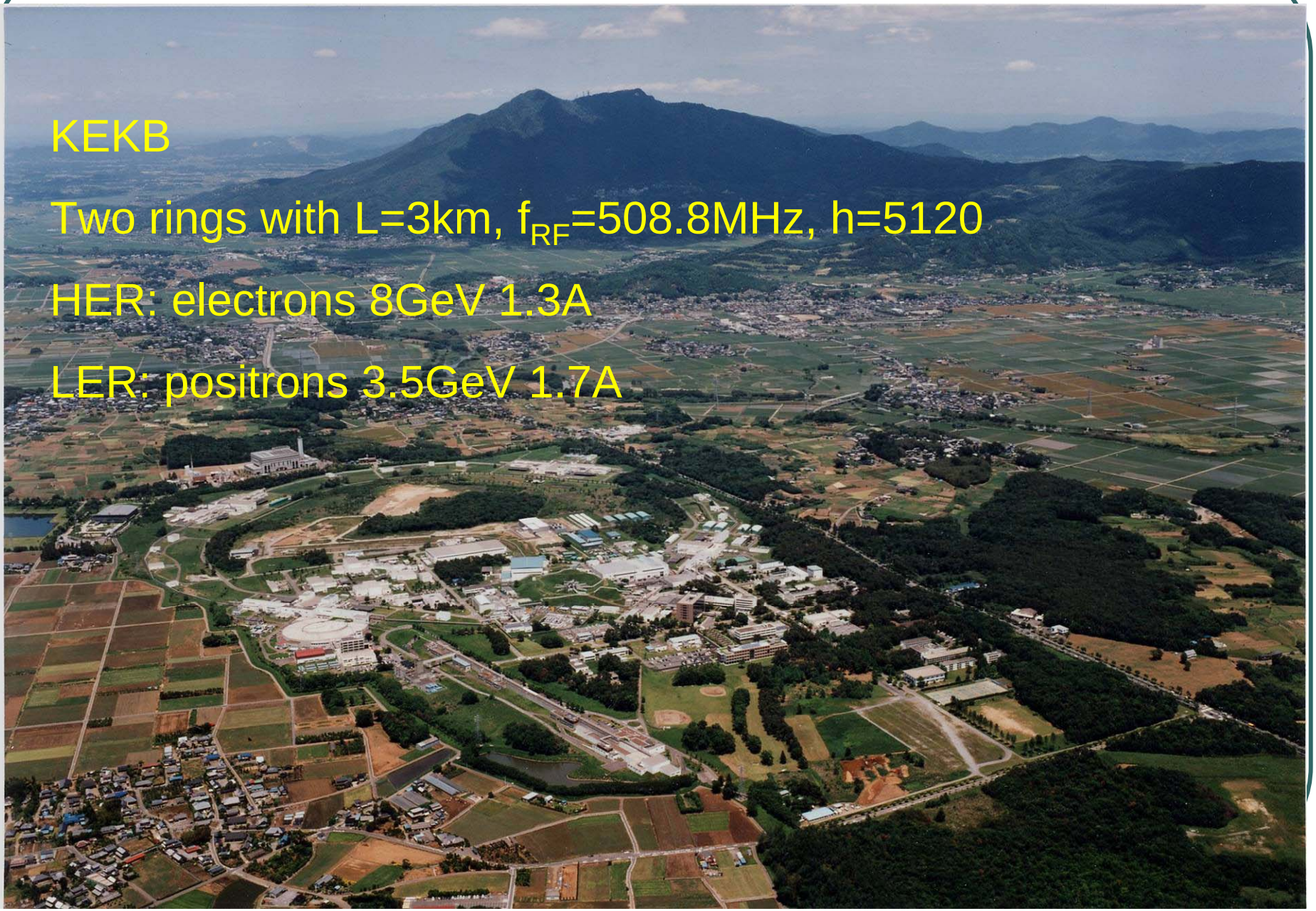
Bunch by bunch feedback systems for KEKB

