	270
Mediumband	fast orbit feedback	3μm	1kHz	60
IR	collision feedback	1μm	1kHz	4 to 8

A narrowband detector covers four BPMs.

E. Construction plan of BPM system

1. Narrowband BPM system and BPM for iBump feedback

   These are minimum systems which are to be prepared at T = 0.

2. Mediumband BPM for fast orbit feedback

   Need detail evaluation of location, quantity and specification.

   Also need evaluation of minimum quantity at T = 0.

   Candidates of a detector are a detector for iBump feedback with modification or a commercial detector.

3. Turn by turn BPM for optics correction during physics

   Need evaluation of minimum quantity at T = 0.

   (Correction scheme at KEKB might be possible at SuperKEKB for single beam.)

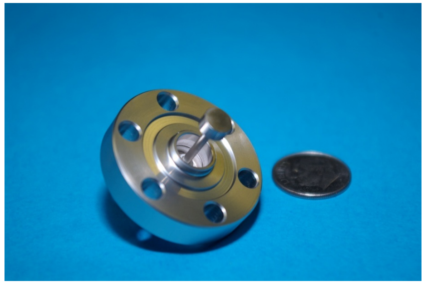
4. The narrowband could be gradually replaced with the mediumband and the turn by turn after T = 0.

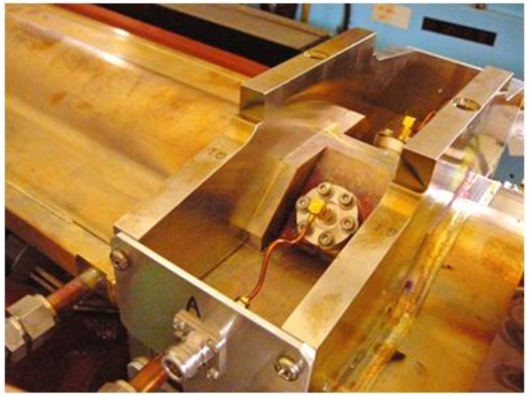
⇨

1) Complete R&D of the narrowband and the BPM for iBump feedback.
2) Continue R&D of the mediumband and the turn by turn.
3) Determine system at T = 0 by the middle of 2012 based on study of beam optics, R&D results, strategy of commissioning and budget.
4) Start construction of the detector system.

2.2 Status of R&D works

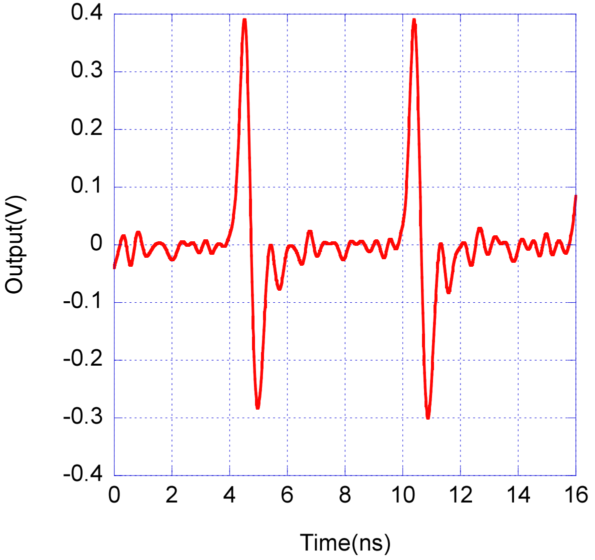
A. Button electrode





Temperature rise ~3deg @ 1.6A

- A button electrode has been developed.
  - ◊Diameter : 6mm
  - ◊Flange type for easy replacement upon trouble and TiN coating
  - ◊Pin-type inner conductor for tight electrical connection
  - ◊Ceramic vacuum seal
- Prototypes were tested at KEKB. Problem is not found.
- The electrode is ready for mass production.



Beam signal

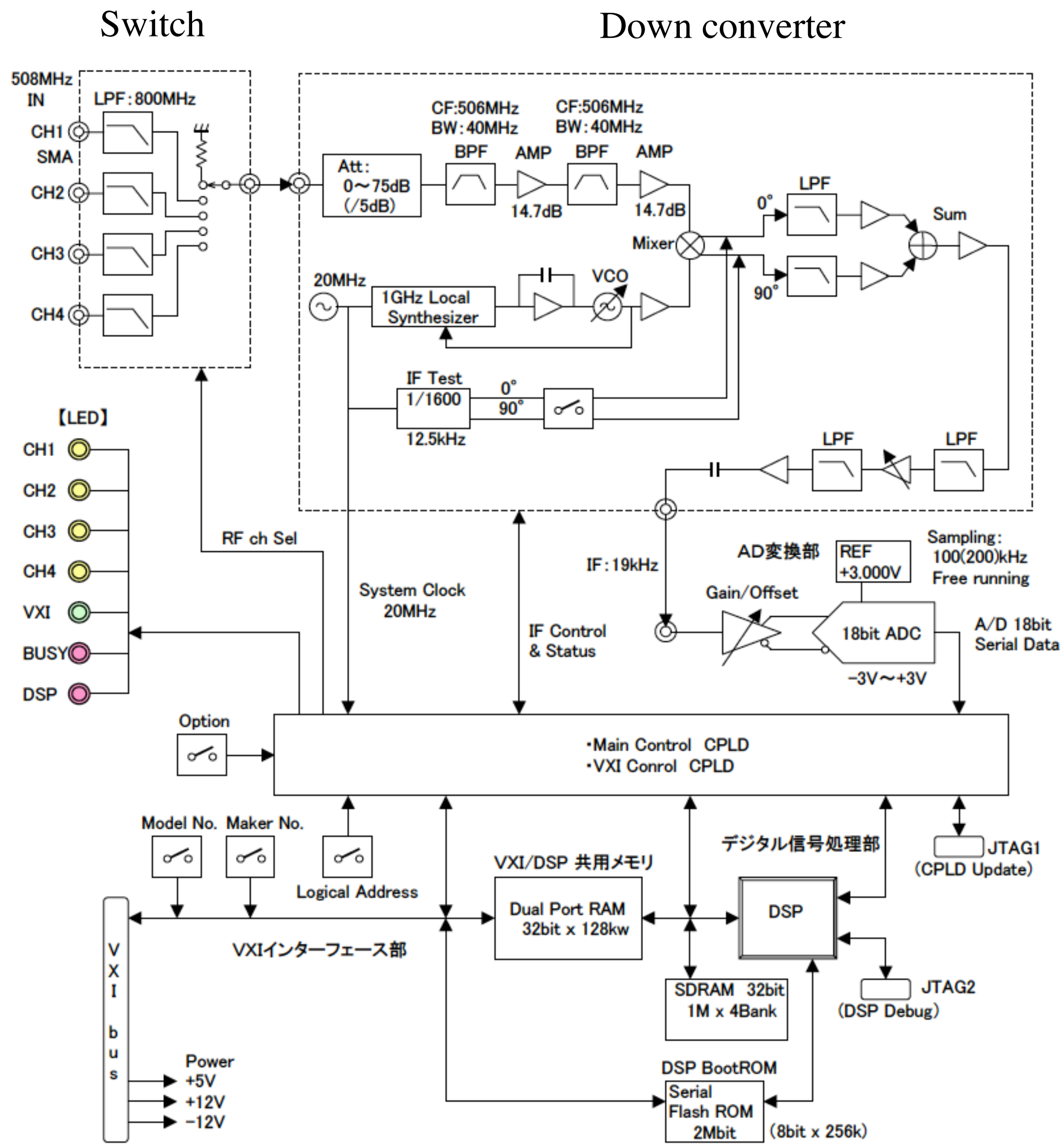
If the HER chamber and the 12ϕ electrode at KEKB are reused, signal power at the electrode is increased than that expected for the 6ϕ electrode.

Analytic estimate : $P_{electrode} = 2.2W$ @ 2.6A for KEKB electrode

The calculation needs to be compared by the EM code.

B. Narrowband 509 MHz super-heterodyne detector

- A narrowband super heterodyne receiver is being developed based on a detector of KEKB.
- Detection frequency is changed from 1GHz at KEKB to 509MHz because the cutoff frequency of a chambers is below 1GHz.



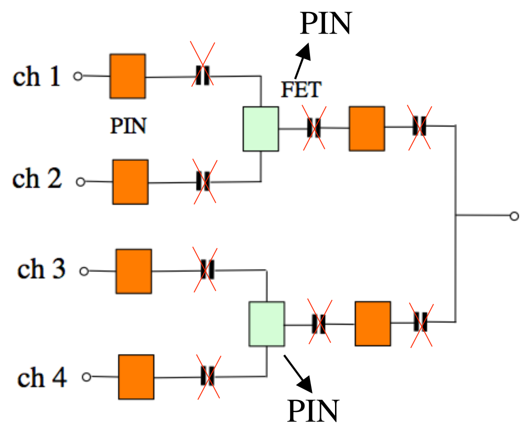
Specification

Detection frequency	508.887MHz
SNR at signal power of -60 dBm	> 89.8 dB
Noise figure	< 7 dB
ADC (bits/sampling freq.)	18 bits / 102.4 kHz
Max. input power	-50 dBm
FFT points (by DSP : SHARC)	2^N (N=4, 5, ..., 12)

B.1 Status of R&D

1) Switch

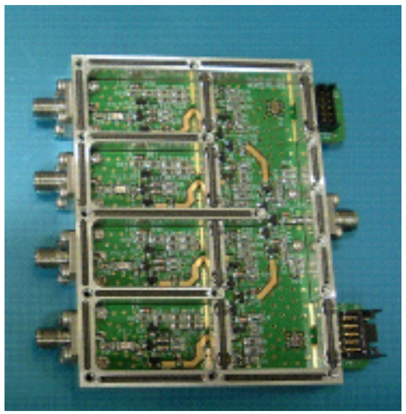
Switch-noise appeared at the end of a switch section.
The switch was redesigned at KEK by replacing FETs to PINs and removing decoupling capacitors between switches.



Preliminary results (test bench, CW input)

Switch

	New switch		Old switch
	No.1	No.2	
Transmission loss	1.485 dB	1.485 dB	2.1 dB
Isolation	99.6 dB	99.7 dB	86 dB
Difference of input/ output reflection coeff. between channels	0.0077	0.0157	0.04



A new switch

Down converter connected with switch

	New switch		Old switch
	No.1	No.2	
S/N	-92.46 dB	-93.05 dB	-83 dB
S/N (ratio of voltages of two channels)	-93.21 dB	-94.1 dB	-93 dB
Apparent shift of beam position for different attenuator settings	9μm	30μm	60μm

Different down converters were used.

$$\sigma_X \approx \frac{1}{2} K \frac{1}{(S/N)} = 0.37\,\mu m$$

for S/N=93dB and K=33mm

1) Switch (continued)

- The change of apparent beam position may be caused by impedance mismatch between a switch section and a variable attenuator after the switch.
- A new attenuator will be tried next fiscal year if budget is available.

2) Linearity

- The measurement of gain error as a function of input power at a company showed the gain error of +/- 0.2 % in the input range of 30dB before improving the switch.

Position error is very sensitive to the gain error.

Position error $\Delta x = (K/4)\cdot \varepsilon$, ε = ΔV/V (Gain error of an electrode), V : signal level

$\Delta x = 1\mu m$ ⇔ $\varepsilon = 0.012\%$, gain difference $1+\varepsilon = 0.001dB$ (K=33mm)

Need very precise adjustment of signal level between four channels.

- A calibration method of input power is being checked at the company.
- Linearity will be measured with the new switch.

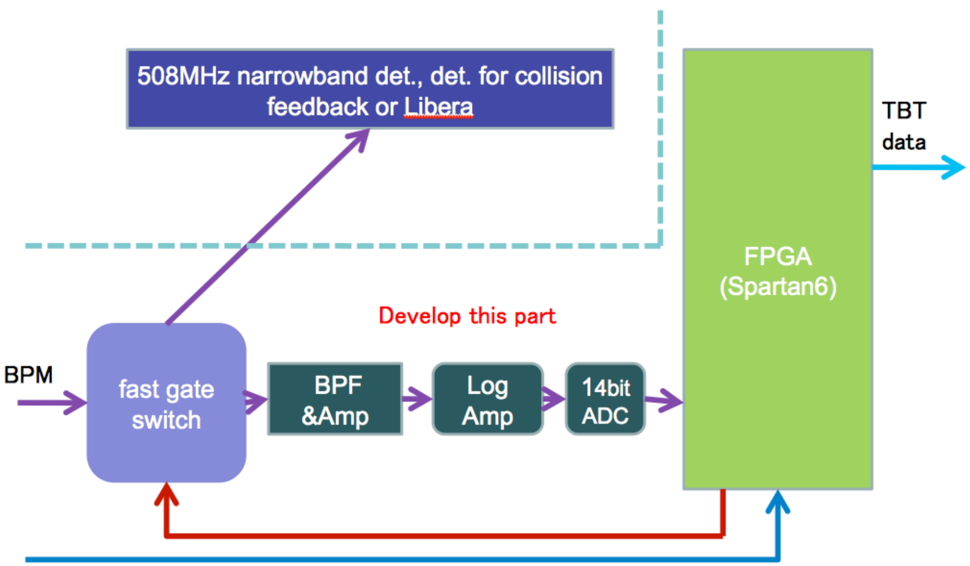
C. Turn by Turn detector

1) Original plan

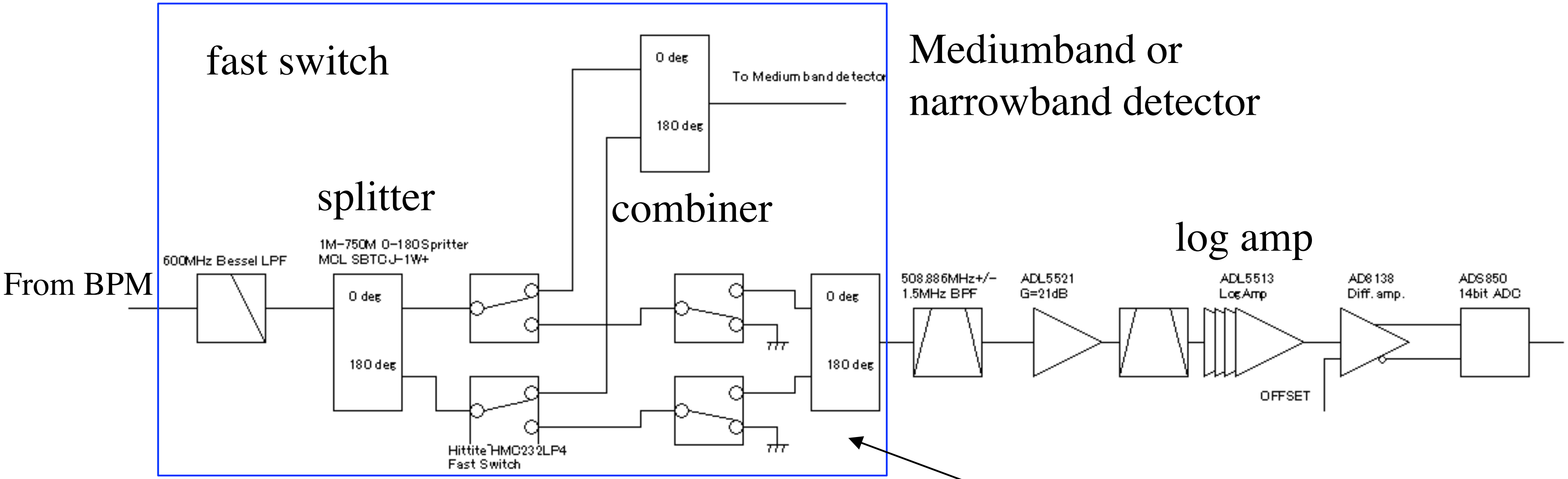
- To develop a detector which houses a mediumband circuit and a turn by turn circuit.

