Beam instrumentation for SuperKEKB Accelerators

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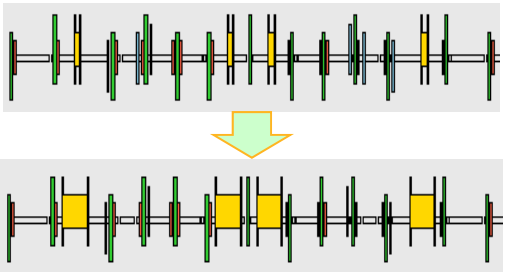
KEK Accelerator Laboratory

Replace LER dipoles with longer ones (0.82m->4.2m) to reduce emittance



Optimize beam optics for low emittance beam

Positron beam 3.6 A

Belle II

New IR

Electron beam 2.6 A

Super-KEKB

New beam pipe & bellows

Construct positron damping ring

Damping ring

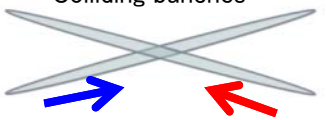
Positron source

Adaptic optics for higher positron yield

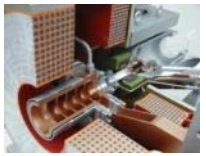
Low emittance gun for high-quality electron beam (HER)

Extend RF system for high beam current operation

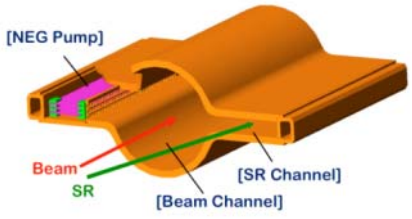
Colliding bunches

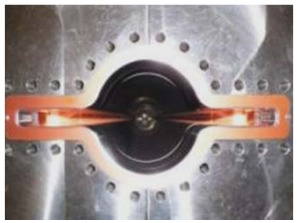