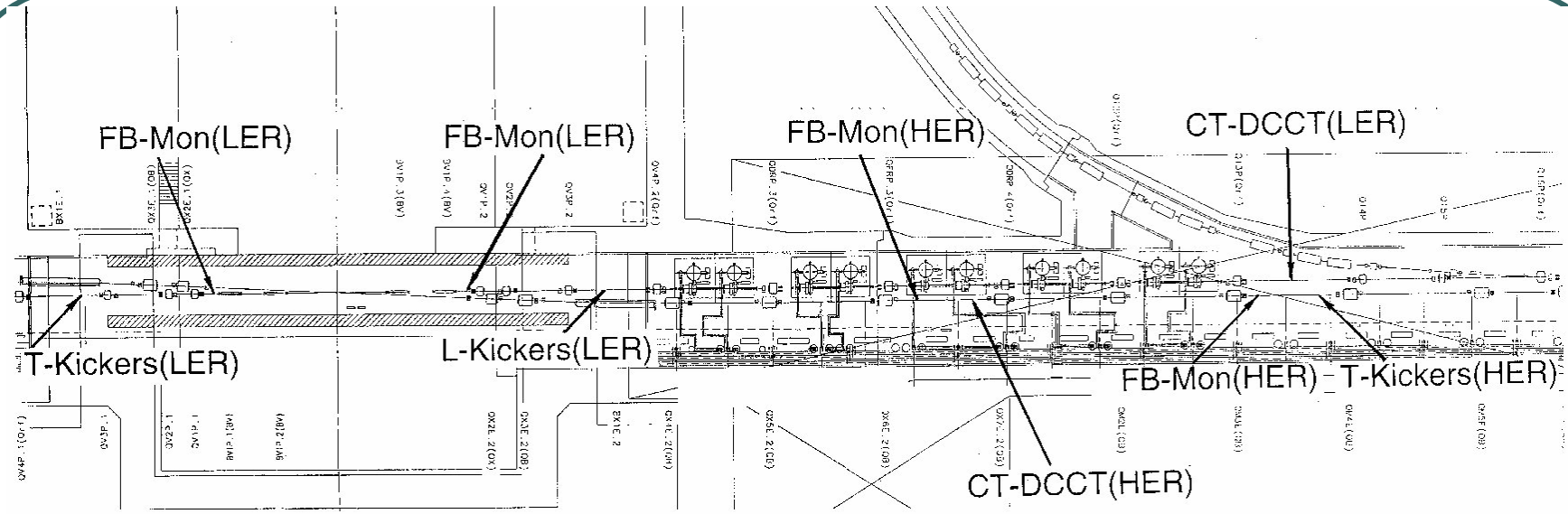
Makoto Tobiyama

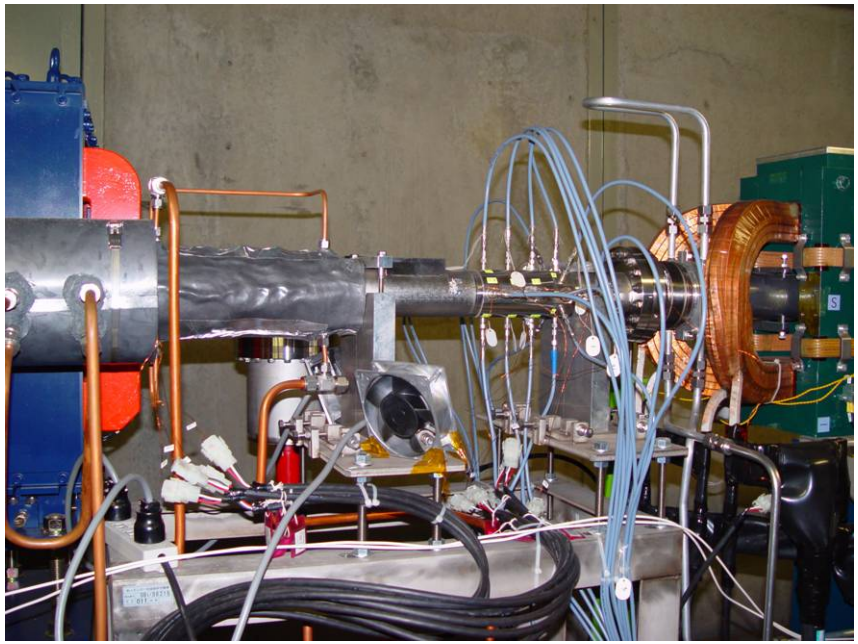
KEK Accelerator Laboratory

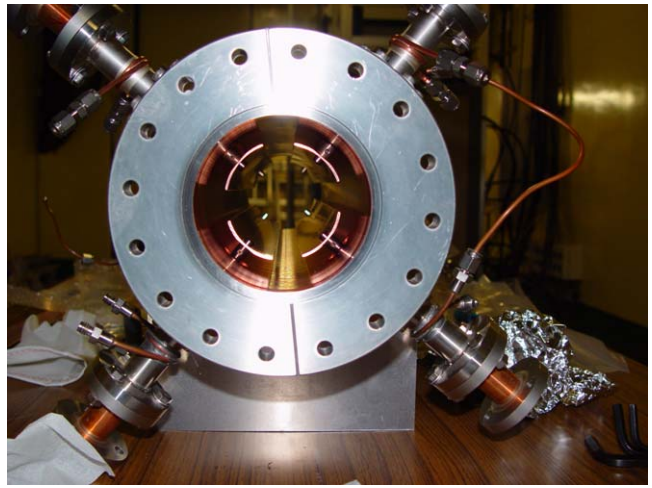

KEKB
Two rings with L=3km, f_{RF}=508.8MHz, h=5120
HER: electrons 8GeV 1.3A
LER: positrons 3.5GeV 1.7A

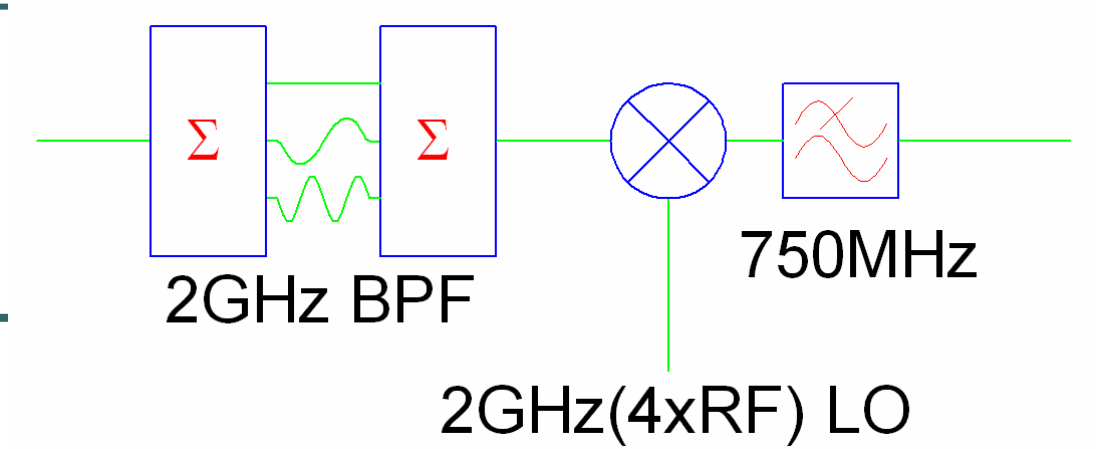
Requirements for bunch by bunch feedback systems

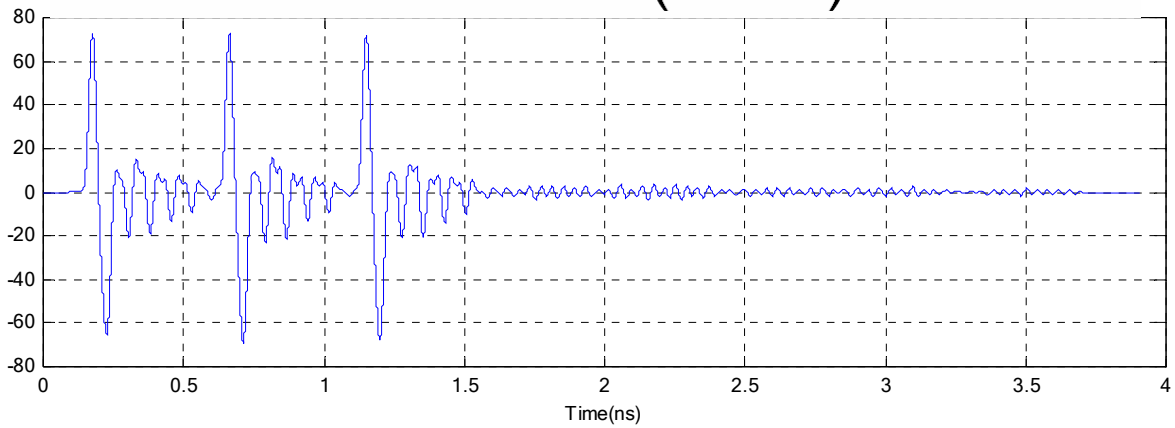
- Feedback system should handle:
  - both horizontal and vertical directions
    - Longitudinal– LER(optional)
  - minimum bunch spacing of 2 ns
  - various modes coming from unknown sources:
    - Resistive wall (HER, LER)
    - Photo electron instability (LER)
    - Fast ion instability (HER)
- Feedback damping time required
  - 1 ms (100 turns) for transverse directions
    - Transverse radiation damping time: 41 ms

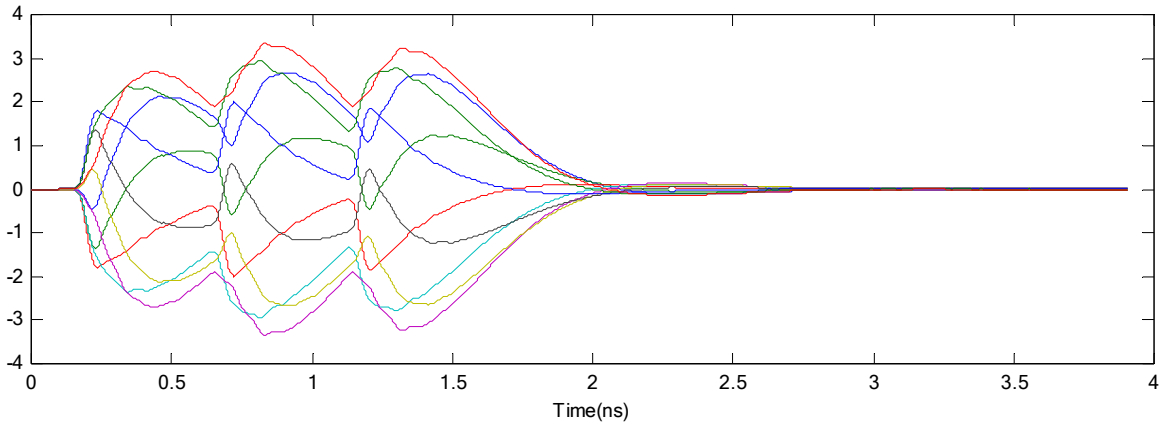

FB-Mon(LER)
FB-Mon(LER)
FB-Mon(HER)
CT-DCCT(LER)
T-Kickers(LER)
L-Kickers(LER)
FB-Mon(HER)
T-Kickers(HER)
CT-DCCT(HER)