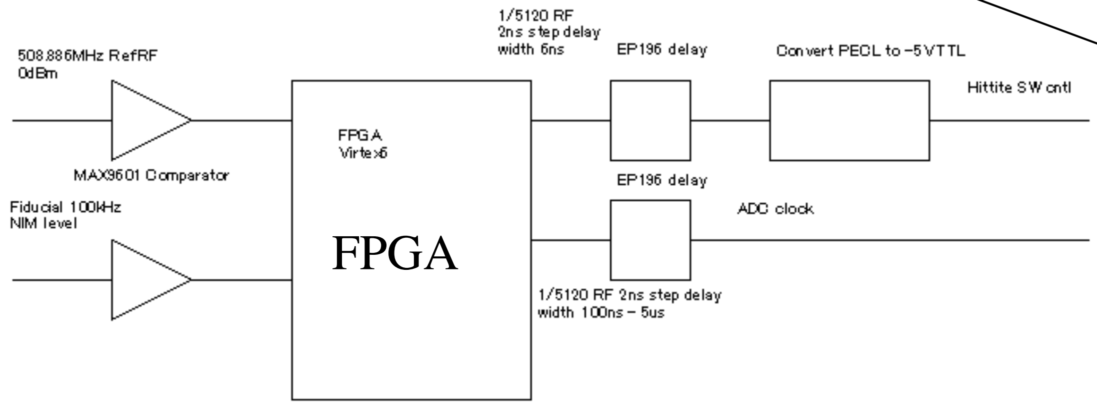
2) Recent plan

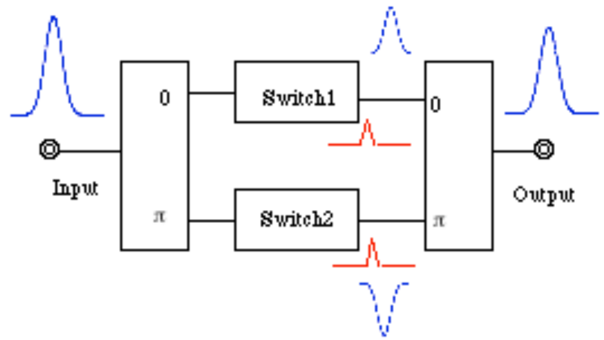
- Recent discussion suggests the required number of the mediumband circuit and the turn by turn circuit much differ, i.e. 60 for the mediumband and 270 for the turn by turn.
- Now we are developing a turn by turn detector which has a gate to divide signals between the pilot bunch and other bunches.
- Just a signal of the pilot bunch is "stolen" for the turn-by-turn measurement.
- Signals of remaining bunches are sent to output ports of the detector connected to a narrowband or a mediumband detector.
- The mediumband detector needs no special gates. (A commercial detector can be a candidate of the detector.)
- Simultaneous measurement by two circuits is possible.
- A bunch signal is detected by a log amp to save the cost of the turn by turn detector.



Block diagram of a turn by turn detector







A glitch cancel circuit by T. Naito

A prototype circuit will be tested in this spring.

D. BPM for iBump orbit feedback

D.1 Requirement (Y. Funakoshi's talk)

1) Vertical positions of both beams are monitored for orbit feedback("iBump feedback") to maintain stable beam collision. For horizontal feedback, BPMs are not used.

2) Location of BPM

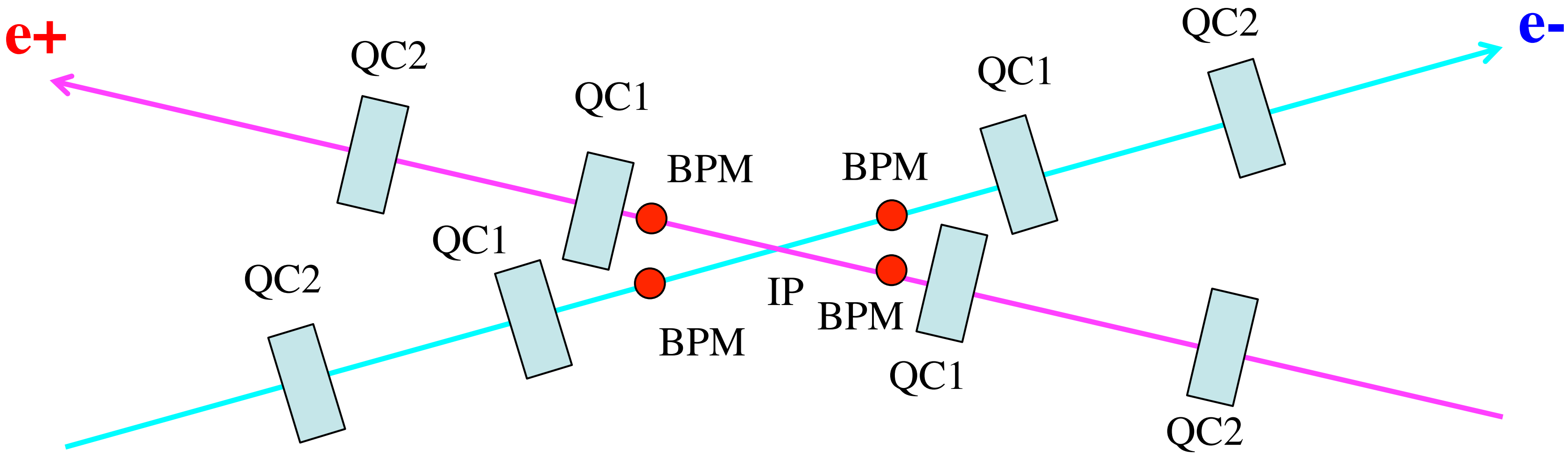
QC1RP, QC1LP, QC1RE, QC1RP

3) Resolution

1 μm (tentative)

4) Repetition

1kHz (tentative)



D.2 Button electrode for IR BPM

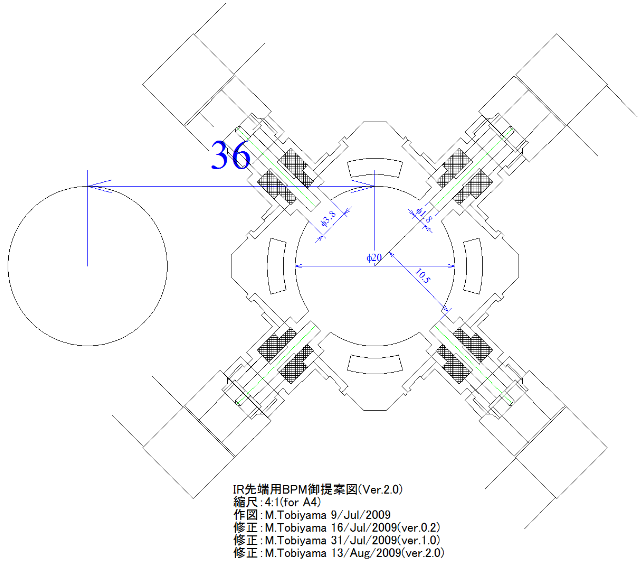
•Reduce signal level at a feed through

⇨ Small button size of $\phi 1.8$

Estimated beam power

Total power：about 10.4W

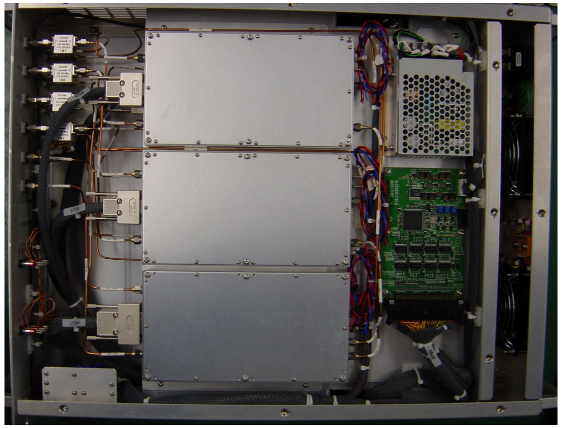
508MHz component：about 6dBm



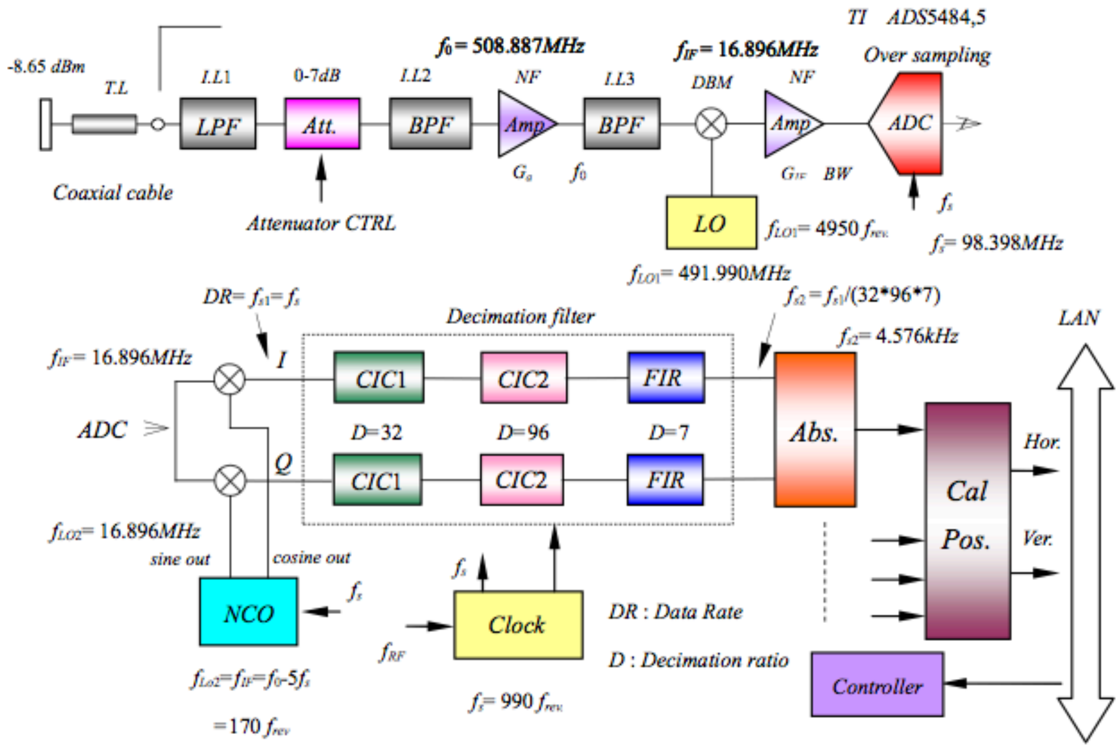
•Fixing of a central conductor to a body of the feedthrough is relatively weak, i.e. 1/10 of Octopos. Improvement may be needed.

D.3 Detector

- Down-covert 508.8MHz component to intermediate frequency (IF) of 16.9 MHz with an analog mixer.
- Convert IF to digital signal by a 16 bit ADC.
- Detect position through digital filters (two CICs and a FIR).
  SNR is relatively insensitive to a clock jitter compared to direct conversion though additional analogue RF circuit is needed.
- A prototype module is being tested.
- Digital processing uses a processor for LLRF system developed by RF group.