Superconducting quadrupoles to shrink colliding beam at IP



Antechamber with TiN coating to suppress electron cloud instability





$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

40 times gain in luminosity
with nano-beam, double beam current

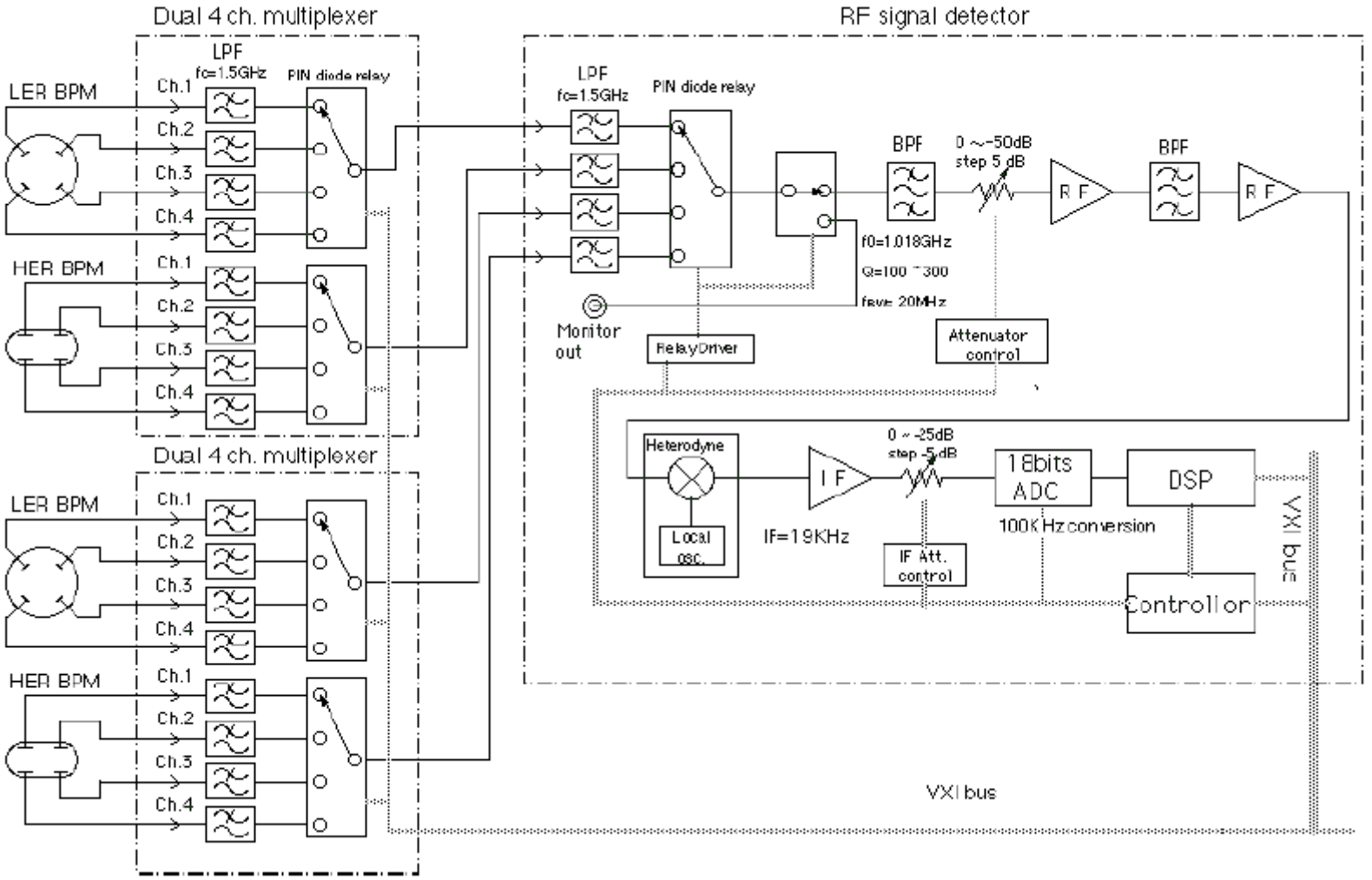
SuperKEKB beam instrumentation

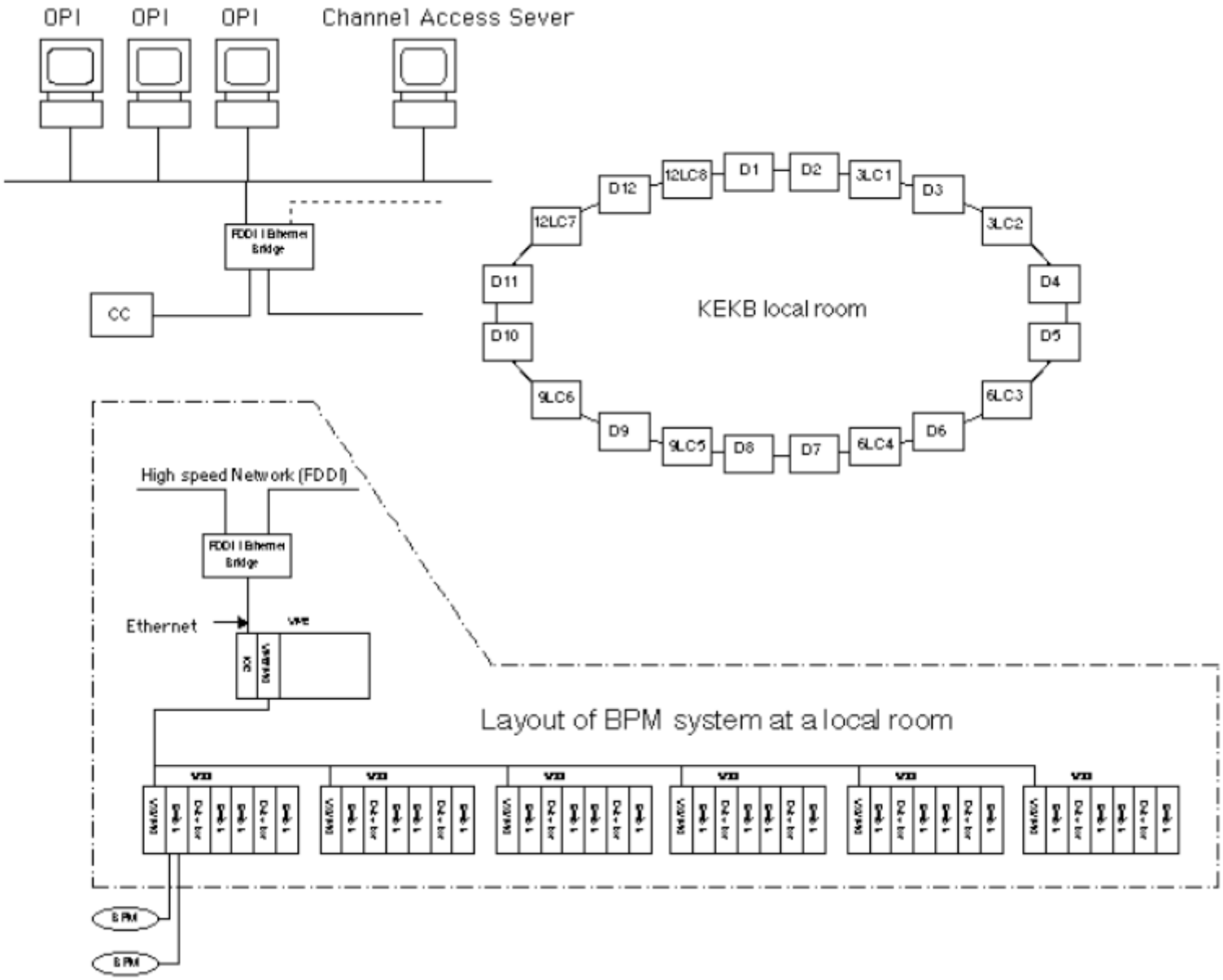
- **Main rings (HER and LER)**
  - COD measurement and optics measurement
    - Button head
    - Narrowband detector
    - Gated turn-by-turn detector
  - Fast orbit feedback
    - IR feedback detector
    - IR feedback processor
    - Medium band detector
  - X-ray size monitor using coded aperture mask
  - Beamstrahlung monitor
  - Bunch feedback related instrumentations
- **Positron damping ring**
  - COD, feedback, etc.