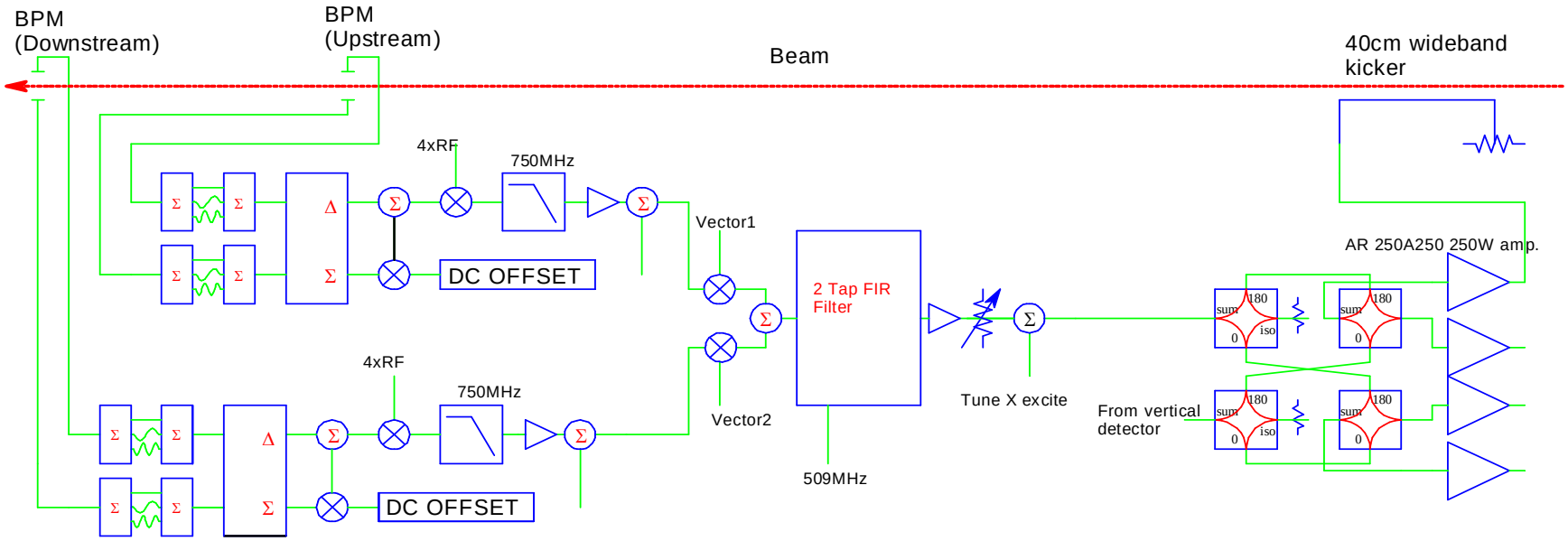




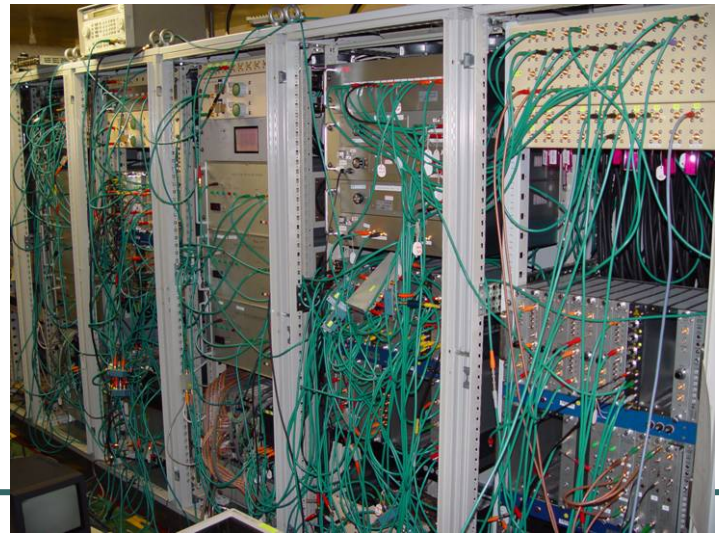

Σ
Σ
2GHz BPF
750MHz
2GHz(4xRF) LO

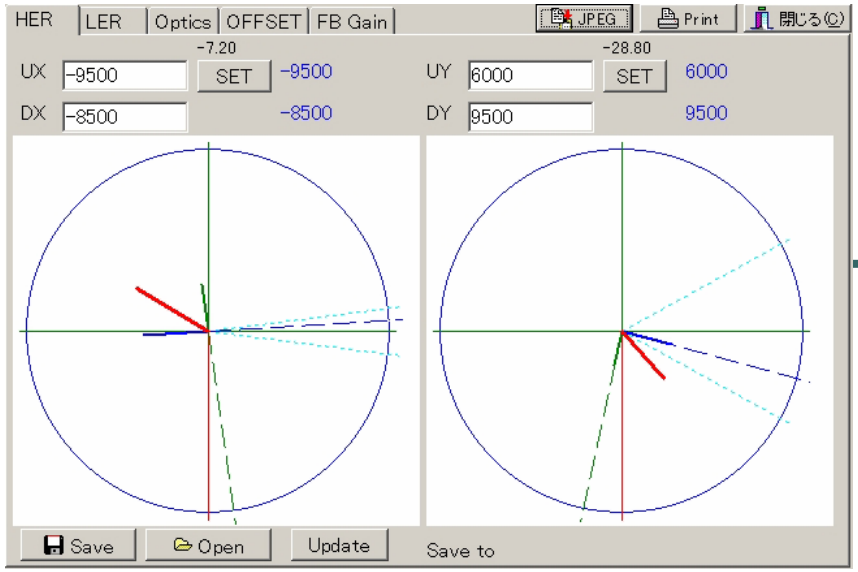

80
60
40
20
0
-20
-40
-60
-80
0
0.5
1
1.5
2
2.5
3
3.5
4
Time(ns)

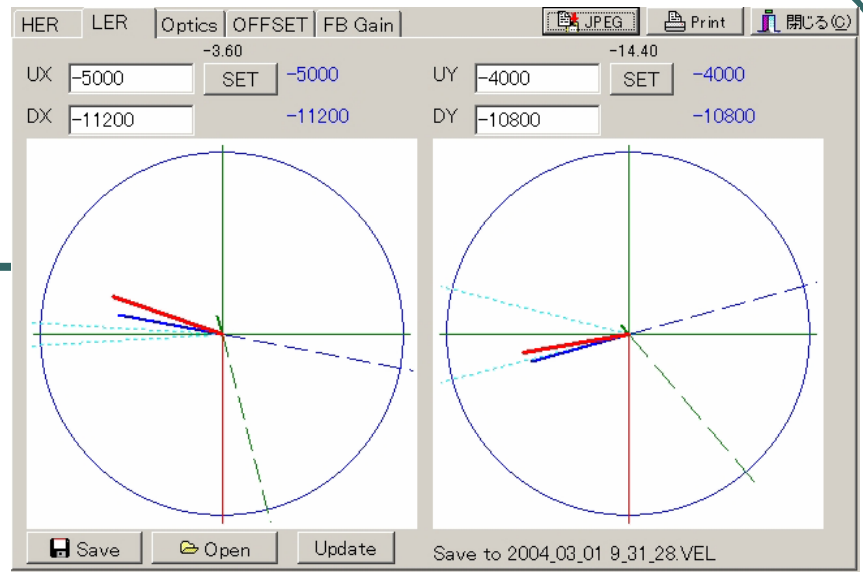

4
3
2
1
0
-1
-2
-3
-4
0
0.5
1
1.5
2
2.5
3
3.5
4
Time(ns)