Top view



Specification

Input level	-10 ~ -3 dBm
Detection frequency	509MHz
LO frequency	492 MHz
IF frequency	16.9 MHz
ADC resolution	16 bits
ADC sampling frequency	99.4 MHz
Sampling clock jitter (target value)	<1ps
CIC1	5 stage, decimation 32
CIC2	5 stage, decimation 96
FIR	201 tap, decimation 7
Noise figure	<20dB
SNR	> 110dB@-2.65dBm sinusoidal wave
Control	EPICS

Performance of a prototype

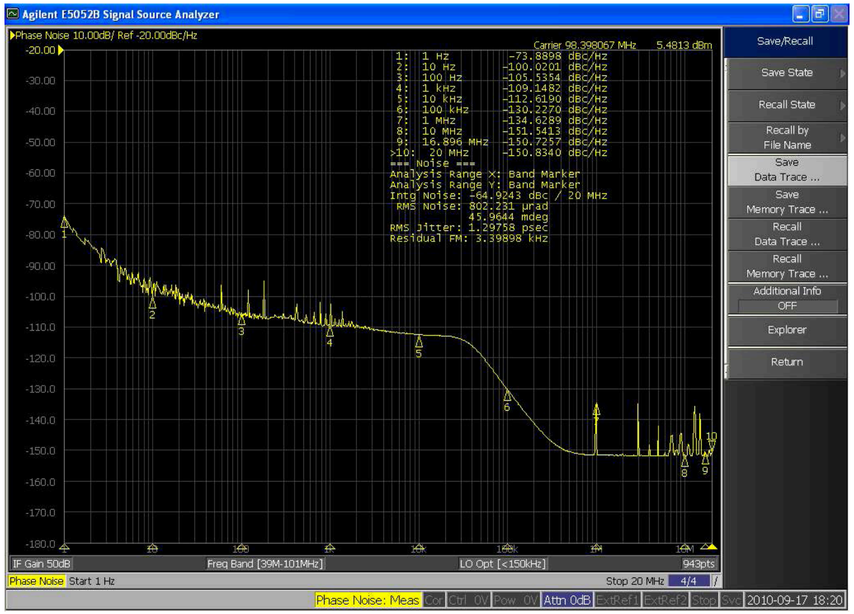
a) Analogue section

Clock jitter 1.30 ps (1 Hz < f < 20 MHz)

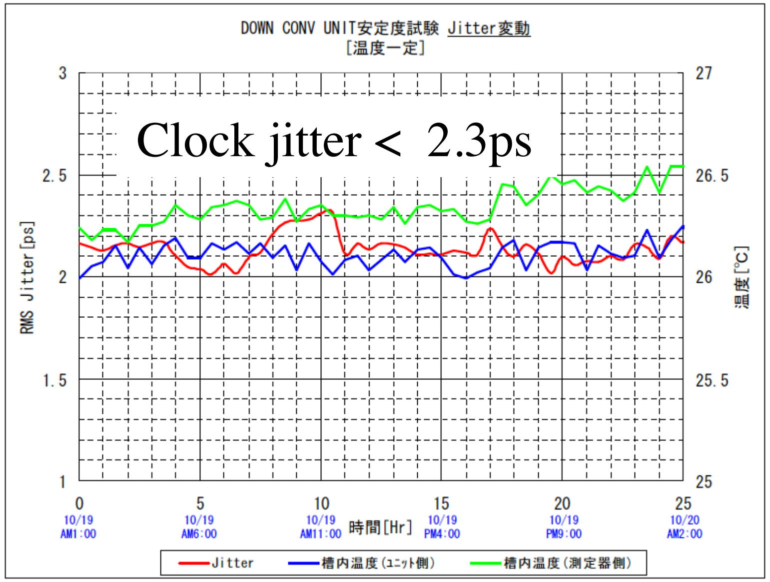
Noise Figure 14.3dB @ 16.9MHz $\left(Noise\ Figure = \frac{S_i/N_i}{S_o/N_o}\right)$

Temperature coefficient of IF out -0.03dB/deg.

Analogue part works well.



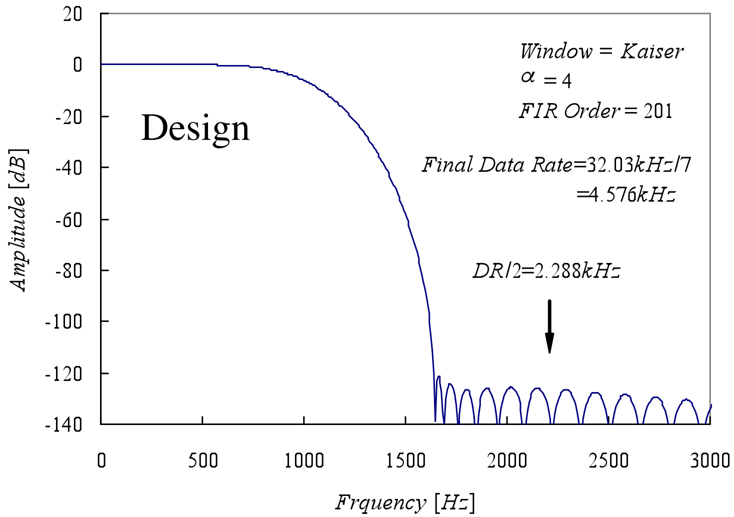
Phase noise of clock

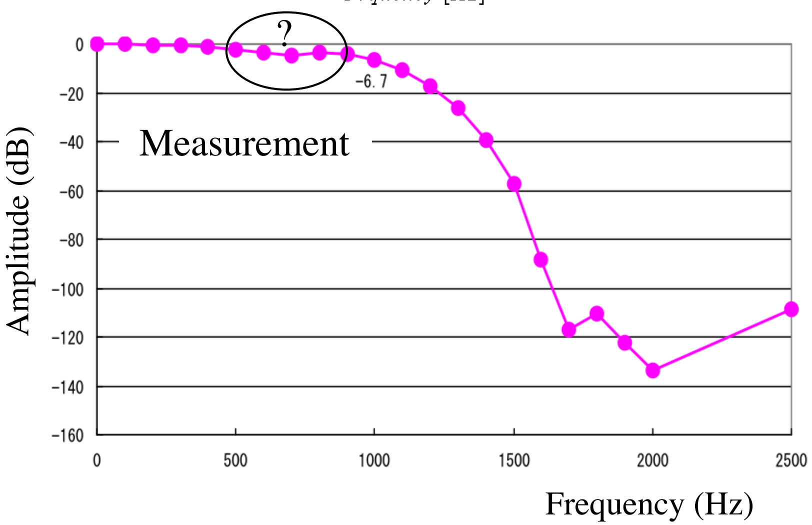


Temperature stability of clock jitter

b) Digital section

Frequency characteristics of the digital filter



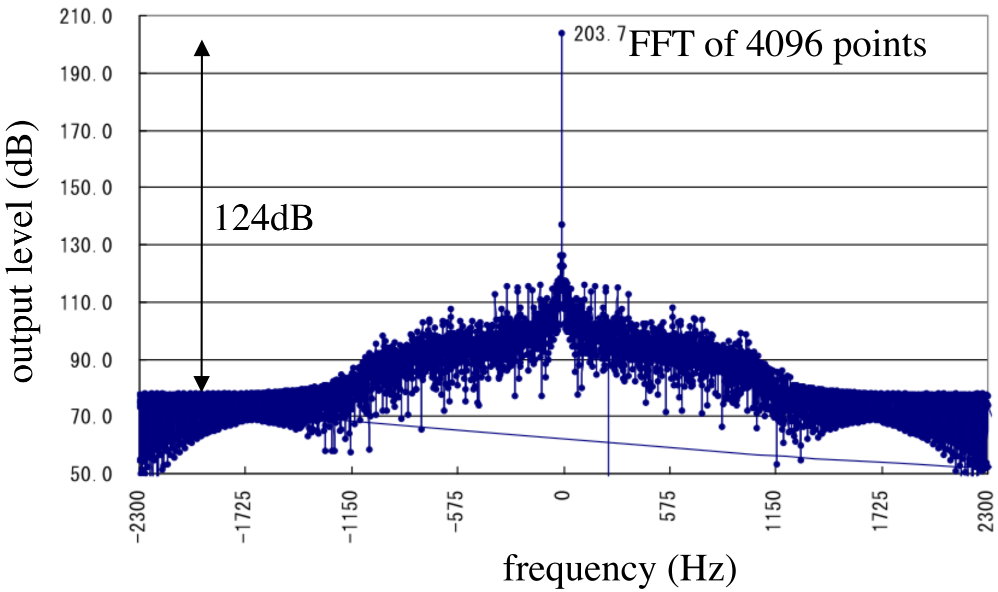


Overall attenuation-characteristics was confirmed by the measurement.

Spectrum at the end of the digital filter

Input : CW in front of ADC.

Input level -1dBFS, input frequency 17MHz-10Hz (intentionally shift by 10Hz from IF freq.).



SNR 100dB ⇔ $\sigma_y \approx 40nm$ for chamber radius of 10mm.

Performance of the filter connected analogue section with digital section will be measured by the beginning of March.

c) Latency

CIC

Transfer function $H(z) = \left(\frac{1 - z^{-RM}}{1 - z^{-1}}\right)^N = \left[\sum_{k=0}^{RM-1} z^{-k}\right]^N$

R : decimation factor,
M : differential delay of comb filter
N : stage of CIC

Order of right hand side $-(RM-1)N \approx -RMN$ for RM>>1

Delay after decimation (RM/R)N=NM samples

1st stage : R=32, N=5, M=1 ⇨ delay : 5 samples = 1/(98.398M/32)x5=1.6 microsec

2nd stage : R=96, N=5, M=1 ⇨ delay : 5 samples = 1/(98.398M/32/96)x5=0.16 msec

FIR (Kaiser window)

$$group\ delay \approx \frac{1}{f_{clock}} \cdot \frac{N_{tap}}{2} = \frac{1}{32kHz} \cdot \frac{200}{2} = 3.1ms$$

f_{clock} : clock rate of the filter, N_{tap} : the number of taps

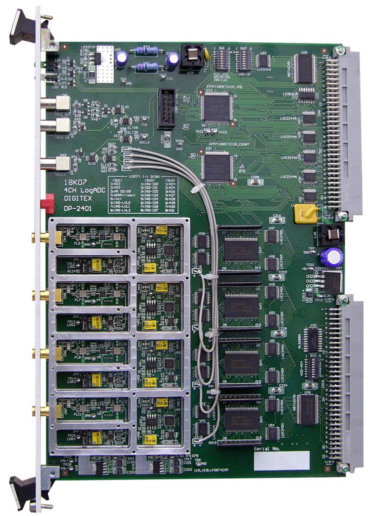
CICs and FIR 3.26ms
MATLAB calculation 3.27ms
Measurement 3.26ms

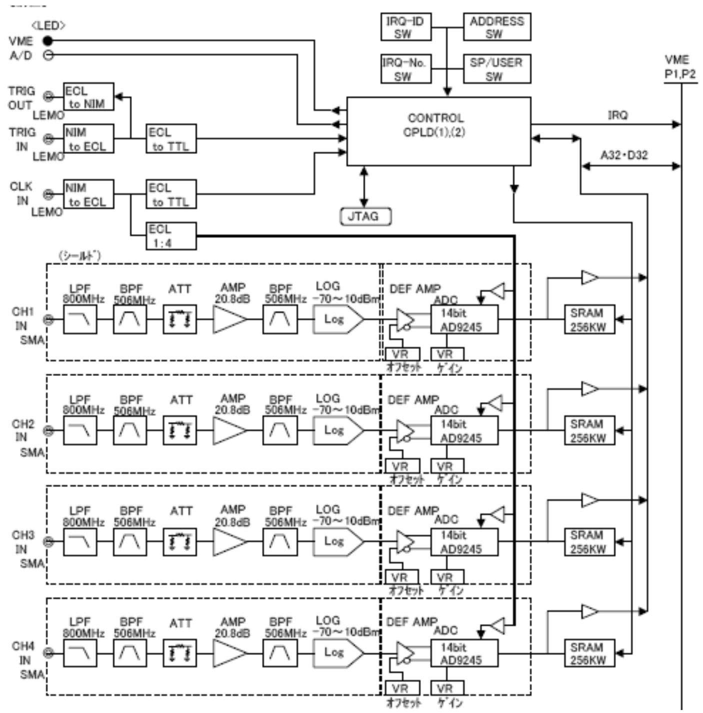
} consistent one another

Latency will be reduced by decreasing decimation rate of the CICs, if necessary.

E. Prototype of a detector for the damping ring

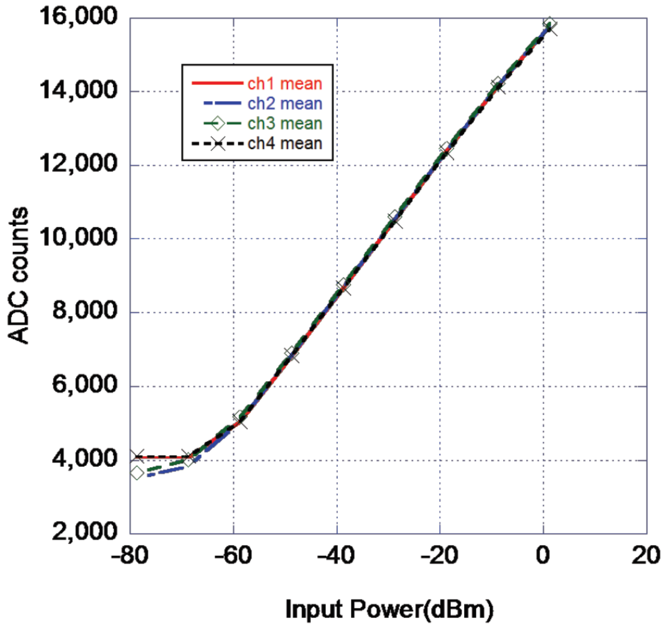
- A prototype VME module was produced.
- Log ratio(L/R) method is used.
  - ◊Cheap
  - ◊Relatively simple circuit
  - ◊Large dynamic range and wide linear range
  - ◊Reasonable resolution and precision
  - ◊Applicable to optics and tune measurement with single bunch
- Specification
  - ◊4ch 508MHz L/R detection (Filter : 506MHz, BW24MHz)
  - ◊Sampling clock : 1 to several MHz
  - ◊Input level : -70 to 0 dBm
  - ◊Memory length : 32k, 64k, 128k, 256k word

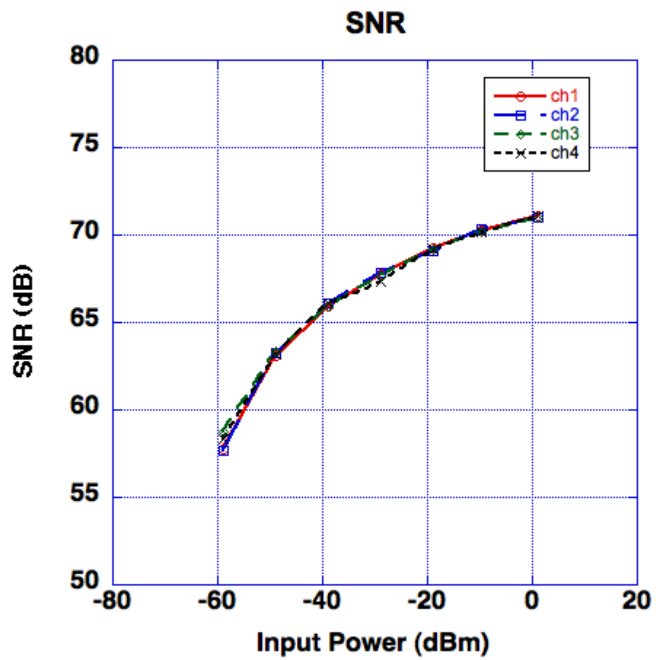




Performance

Linearity





◊Linearity of four channels is adjusted well.