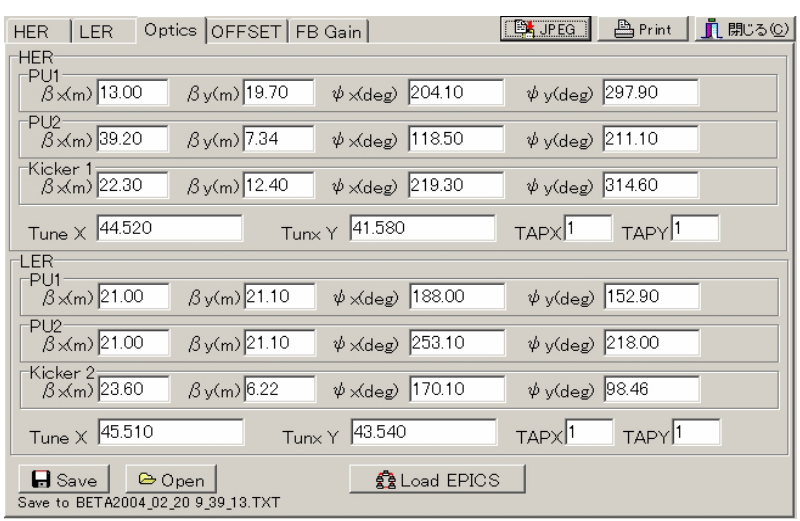


KEKB Transverse Bunch Feedback System




HER
LER
Optics
OFFSET
FB Gain
JPEG
Print
閉じる(C)
-7.20
UX
-9500
SET
-9500
DX
-8500
-8500
-28.80
UY
6000
SET
6000
DY
9500
9500
Save
Open
Update
Save to

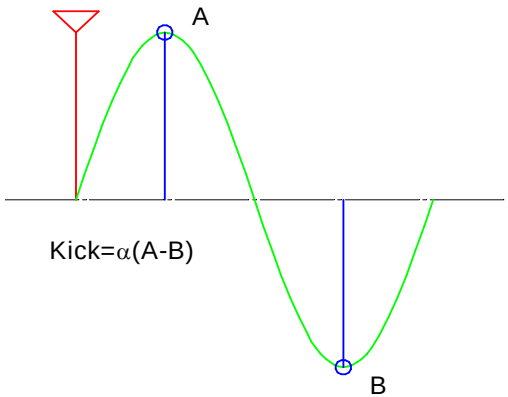

HER
LER
Optics
OFFSET
FB Gain
JPEG
Print
閉じる(C)
-3.60
UX
-5000
SET
-5000
DX
-11200
-11200
-14.40
UY
-4000
SET
-4000
DY
-10800
-10800
Save
Open
Update
Save to 2004_03_01 9_31_28.VEL

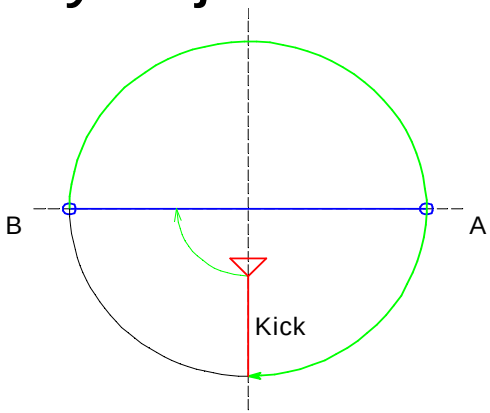

HER
LER
Optics
OFFSET
FB Gain
JPEG
Print
閉じる(C)
HER
PU1
βx(m) 13.00
βy(m) 19.70
ψx(deg) 204.10
ψy(deg) 297.90
PU2
βx(m) 39.20
βy(m) 7.34
ψx(deg) 118.50
ψy(deg) 211.10
Kicker 1
βx(m) 22.30
βy(m) 12.40
ψx(deg) 219.30
ψy(deg) 314.60
Tune X 44.520
Tunx Y 41.580
TAPX 1
TAPY 1
LER
PU1
βx(m) 21.00
βy(m) 21.10
ψx(deg) 188.00
ψy(deg) 152.90
PU2
βx(m) 21.00
βy(m) 21.10
ψx(deg) 253.10
ψy(deg) 218.00
Kicker 2
βx(m) 23.60
βy(m) 6.22
ψx(deg) 170.10
ψy(deg) 98.46
Tune X 45.510
Tunx Y 43.540
TAPX 1
TAPY 1
Save
Open
Load EPICS
Save to BETA2004_02_20 9_39_13.TXT

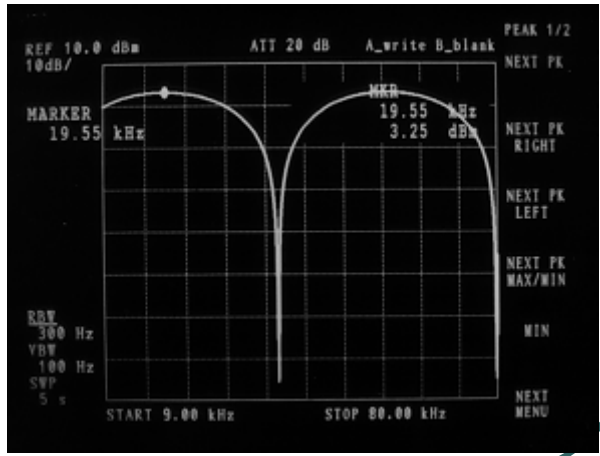

File
Control
Setup
Measure
Analyze
Utilities
Help
17:36
4.00 GSa/s
1.00 V/div
1.00 V/div
500 mV/div
1.00 V/div
More (1 of 2)
Clear All
5.00 ns/div
443.850 ns
-633 mV

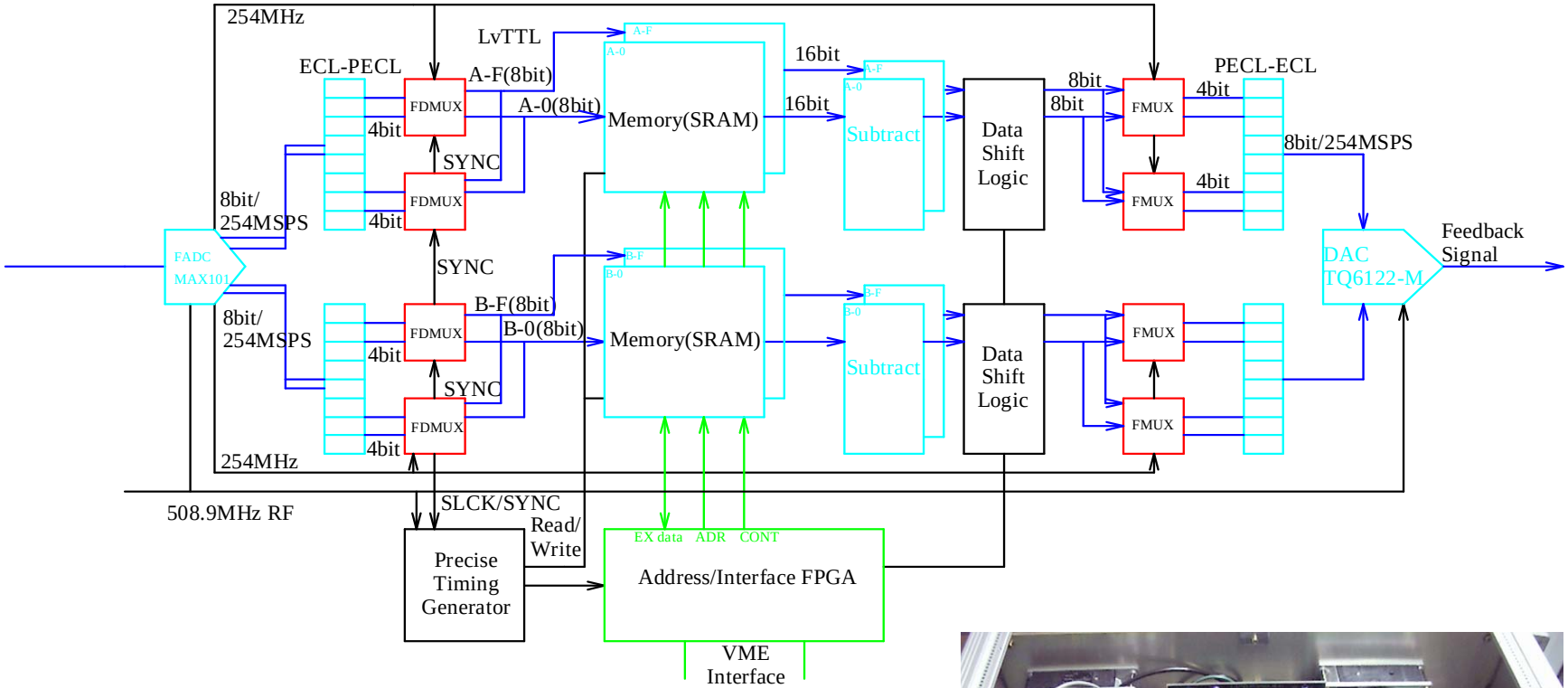
Signal processing

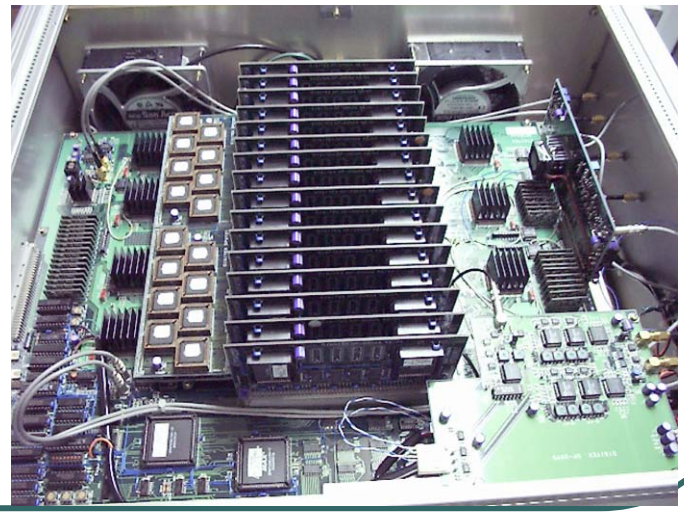
- Hardware 2-tap FIR filter :simplest digital filter
  - DC rejection
  - 90-degree phase shift (for longitudinal plane)
  - One-turn delay adjustment





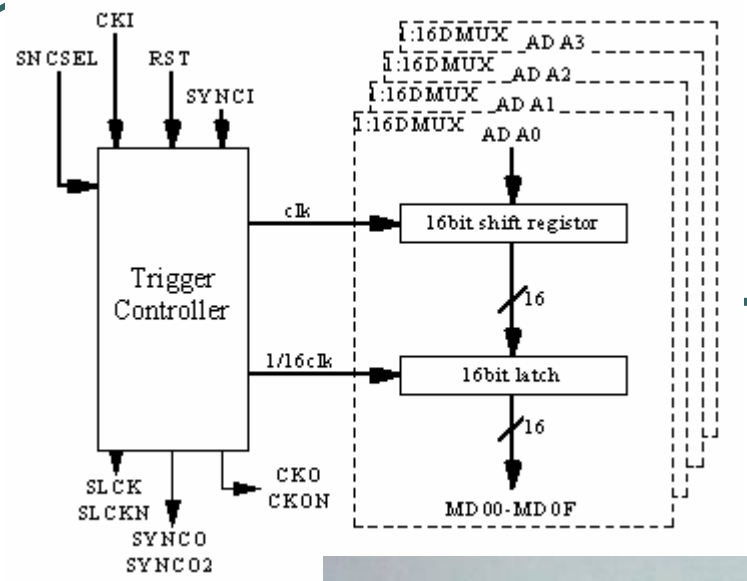


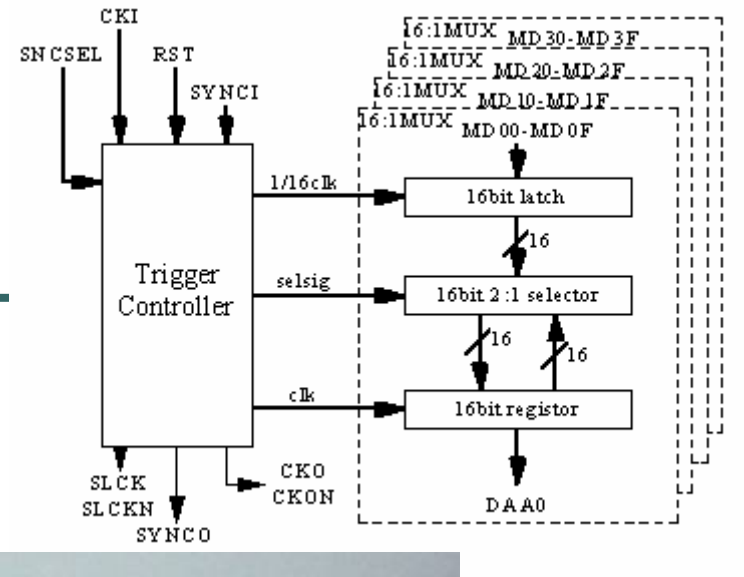

254MHz
LvTTL
ECL-PECL
A-F(8bit)
A-0(8bit)
FDMUX
4bit
SYNC
Memory(SRAM)
16bit
Subtract
Data
Shift
Logic
8bit
FMUX
PECL-ECL
8bit/254MSPS
8bit/
254MSPS
FADC
MAX101
DAC
TQ6122-M
Feedback
Signal
B-F(8bit)
B-0(8bit)
508.9MHz RF
SLCK/SYNC
Read/
Write
EX data
ADR
CONT
Precise
Timing
Generator
Address/Interface FPGA
VME
Interface