◊SNR is 70dB.

◊Position resolution is about 18μm in x and y directions.

The module can be a prototype of a turn by turn detector in the main rings.

3. Bunch by Bunch Feedback System

3.1 Transverse feedback system

A. Requirements

Growth time of Coupled bunch instability

1) RF cavity

	LER	HER
ARES (HOM)	7 ms	39 ms
Super (HOM)	---	14 ms

2) Resistive wall

LER (Cu)	LER (Al)	HER (Cu)
3.6 ms	2.8 ms	3.1 ms

(Transverse radiation damping time : LER 43 ms, HER 53 ms)

3) Electron cloud instability (ECI) in LER

0.5ms at the average/central electron density of 5 10^{10}/1.1 10^{11} m^{-3} in drift space without solenoid field (Y. Susaki at LER2010). The growth time will be increased if solenoids reduce the electron density.

4) Fast ion instability (FII) in HER

Simulated growth time 0.3 ms (given at KEKB review 2010)

- Required feedback damping time ⇨ LER : < 0.5 to 1ms, HER : < 0.3 ms
- Noise in transverse feedback system should be minimized to reduce the blowup of the beam size during collision.

B. System

1) BPM with good time and frequency response.

2) Low noise front-end electronics

3)Digital filter iGp

4)Power amp

Eight amps of 250 and 500 W per ring.

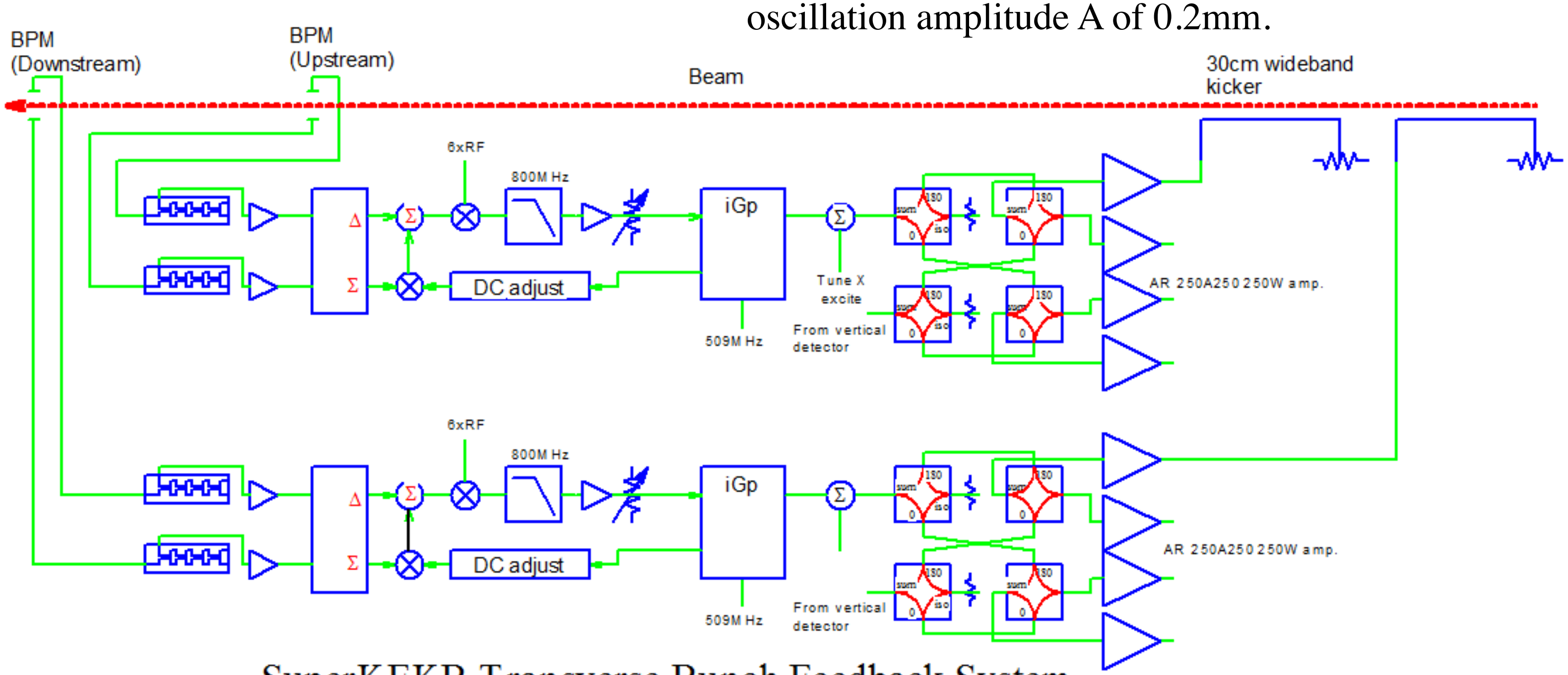
5) Kicker

Two sets of a short stripline kicker per ring which cover two feedback loops with 90 deg phase difference.

R_{sh}=10kΩ per kicker, 500W amp, 2 kickers ⇨ V_{kicker}=8.94 kV

$$A(\mu m)/(\tau_{damp}/T_{rev}) = 6.4(\mu m)[HER],\ 11.2[LER]$$

Damping time τ_{damp} 0.31ms (HER), 0.18ms (LER) for oscillation amplitude A of 0.2mm.



SuperKEKB Transverse Bunch Feedback System

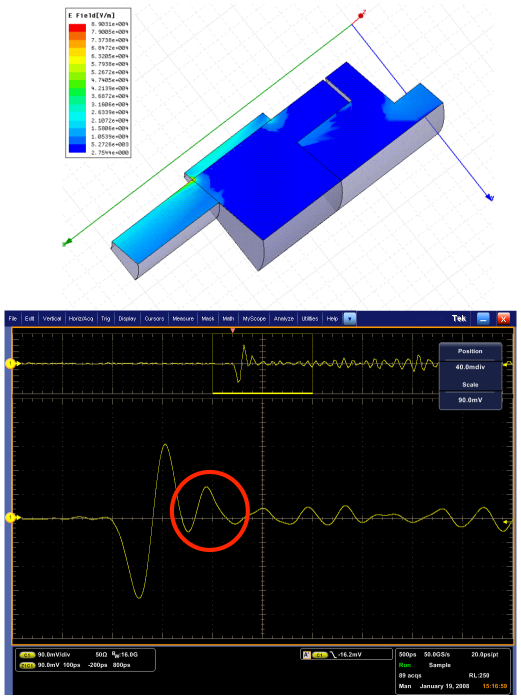
B.1 Monitor chamber

- The present chamber will be replaced with a chamber of 50 mm ϕ.

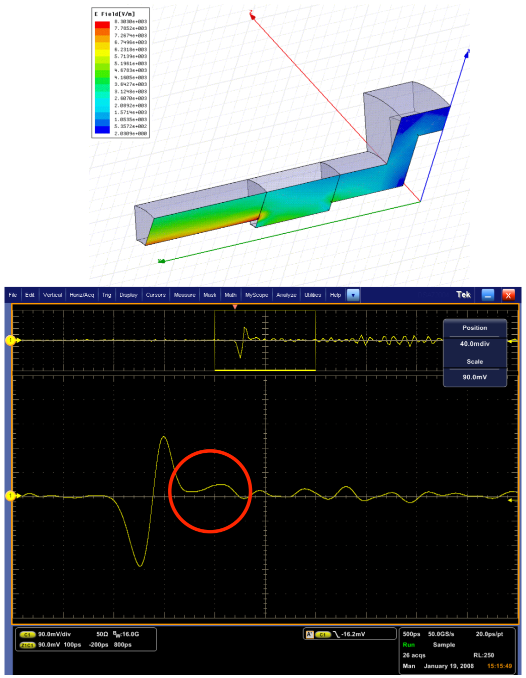
  Its higher cutoff frequency of 3.5 GHz is favorable for better detection for precise position measurement.

- The chamber will be equipped with twenty-four ϕ6 electrodes with a glass feed through.

Present feedthrough



Glass feedthrough

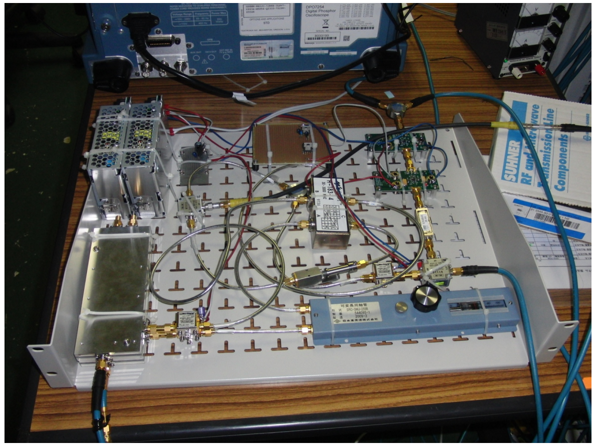


Sharper signal

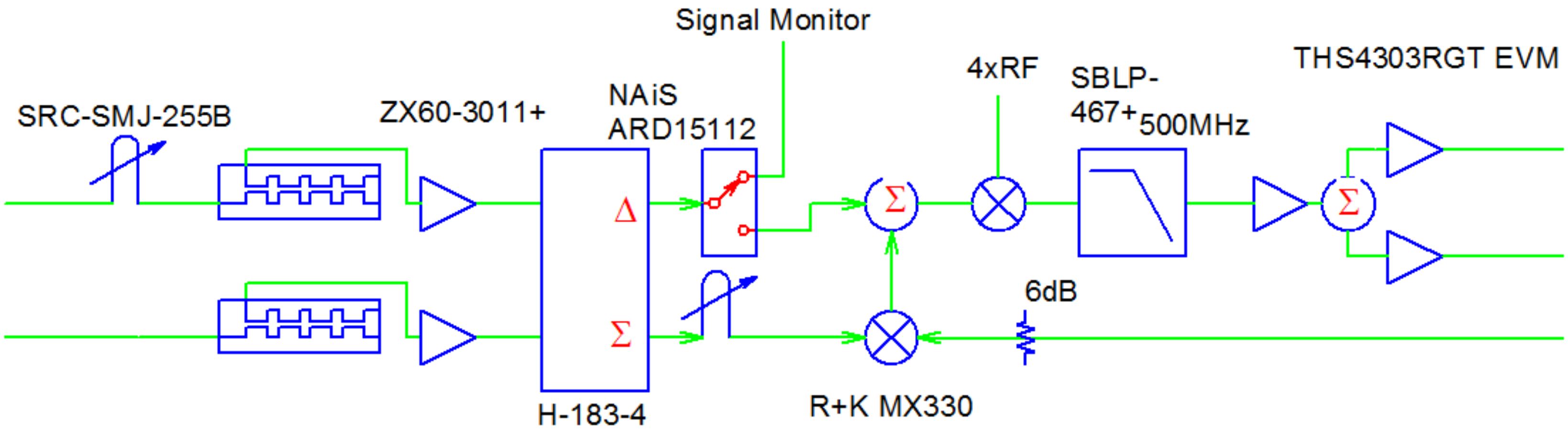
Development has almost completed.

B.2 New bunch detector

- Comb filter at 2GHz or 3 GHz
  To cut low frequency noise
  To improve isolation between bunches
- Low Noise Amp with high IP3
- Bessel low pass filter
- DC amp
  To improve transient response



Test circuit



The system will be built after decision of detection frequency.

B.3 Digital filter

•The iGp processor is a baseline system.

•Developed under US-Japan collaboration (KEK-SLAC).

1.5GSPS 8 bit ADC, 600MSPS 12 bit DAC

FPGA Vertex II

•iGp was tested successfully for the transverse and longitudinal system at KEKB and routinely used in longitudinal feedback at KEK-PF.

•iGp is ready for use.

•Upgrade to 12 bits system is being discussed.