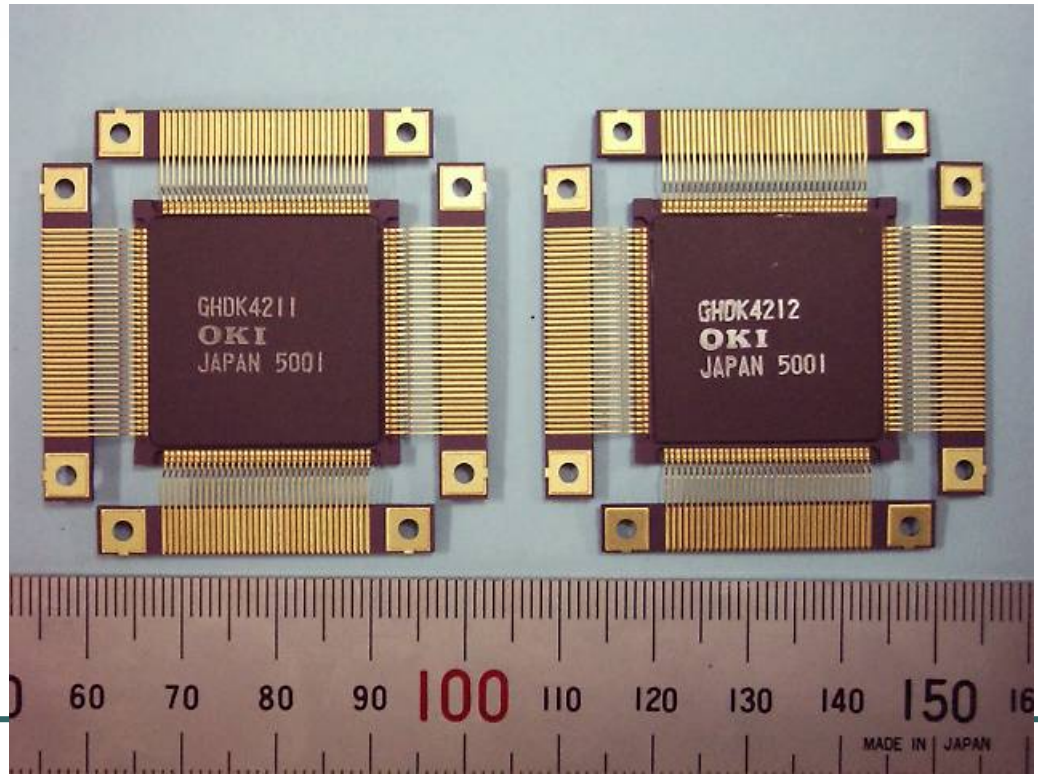


Digital filter system

- A/D(MAX101, 8bit) works with ring RF clock=509MHz.
- Demultiplex the output of A/D down to manageable frequency: 509MHz/32=15MHz.
- Write the data to two ring memories (M1 and M2) simultaneously, read two different data (from M1 and M2), and subtract (M1-M2) within 1/15 MHz (67 ns): two actions /cycle.
  - Address counter: one for data-write address and two full-adder (subtracter) to get two data-read addresses
- Multiplex the calculated result up to 509MHz/2 (D/A:TQ6122-M has internal-multiplexer).


CKI
SNCSEL
RST
SYNCI
1:16DMUX
ADA3
1:16DMUX
ADA2
1:16DMUX
ADA1
1:16DMUX
ADA0
Trigger Controller
clk
16bit shift registor
16
1/16clk
16bit latch
16
SLCK
SLCKN
SYNCO
SYNCO2
CKO
CKON
MD00-MD0F


CKI
SNCSEL
RST
SYNCI
16:1MUX
MD30-MD3F
16:1MUX
MD20-MD2F
16:1MUX
MD10-MD1F
16:1MUX
MD00-MD0F
Trigger Controller
1/16clk
16bit latch
16
selsig
16bit 2:1 selector
16
16
clk
16bit registor
SLCK
SLCKN
SYNCO
CKO
CKON
DAA0

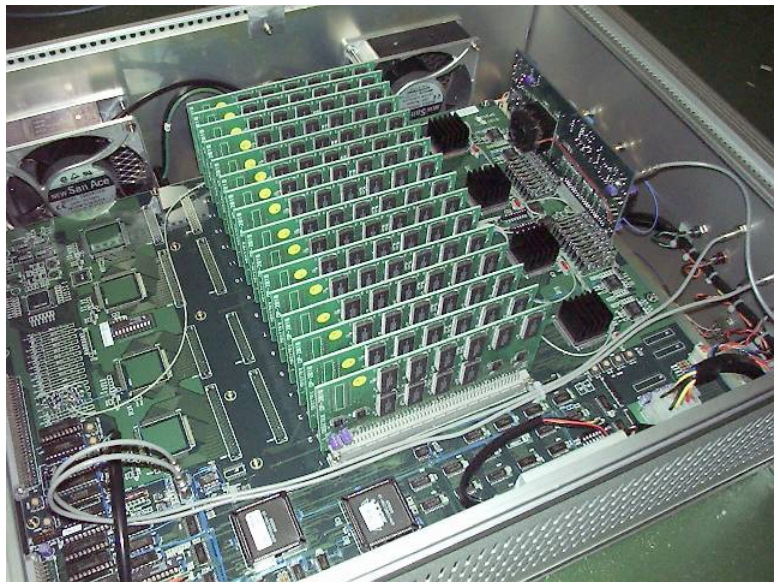

GHDK4211
OKI
JAPAN 5001
GHDK4212
OKI
JAPAN 5001
60
70
80
90
100
110
120
130
140
150
MADE IN JAPAN

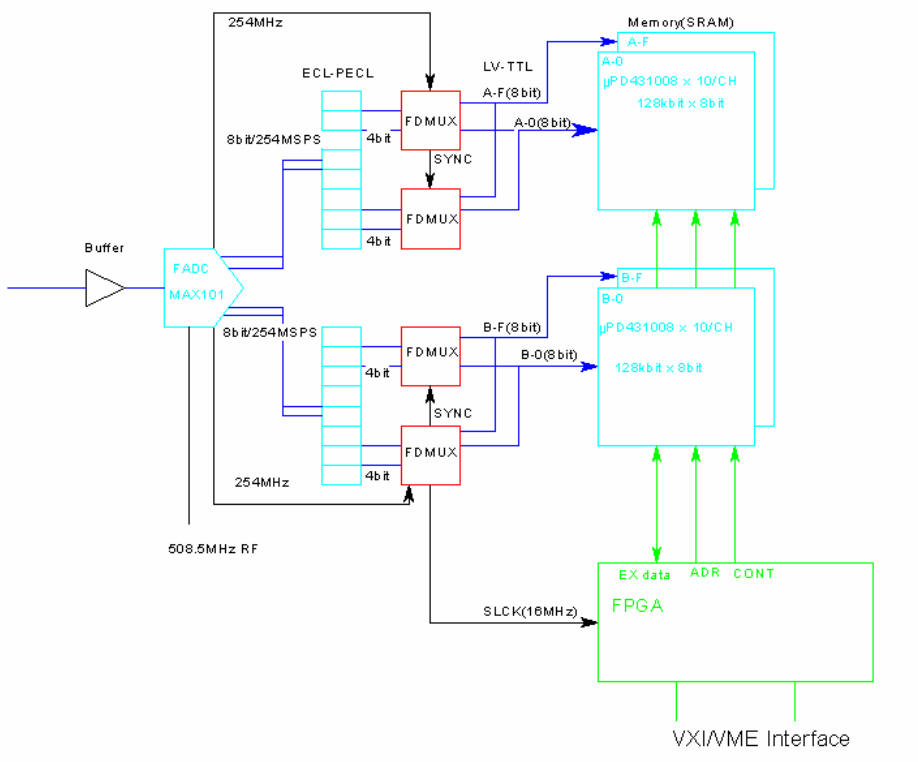
Custom LSIs

- 0.5μ gated GaAs DC FET logic, 136 pins QFP
- Synchronizing circuit between chips
- FDMUX
  - Demultiplex 4-bit signal (PECL) into 16ch x 4bit (LvTTL) signal
  - 600 MHz (max),1.5k gates
- FMUX
  - Multiplex 16ch x 4bit (LvTTL) signal to 4-bit PECL signal
  - 600 MHz (max),1.7k gates