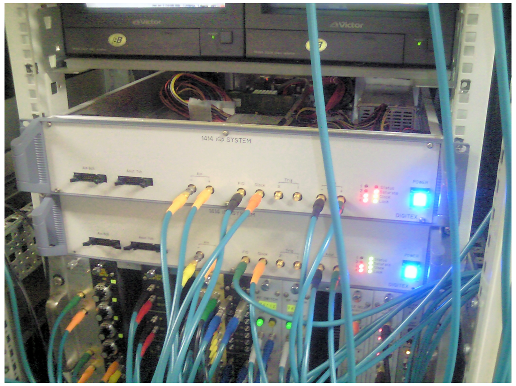
◊Larger dynamic range

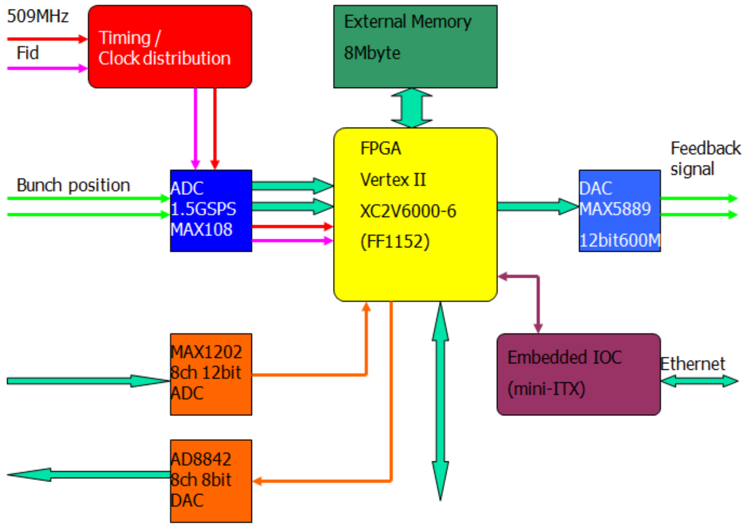
Large margin for offset

◊Higher resolution

◊Powerful FPGA (Vertex5)

◊Large memory size

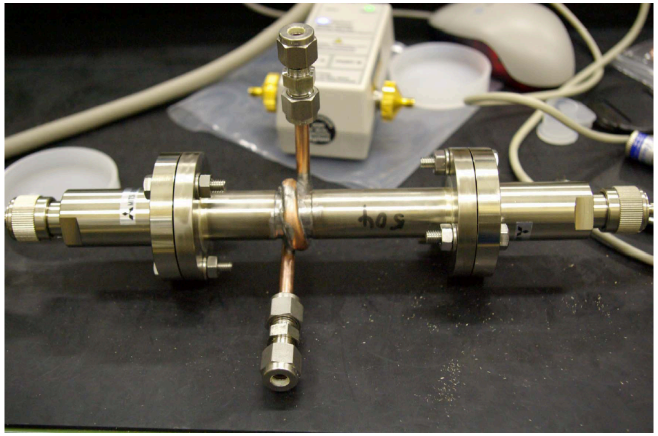


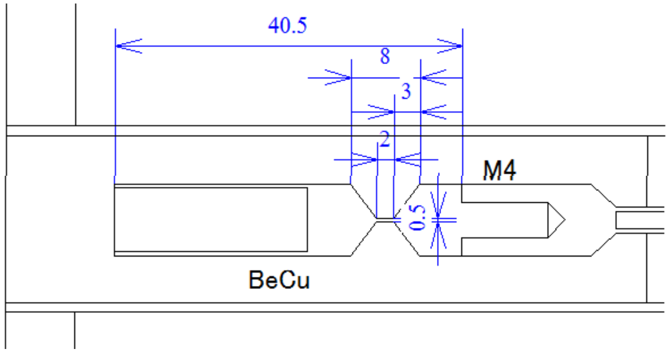


B.4 Transverse kicker

- Two sets of a short stripline kicker per ring
- Similar design with a present kicker
- Planned improvement
  - ◊Change the feed through from 20D type to EIA-7/8 with low loss ceramics.
  - ◊Change high-power cables from 10D to 20D
  - ◊The new feedthrough is under development.
- A prototype of a kicker will be designed and made in next fiscal year if budget is available.

EIA-7/8 Feedthrough (bend type)





The measurement of S parameters shows the feedthrough can be used for the transverse feedback.

3.2 Longitudinal feedback system

A. Requirement for the feedback damping time

CBI growth time by cavity impedance

	LER	HER
ARES (HOM)	12 ms	59 ms
ARES (0-π mode)	20 ms	---
Super (HOM)	---	58 ms

(Longitudinal radiation damping time : LER 21 ms, HER 26 ms)

⇨ LER needs a feedback system with a damping time of about 10 ms.

B. System

1) BPM, frontend electronics and digital filter

Same as those of transverse system

2) Power amp

Four 500 W amps per kicker

3) Kicker

Two DAFNE type kickers with Q value of about 5

R_{sh}=650Ω/kicker, amp. 500W x 4 / kicker, two kickers ⇨ V_{kicker}=3.2kV

$$(\Delta E / E)/(\tau_{damp} / T_{rev}) = 0.4 \times 10^{-6} [LER]$$

Damping time τ_{damp} 10ms (LER) for oscillation amplitude ΔE/E of 4×10^{-4} .

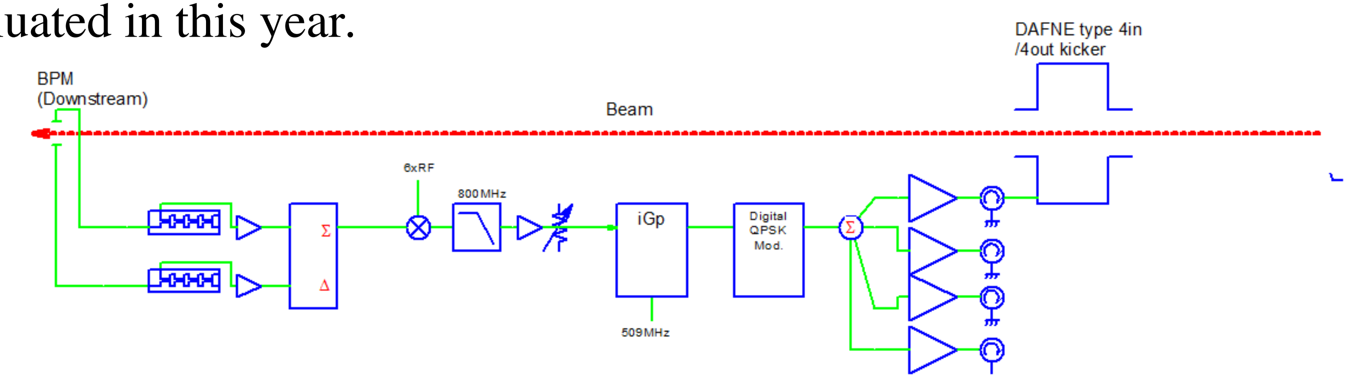
Space is reserved for additional two kickers.

A prototype of a kicker will be designed and made in next fiscal year if budget is available.

4) Power cable, feedthrough and filter

New power cables and connectors have been tested.

An absorptive filter to reduce out-of-band power from the kicker will be evaluated in this year.



SuperKEKB Longitudinal Bunch Feedback System

4. Synchrotron Light Monitor

4.1 Visible light monitor

A. Extraction Mirror

- Heat load at high beam current causes mirror distortion.
- A magnet of light source in LER will be a reused KEKB bend.
- Power on the extraction mirror in HER is slightly larger than that in KEKB.

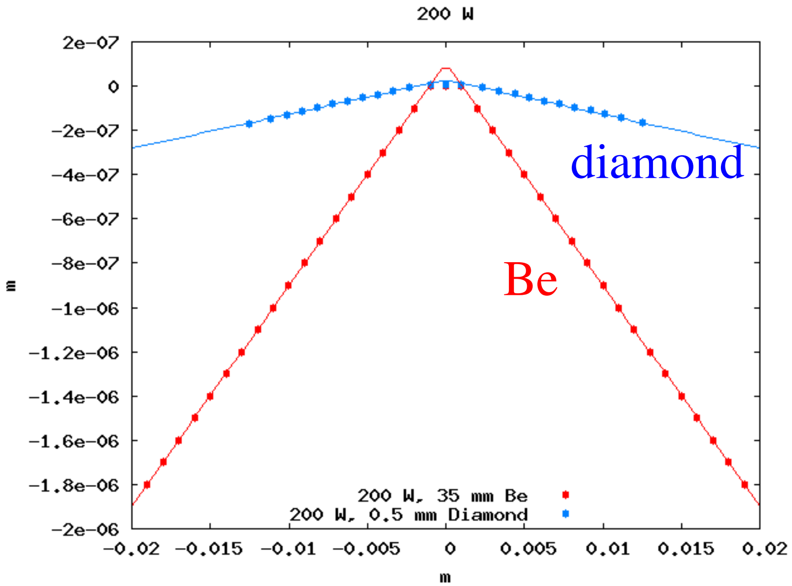
	LER (BSWFRP)		HER (BSWOLE)	
	SuperKEKB	KEKB	SuperKEKB	KEKB
Energy(GeV)	4	3.5	7	8
Current(A)	3.6	2	2.6	1.4
Bending radius(m)	177.4	85.7	580	580
Power(W/mrad)	72	48	149	136
Distance to mirror (m)	11	11	13	13
Mirror width (mm)	35	35	35	35
Total incident power(W)	161	109	283	260

In order to reduce thermal deformation of the mirror further, we are developing a new mirror made of diamond.

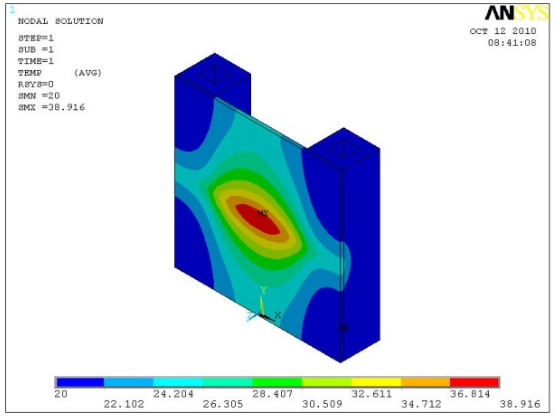
Diamond mirror

Single crystal diamond

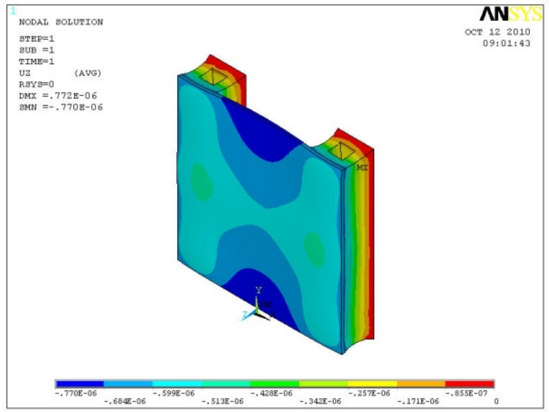
- Au on surface
- Good flatness of surface (< λ/50) is expected because a plane of diamond surface coincides with that of crystal.
- Good thermal conductivity reduces change of apparent current-dependent beam size by 85% compared with that of a present Be mirror.



Calculated mirror surface distortion due to SR power of 200W at the center of the mirror (Be and Diamond).



Temperature distribution of a diamond mirror due to 200W of SR power.

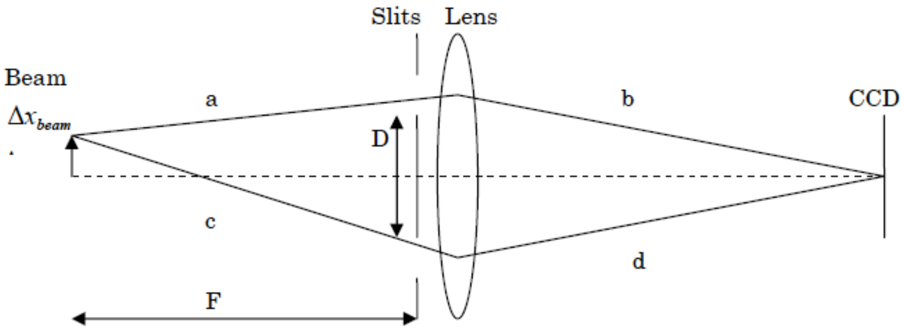


Surface distortion of a diamond mirror due to 200W of SR power.

ANSYS simulations

B. Interferometers

- Resolution fundamentally limited by measurement wavelength and opening angle between slits from beam (D/F).
- Max. slit separation determined by beam spread and mechanical considerations.



SR Source Bend Parameter	S-LER1 (BSWFRP)	S-HER (BSWOLE)	Units
ε_x	3.20E-09	4.30E-09	m
κ	0.27%	0.24%	
ε_y	8.64E-12	1.03E-11	m
β_y	29.98	32.49	m
σ_y	16.1	18.3	μm
Beam Energy	4	7	GeV
Bend effective length	0.89	2.90	m
Bend angle	5.04	5.00	mrad
Bend radius ρ	179.0	580.0	m
Observation wavelength λ	4.00E-07	4.00E-07	m
SR Opening angle $\theta_c(\lambda)$	1.0	0.7	mrad
Slits opening angle D/F	0.8	0.7	mrad
Max. Visibility (fringe depth) γ_{max}	99%	99%	
Min. measurable beam size $\sigma_{y\,min}$	11.8	12.5	μm

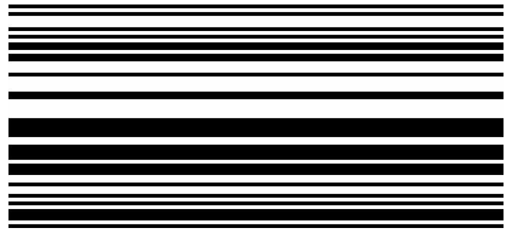
- Vertical beam size measurement is possible with interferometers, though is near the limit of the interferometer resolution.
- Measurement wavelength needs to be lowered to fit beam size into dynamic range. Also need to be able to measure 99% visibility (very difficult).
- Limitation on slit separation is due to ante-chamber height (14 mm). Extraction mirror will be in ante-chamber for reduced impedance.

⇨ Interferometers are used for measuring mainly horizontal beam size. Vertical beam size is measured by a newly developed X-ray monitor.