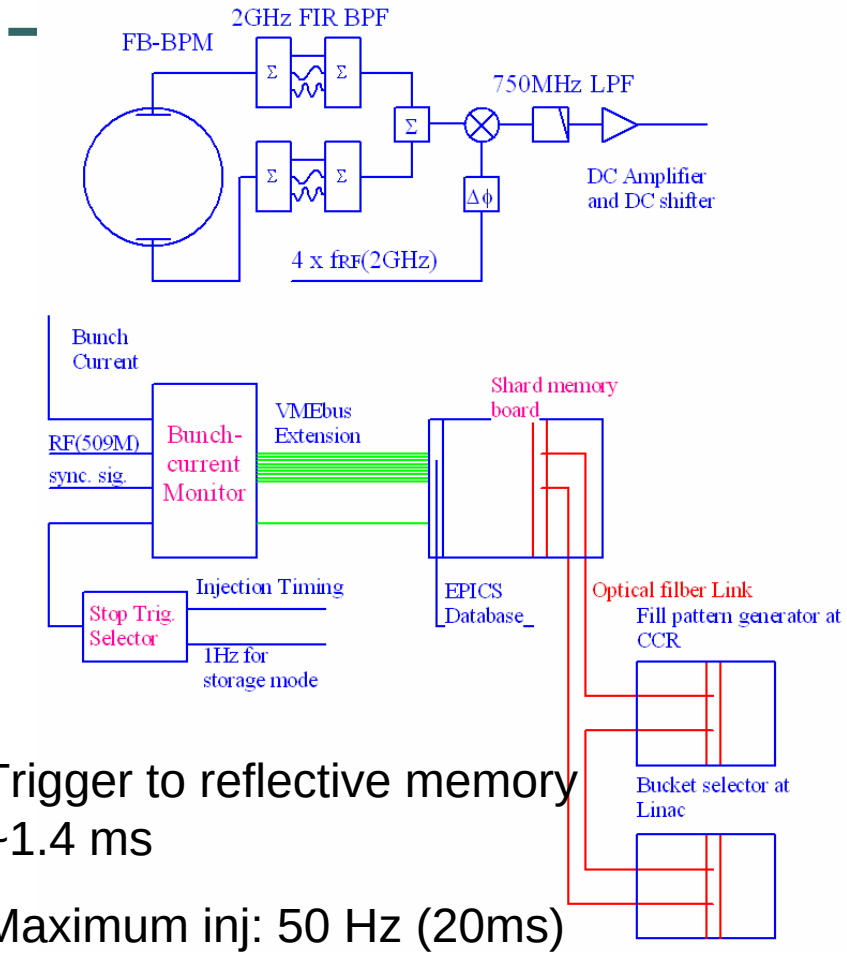
Application to related systems

- Memory board (20MB)



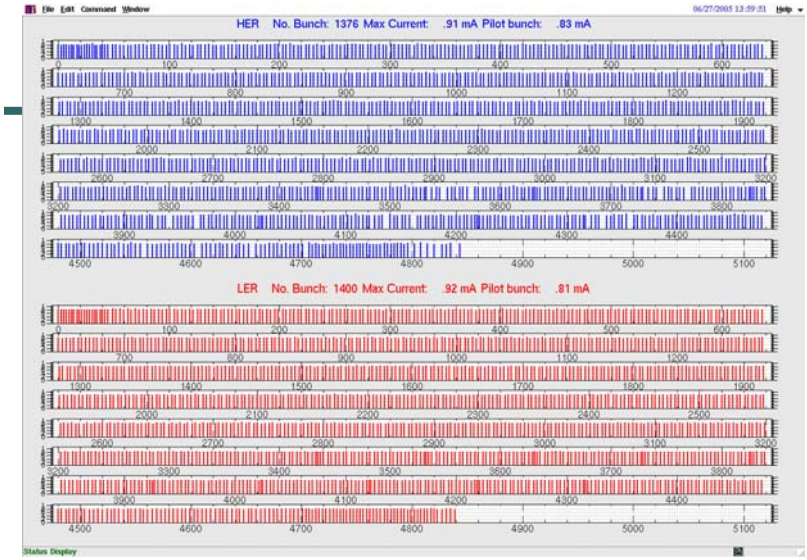


Bunch current monitor



Trigger to reflective memory ~1.4 ms

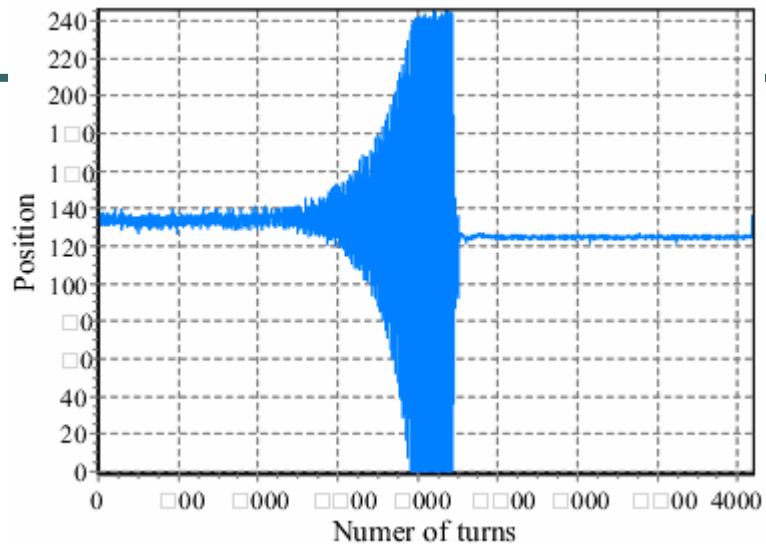
Maximum inj: 50 Hz (20ms)

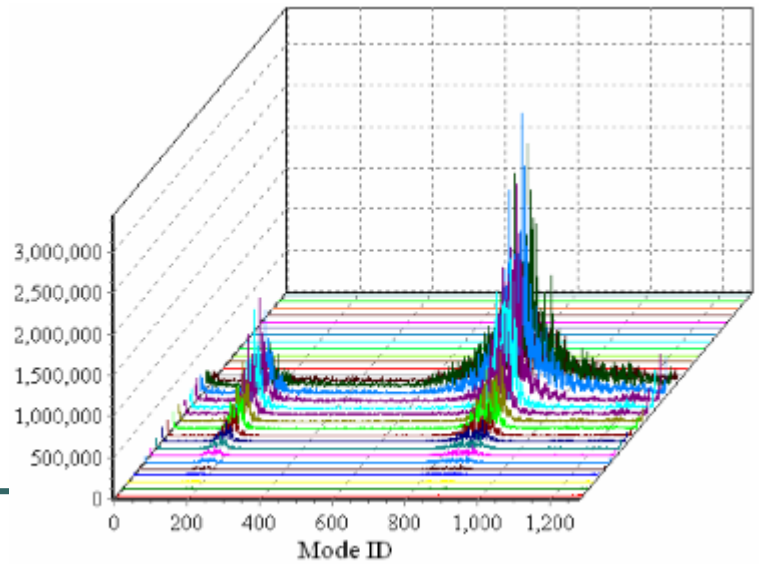


- Injection trigger stops the data-taking of the BCM
- BCM sends interrupt to VME-bus
- Data transfer from BCM to VME CPU
- Convert the data to bunch current, write the information to reflective memory and EPICS record
- Reflective memory sends interrupt to bucket selection code