4.2 X-ray Beam Size Monitors

A. Coded Aperture Imaging

- Technique developed by x-ray astronomers using a mask to modulate incoming light. Resulting image must be deconvolved through mask response (including diffraction and spectral width) to reconstruct object.
- Open aperture of 50% gives high flux throughput for bunch-by-bunch measurements. Heat-sensitive and flux-limiting monochromator not needed.
- We need such a wide aperture, wide spectrum technique for shot-by-shot (single bunch, single turn) measurements.



Uniformly Redundant Array (URA) for X-ray imaging to be used at SuperKEKB. Pseudo-random pattern gives relatively flat spatial frequency response.

Source distribution:

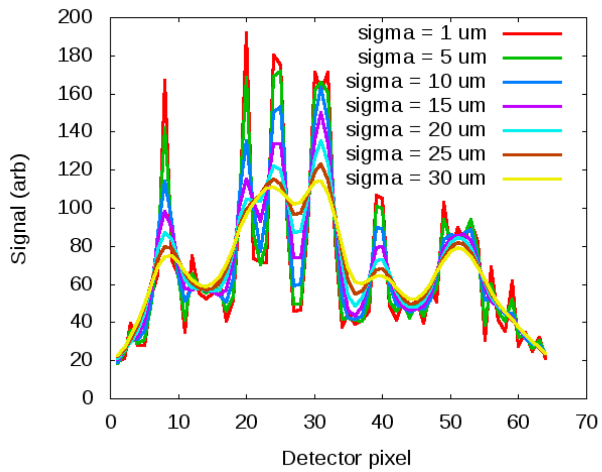
$$\begin{bmatrix} A_\sigma \\ A_\pi \end{bmatrix} = \frac{\sqrt{3}}{2\pi}\gamma\frac{\omega}{\omega_c}(1+X^2)(-i)\begin{bmatrix} K_{2/3}(\eta) \\ \frac{iX}{\sqrt{1+X^2}}K_{1/3}(\eta) \end{bmatrix}$$

$$X = \gamma\psi,\ \eta = \frac{1}{2}\frac{\omega}{\omega_c}(1+X^2)^{3/2}$$

+

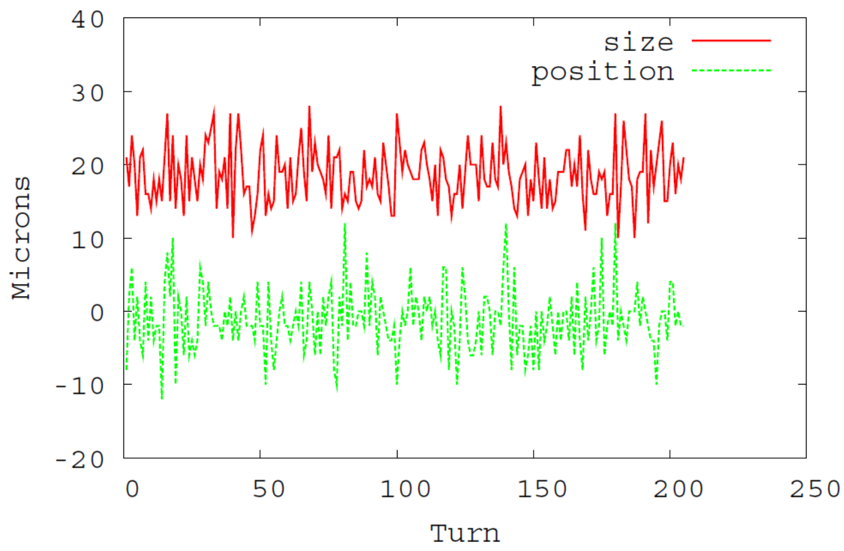
Kirchhoff integral over mask (+ detector response)

⇨ Detected pattern: $$A_{\sigma\pi}(y_d) = \frac{i\cdot A_{\sigma\pi}(source)}{\lambda}\int_{Mask}\frac{t(y_m)}{r_1 r_2}e^{i\frac{2\pi}{\lambda}(r_1+r_2)}\left(\frac{\cos\theta_1+\cos\theta_2}{2}\right)dy_m$$

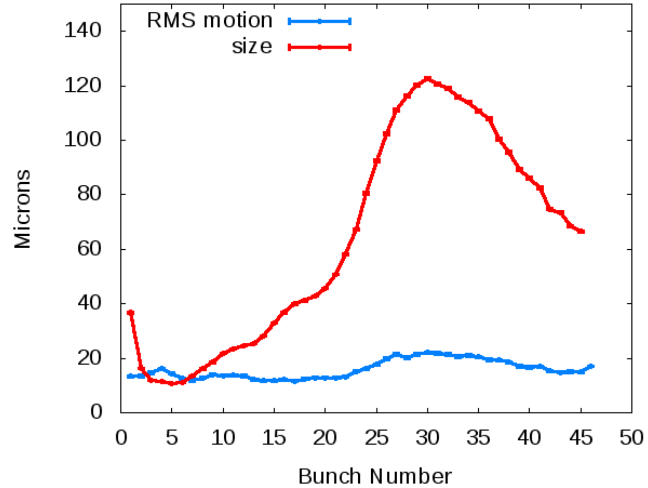


Simulated detector response for various beam sizes at SuperKEKB LER.

Coded Aperture tests at CesrTA



Example of turn-by-turn size and position data (one bunch out of train)

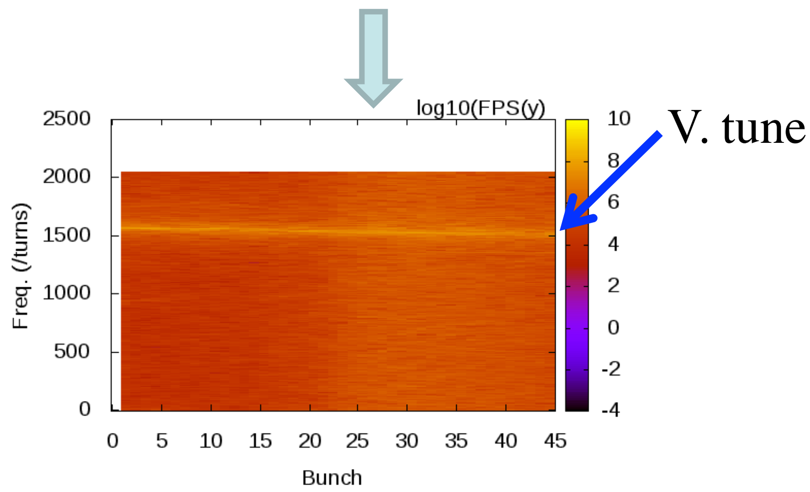


Example of bunch-by-bunch data (electron-cloud blow-up study data)

Single-shot data average for each bunch

Expect to be able to make similar measurements at SuperKEKB

Bunch-by-bunch position spectra



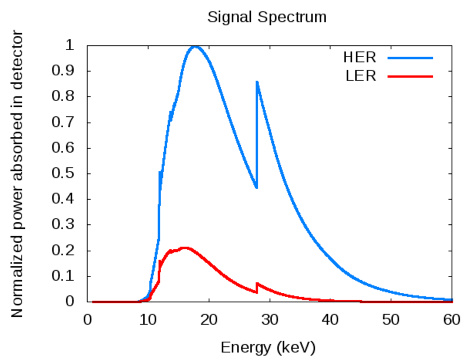
Expected single-shot resolution

Xray Source Bend Par.	S-LER (BS2FRP.1)	S-HER (BS2E.82)	Units
ε_x	3.20E-09	4.30E-09	m
κ	0.27%	0.24%	
ε_y	8.64E-12	1.03E-11	m
β_y	50.0	11.5	m
σ_y	20.8	10.9	μm
Beam Energy	4	7	GeV
Effective length	0.89	5.9	m
Bend angle	28.0	55.7	mrad
ρ	31.7	105.9	m
Critical Energy	4.4	7.1	keV

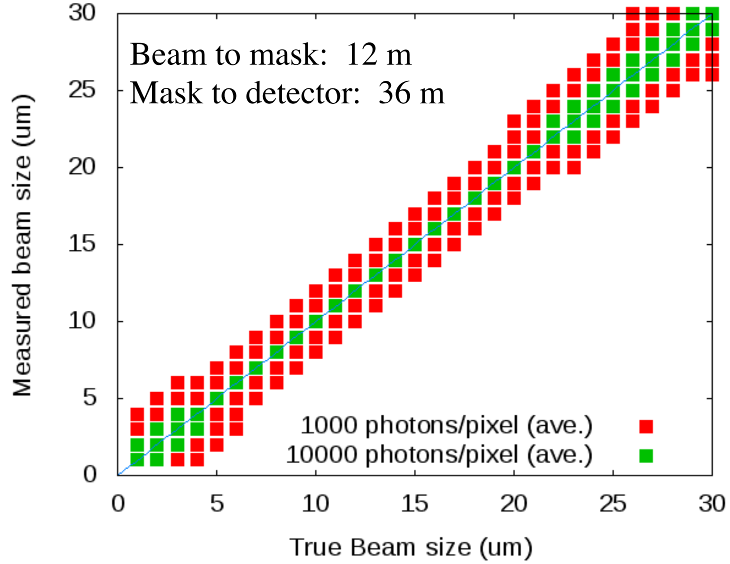
Red：assuming the same type of a detector as that used in CesrTA

Green：assuming an under-developed detector

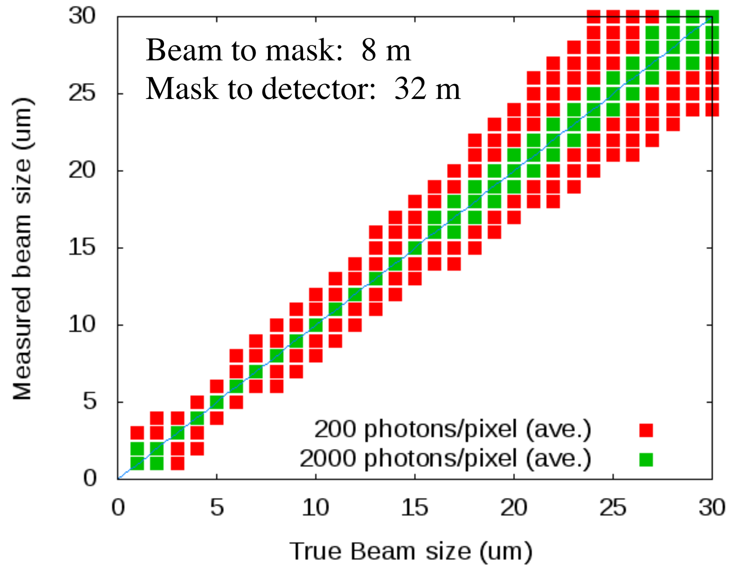
Resolution is calculated from statistical fluctuation of the number of detected photons in single-bunch and single turn.



Resolution of beam size (SuperKEKB full current)



HER: 10 μm pitch coded aperture



LER: 10 μm pitch coded aperture

URA Mask and window

- Tests at CesrTA show URA mask gives better resolution than Fresnel zone plate or pinhole (as expected).

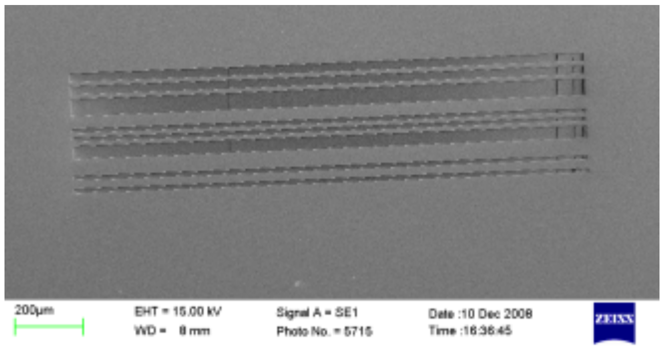
- High-power mask needs to be tested.

  Thick Si mask installed at CesrTA for high-power testing.

    CesrTA at 5.3 GeV can duplicate power load expected at SuperKEKB.

  Diamond substrate mask also under consideration.

- Also may need a diamond window to separate detector box vacuum and ring vacuum.

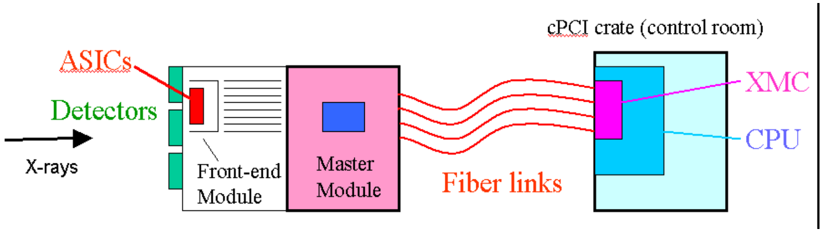


Microscope's view of URA mask

X-ray detectors and readout

- Fermionics InGaAs sensor array in use at CesrTA, also begun testing at ATF2.
- Have also done some tests at KEK PF.
- Determined that Fermionics detector efficiency too low at high x-ray energies (such as will be seen at SuperKEKB).

  ⇨ Need new detector. Studying new detector technologies:
  - Geiger-mode array of small photon-counting elements (various companies and labs).
  - 3D (deep but thin) silicon detector (SLAC/UH) (calorimeter style detector).
- Compact-PCI based DAQ being developed.



Signal flow diagram for x-ray monitor system

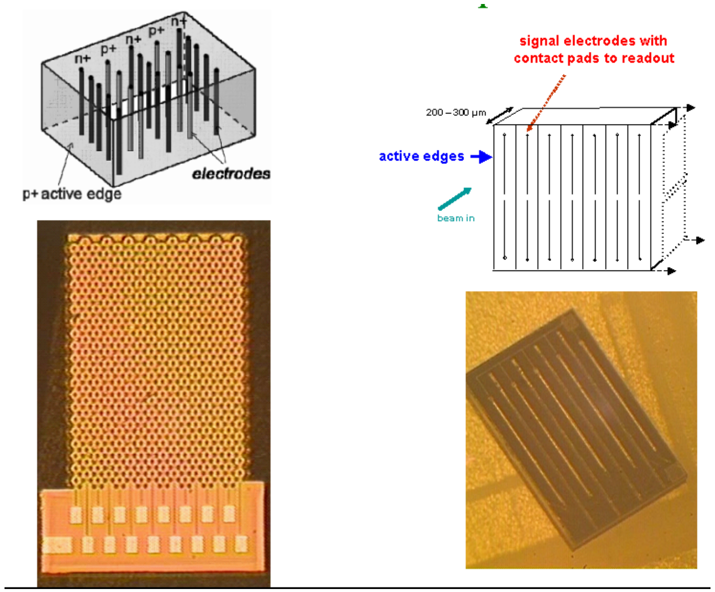
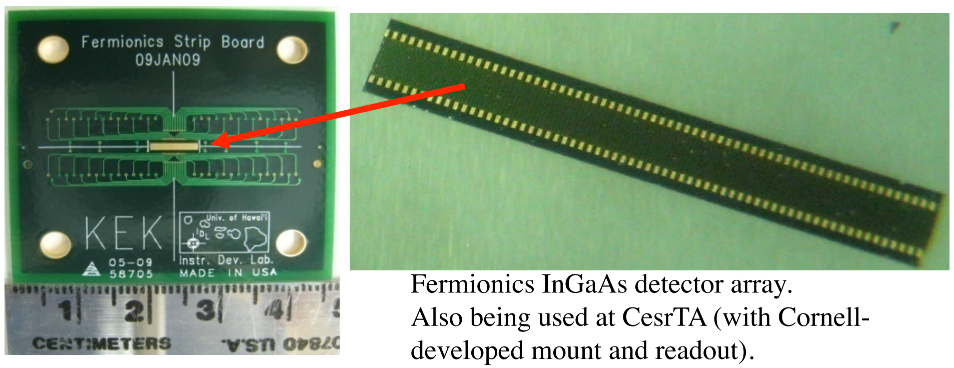


Illustration of two of the detector concepts to be explored in next phase of x-ray detector development. At left, a regular pattern of n and p electrodes, at right, a trench structure, which provides a more uniform drift volume.



Fermionics InGaAs detector array.
Also being used at CesrTA (with Cornell-developed mount and readout).

STURM2 Digitizer

"Flanagan" in Japanese →

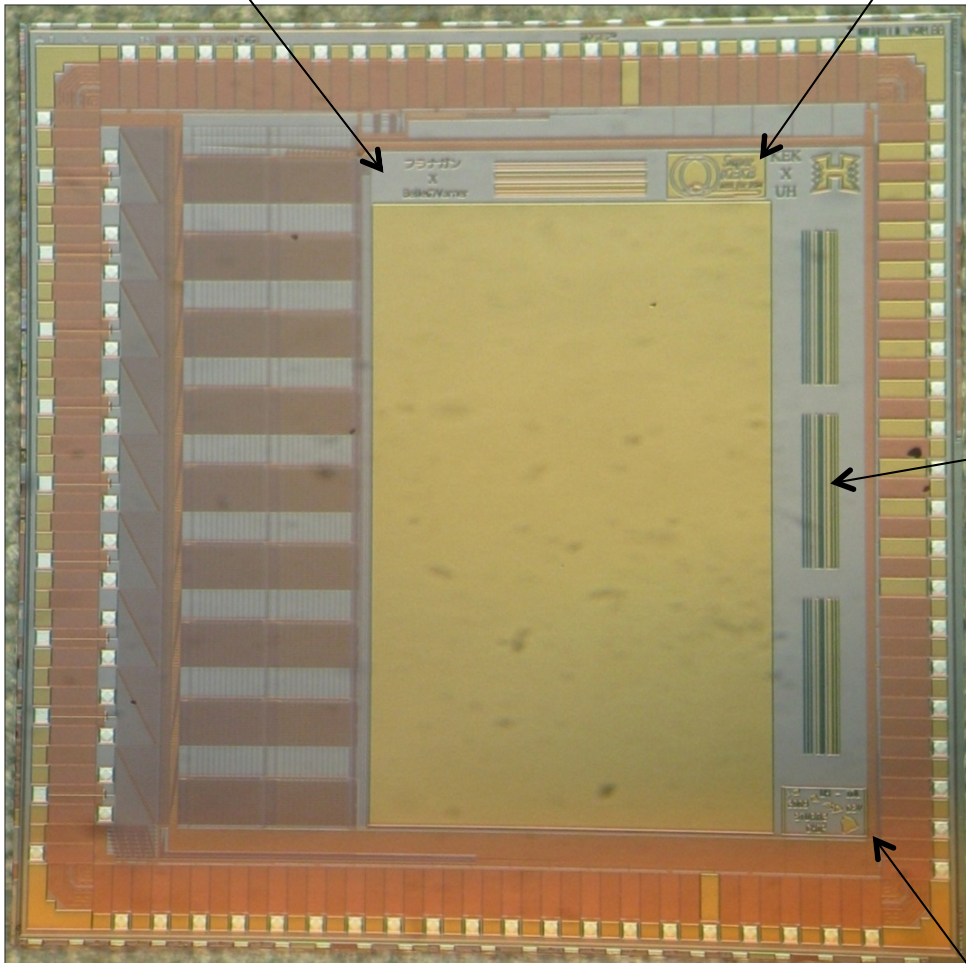
STURM ASIC for high-speed readout (G. Varner).

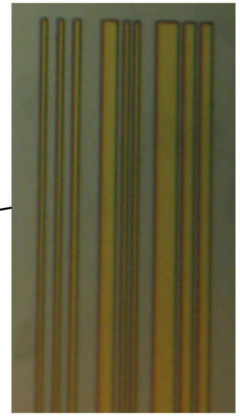
Ver. 1 tested at KEK PF, March 2009.

Ver. 2 fabricated.

Ver. 2 specs:

8	channels/STURM sampling
1	monitor channel
4	TSA sample buffers
8	samples/TSA buffer (32x channel)
288	Wilkinson conversion cells
1-200	GSa/s effective (5ps - 1ns Tstep)
1	word (RAM) sample readout
1+n*0.02	us to read n samples
100	kHz sustained readout (orbit)





Hawaii islands

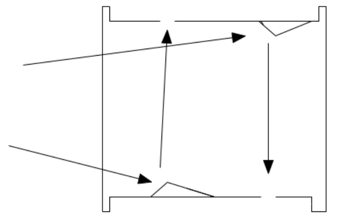
Testing at ATF2 for use at SuperKEKB

4.3 Beamstrahlung Monitor

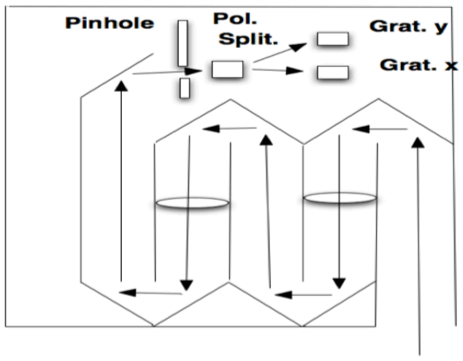
- Developed by G. Bonvicini (Belle, Wayne State U.) originally for use at CESR.
- Detection of the radiation of the particles of one beam due to the bending force of the EM field of the other beam.
- Beamstrahlung polarization at specific azimuthal points provides unique information about the beam-beam geometry.

A. Design of the SuperKEKB detector

- Better signal to noise ratio due to strong beams at SuperKEKB.
- View port location at ±90 degrees minimizes backgrounds, polarization measurement errors, and provides redundancy against beam orbit errors.
- To be located anywhere between 5 and 10 mrad from the beam direction at the IP.
- Suggested mirror and window sizes: 2.83 X 2mm^2 and 2.1 X 2.1 mm^2.
- Light is transported to optics boxes by means of simple black-anodized pipes and mirrors.
- Device consists of achromatic telescope with pinhole optics, polarization splitter, and two gratings illuminating 4 PMT with filters.



mirror and view port



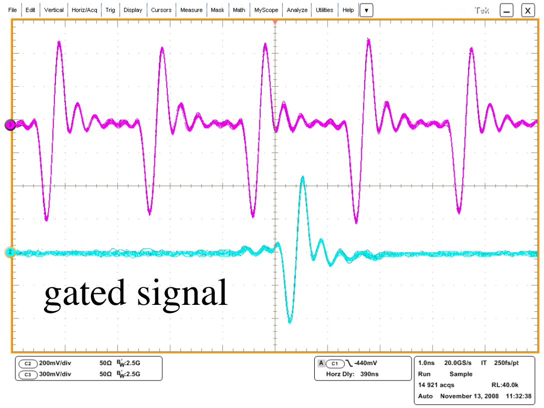
transport line of light

G. Bonvicini

5. Gated Measurement for Bunch-Tune, -Orbit and -Phase

5.1 Development of a fast gate module

- A fast gate module has developed for a fast gate to measure the tune, orbit and longitudinal phase of each bunch separated by 2ns.

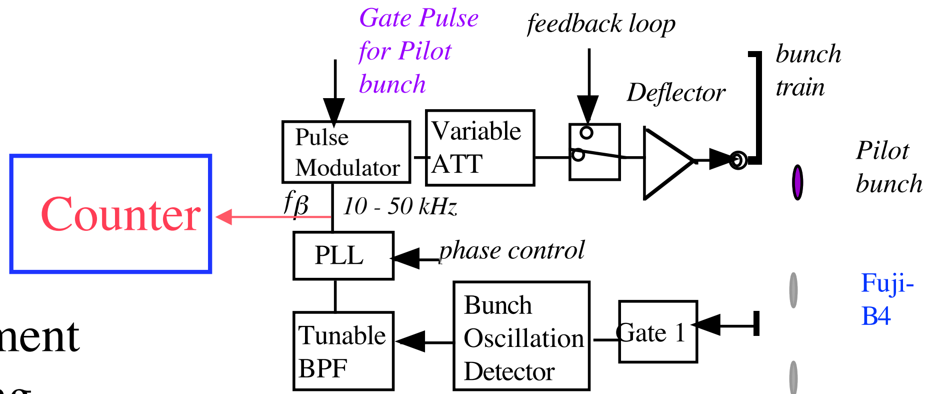


1 ns/div

5.2 Fast and high resolution measurement of gated tune

- An exciter of betatron oscillation was successfully tested at KEKB.
- The system is used in SuperKEKB to kick the pilot bunch for the optics measurement and the tune measurement.

- Measuring locked signal of a PLL loop which tracks the tune enables precise measurement of betatron frequency by reciprocal method.
- Frequency resolution is 10^{-6} for measurement time of 2ms if error source is only counting error.

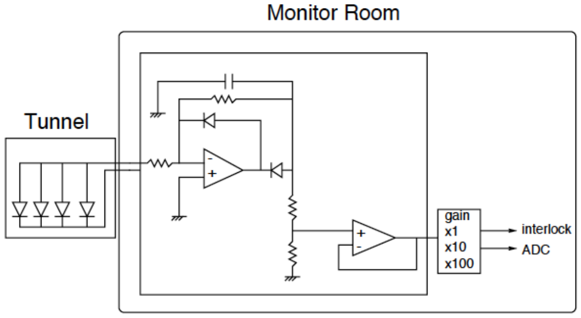


PLL exciter

6. Loss Monitor and DCCT

6.1 Loss monitor

- •Sensors are ion chambers and pin diodes.
- •Electronics of KEKB are reused as much as possible.
- •The system parameters such as quantity, location, density and so on, is decided after evaluation of beam loss by the commissioning group by this summer.



PIN diode

6.2 DCCT

- •Electronics of LER-DCCT will be modified to fit the increased beam current of 3.6A.
- •HER-DCCT can be reused without modification.

DCCT

7. Damping Ring

Damping ring diagnostics

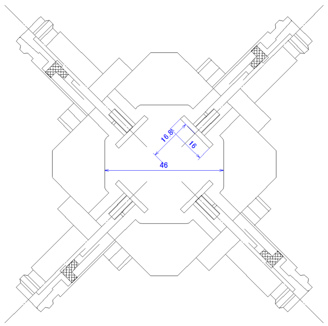
System	Quantity	Comments
BPM	84	Log Ratio detector
Synchrotron light monitor	1	Streak camera, gated camera
Transverse bunch by bunch feedback	1	Tune measurement is incorporated.
DCCT	1	Reuse of DCCT at KEKB
Beam loss monitor	36 in the ring, 17 in BT	Ion chamber and/or PIN
Bunch current monitor	1	

7.1 BPM system

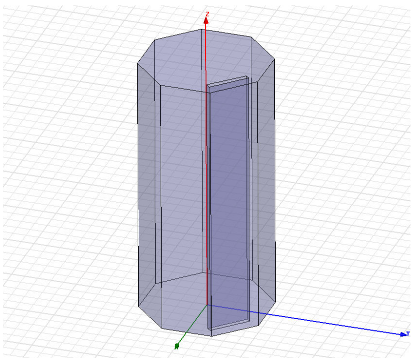
- Recent calculation of CSR is affecting to the design of a vacuum chamber.
- Re-design of a BPM button and a feedthrough might be necessary.
- A prototype of a log ratio detector has been developed as described. It will be used in the damping ring with minor changes of a circuit to fit the gain to the input level.

7.2 Transverse feedback system

- Detector : 2GHz detection, same as that of the main ring.
- Digital filter : iGp with firmware matched with the damping ring.
- Power amp : Use spares of KEKB, 250W x 4.