Bunch oscillation recorder

- Post-mortem analysis of beam abort
  - Beam-loss trigger from DCCT
  - Automatic data transfer
- Transient-domain analysis of instabilities
  - Dominant mode of the instability
  - Clear (linear) behavior with small amplitude of oscillation
- Precise oscillation measurement with long-time data accumulation
  - Measurement of sideband of PEI during collision





Performance of the system

- Transverse feedback damping time at high current:~0.2 ms (20 turns)
  - Without feedback systems, we observe strong transverse instabilities starting from 20~40 mA
  - With feedback system on (both horizontal and vertical planes), we can inject single beam up to maximum current.
- Very flat filling pattern for good luminosity
- Understanding the new instabilities
  - Photo-Electron Instability, Fast Ion Instability

Lessons learned during the operation of transverse feedback systems

Problem: A/D easily saturates with the change of residual offset of the detection system

- Continuous Closed Orbit Correction
- Feedback of reference RF phase
- Gain optimization before/after the digital filter
- Need to monitor the “real” offset observed by the digital filter

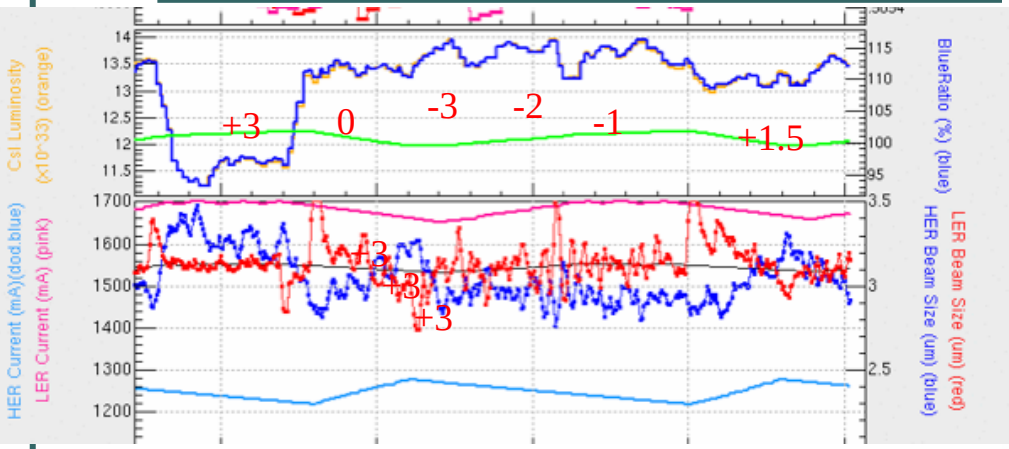
Problem: Difficulty to find the best analog vector sum of the detection system

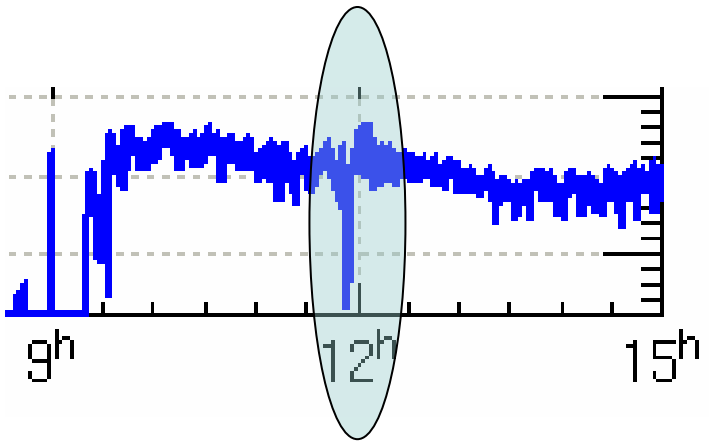
- Fine tuning with minimum feedback gain
- The best position is affected by the dynamic beta effect
- Desirable to use only one pickup and tune the phase in the digital filter

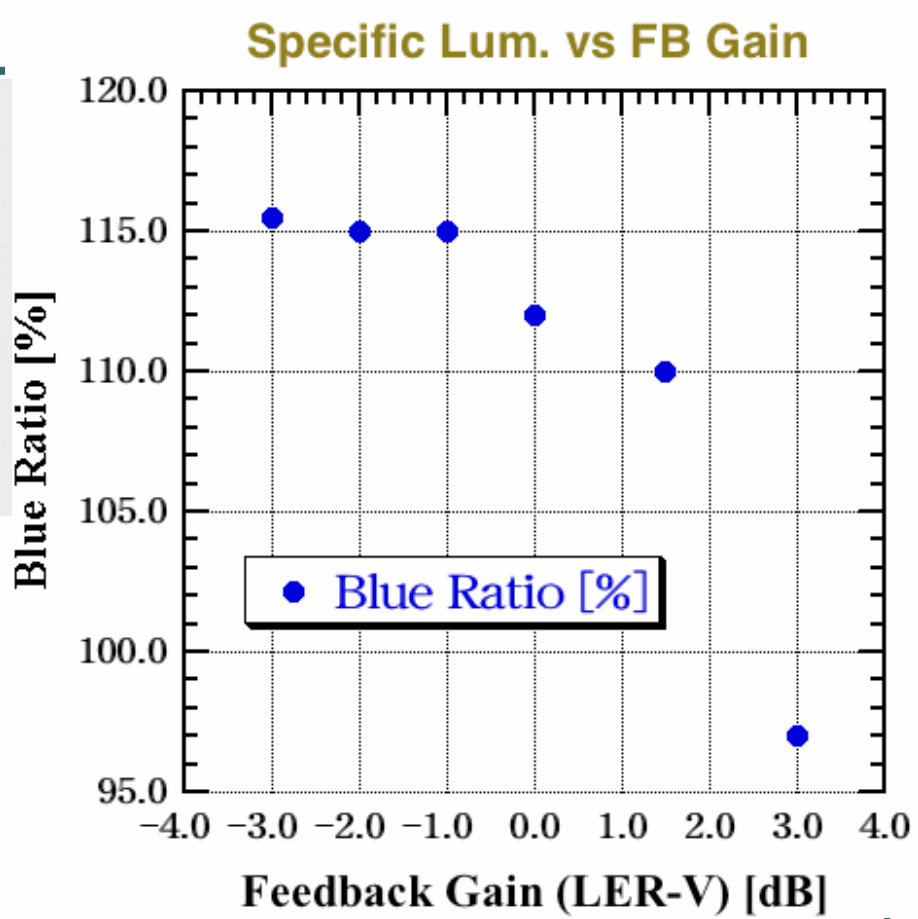
Problem: Not easy to find problems in the filter

- Need self checking system

Specific Luminosity vs FB Gain







FB gain of the LER vertical affects the specific luminosity.
The other gains (LER H, HER H/V) have no effect.

Luminosity depends on LER-V feedback gain

- Speculated sources
  - Feedback gain is too high??
    - Maximum stable damping rate of the system from simple simulation shows less than 10 turns
  - Reactive component of the feedback kick affects the luminosity??
    - No obvious tune-shift due to feedback gain is observed
  - Residual noise blows up the vertical size??
    - Beam-beam simulation shows only a few percent of blowup of the vertical beam size reduces the luminosity greatly.
- Might be showing the limitations of two-tap FIR filter system

Summary

- Bunch by bunch feedback systems for KEKB are working very well and contributing to improving in ring operation and physics runs.
- Effect of the feedback systems on luminosity might be coming from the limitations of hardware two-tap FIR filter system.
  - Need new generation digital filter system:
    - Multi-tap, non-downsamping digital filter
  - Gboard is under development with the collaboration of KEK, SLAC and INFN