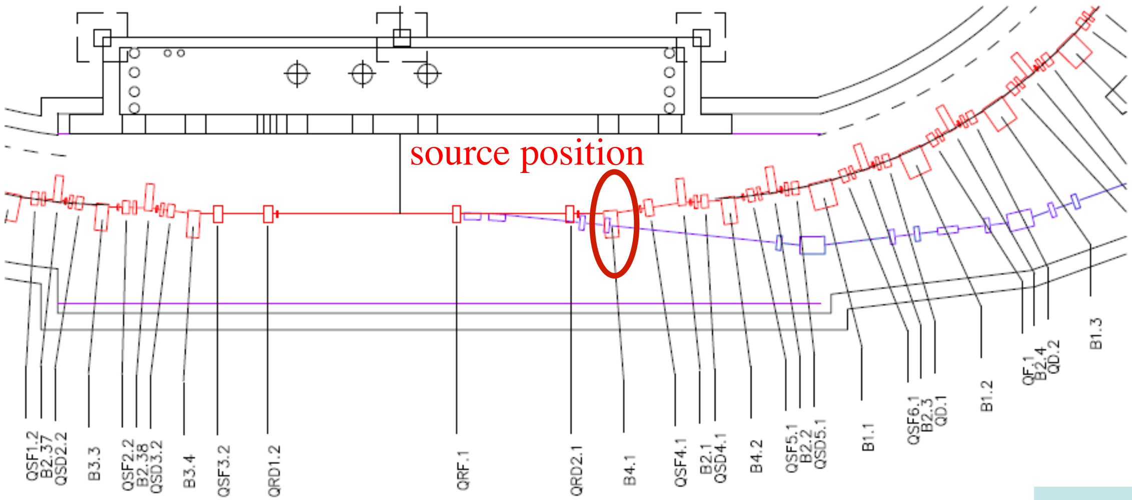
Kicker



Chamber-center to electrode：16.8mm
Characteristic impedance : 50 Ohm
Electrode : 2mm thick, SUS+Cu plating

7.3 Synchrotron radiation monitor (SRM)

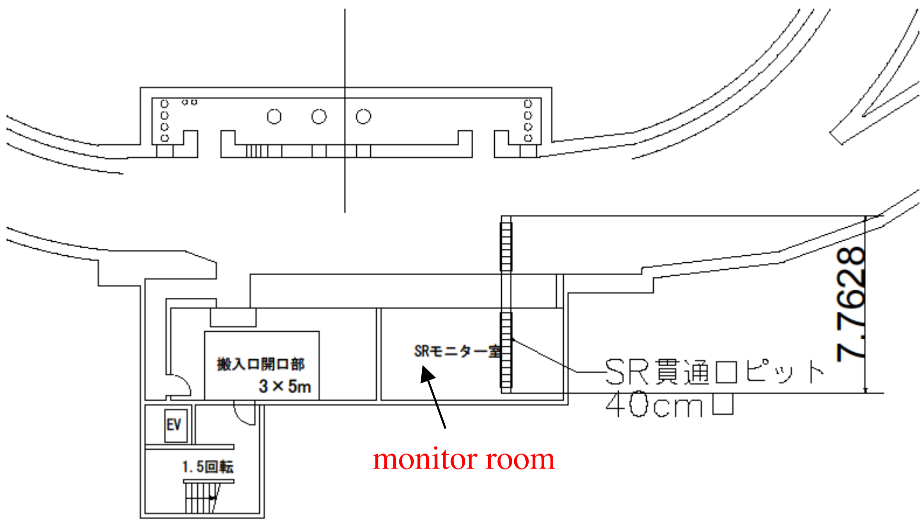
Layout



Instruments

Streak camera : longitudinal profile

Gated camera : transverse profile



Total length of light path : 10m

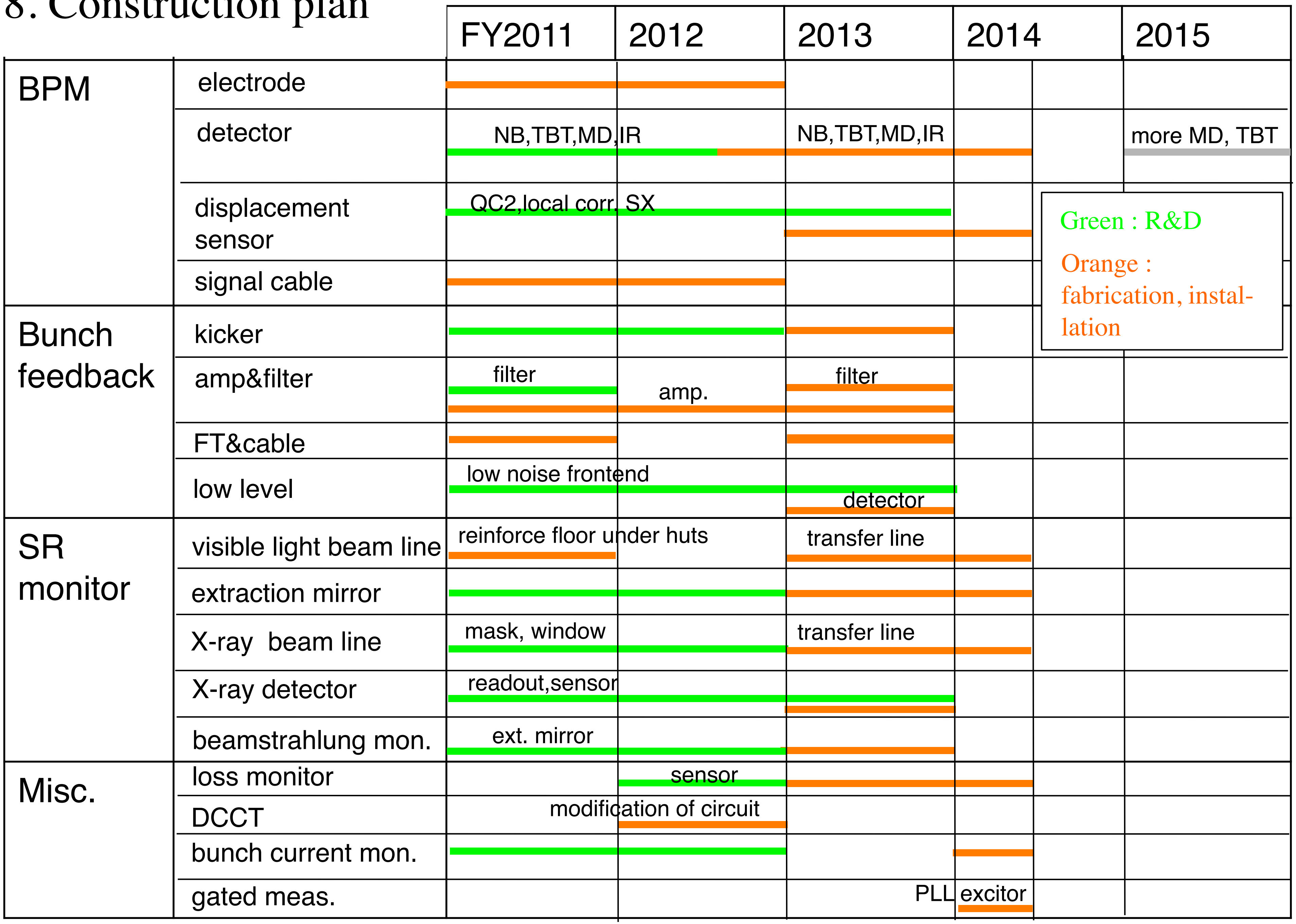
Related parameters to SRM

				unit
	Injection	Extraction	Final	
Beam size σ_x	2060	385	381	µm
Beam size σ_y	3950	121	75	µm
Point Spread Function	25	25	25	µm
Smeared σ_x	2063	385	382	µm
Smeared σ_y	3948	121	77	µm

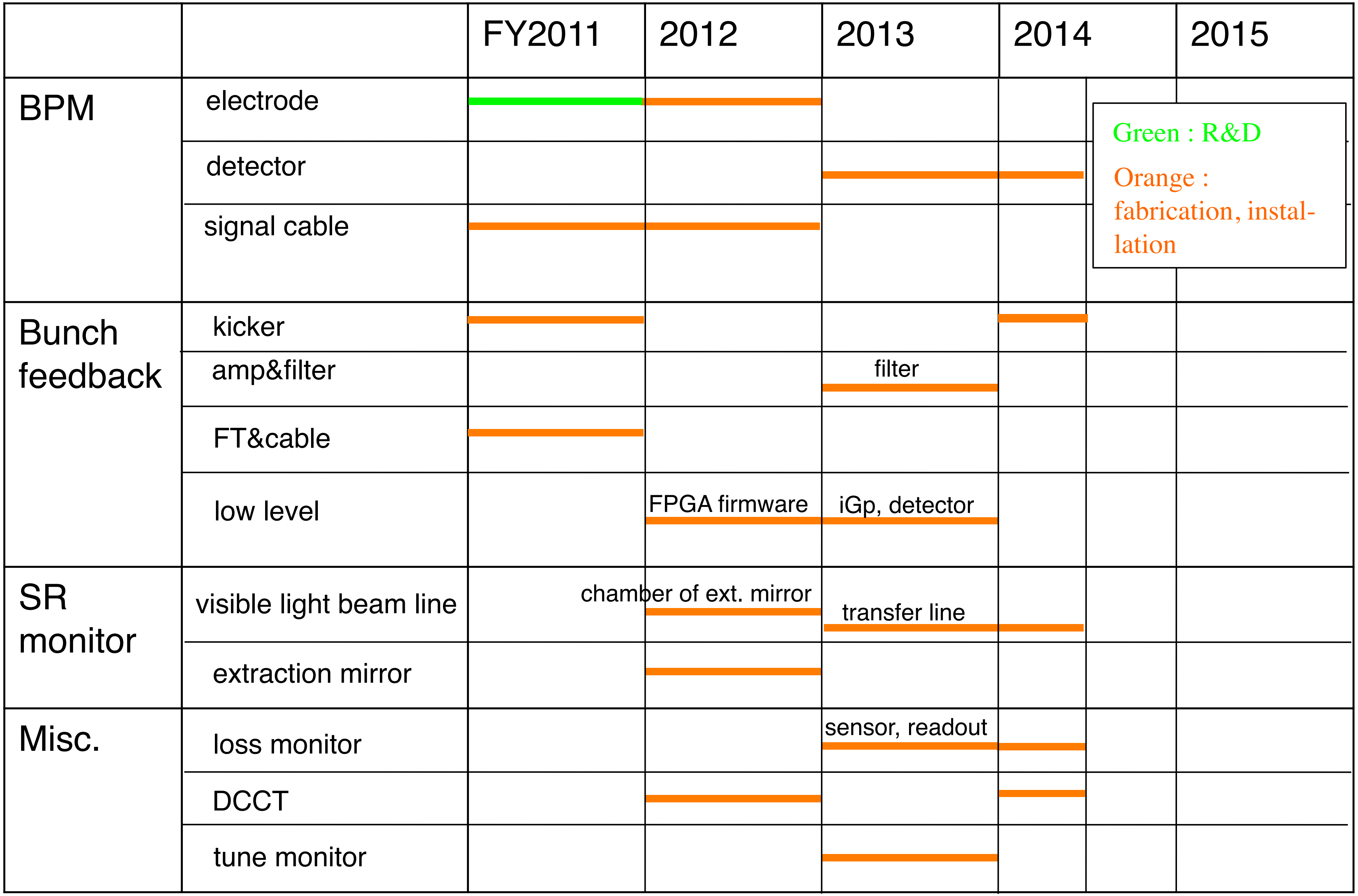
Resolution of the measurement is OK.

8. Construction plan

Main Ring



Damping Ring



9. Summary

9.1 Beam position monitor

A. Button electrode

- φ6 electrode has been developed and tested with beam. Mass production for LER will start next fiscal year.

B. Narrowband detector for slow orbit measurement

- A prototype shows resolution is OK. Now trying to reduce the change of offset. Linearity may need to be improved.

C. BPM for collision feedback

- A button electrode is under development.
- A prototype of a detector has been made. Performance of analogue section is as expected. Overall performance will be tested by this March.

D. Turn by turn detector

- A prototype log-ratio circuit including a fast switch will be tested in this year.

E. Mediumband detector for fast orbit feedback

- System requirements such as quantity, installed location, function, resolution etc. should be fixed. A system design for fast orbit feedback including correction algorism, magnet-control and network configuration should be started soon.

F. Displacement sensor

- The sensors in cryostats and at sextupoles for local chromaticity correction might need R & D.

9.2 Bunch by bunch feedback system

A. Transverse feedback system

- Two stripline kickers for each ring will be used.
- Kickers with minor improvements of a KEKB kicker will be used in early stage of operation.

B. Longitudinal feedback system

- Two DAFNE type kickers will be used in LER.
- New power cables and connectors have been tested.
- An absorptive filter will be evaluated in this year.

C. Common components for transverse and longitudinal system

- The iGp digital filter is ready for use.
- Low noise frontend is being developed.
- High power feedthroughs are successfully tested.

9.3 Synchrotron light monitor

A. Visible light monitor

- Reuse present source bend locations.
- σ_z measurement by the streak camera is OK, σ_x by the interferometer is OK.
  σ_y measurement by the interferometer will be difficult to get required resolution.
- Floors under huts will be reinforced to reduce vibrations.

B. X-ray monitor

- Source bends upstream of source bends for the visible light monitors.
- σ_y measurement by the coded aperture mask (CAM) is OK.
  Single-shot (single-bunch, single turn) resolution is expected to be sufficient.
- σ_x measurement by CAM is possible, if single-shot measurements are needed.
- The system will start with vertical measurement.
- Being developed in collaboration with Cornell U. and U. Hawaii.
  Testing at different components at CesrTA and ATF2.

C. Beamstrahlung monitor

- The system requires extraction windows and extraction mirrors.
- Location of the mirrors and the windows are not decided yet.
- R&D of an extraction mirror made of diamond will be tried in this or next year.
- Components are being tested by a group of Prof. G. Bonvicini.