Optics measurement

- **X-Y coupling, dispersion, betatron function**
- **Single kick method (mainly used on KEKB)**
  - Excite a steering magnet and measure the response
  - X-Y coupling and betatron function measurement
- **Turn-by-turn monitor (will be required for SuperKEKB)**
  - Excite betatron oscillation and measure the phase advance between the BPM.
  - Betatron function, X-Y coupling, (dispersion function)

KEKB COD measurement system




OPI
OPI
OPI
Channel Access Sever
FDDI / Ethernet Bridge
CC
12LC8
D1
D2
3LC1
D3
3LC2
D4
D5
6LC3
D6
6LC4
D7
D8
9LC5
D9
9LC6
D10
D11
12LC7
D12
KEKB local room
High speed Network (FDDI)
FDDI / Ethernet Bridge
Ethernet
Layout of BPM system at a local room
BPM
BPM

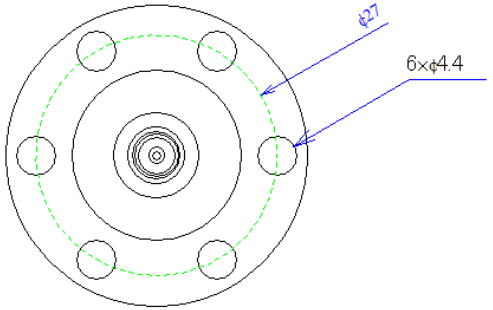
Vacuum chamber

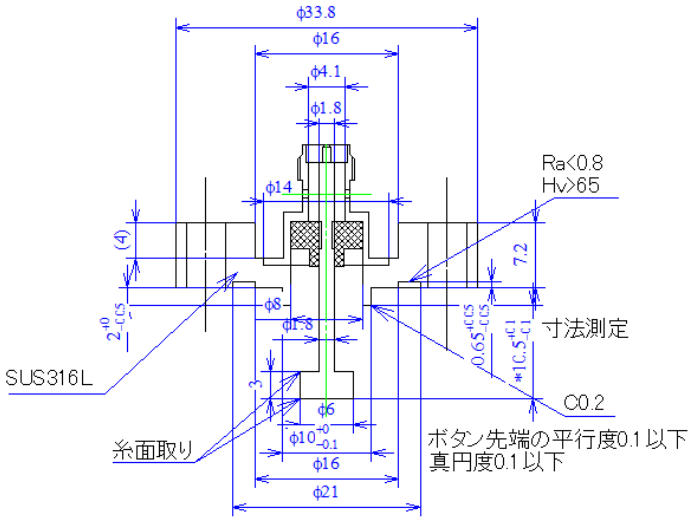
- Aluminum alloy antechamber
- cutoff frequency <1 GHz

Aluminum-alloy duct

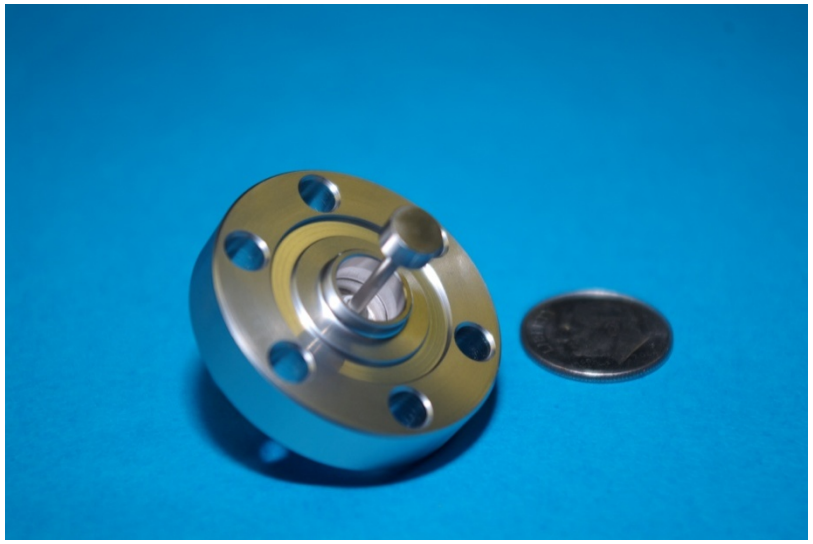
Aluminum-alloy duct

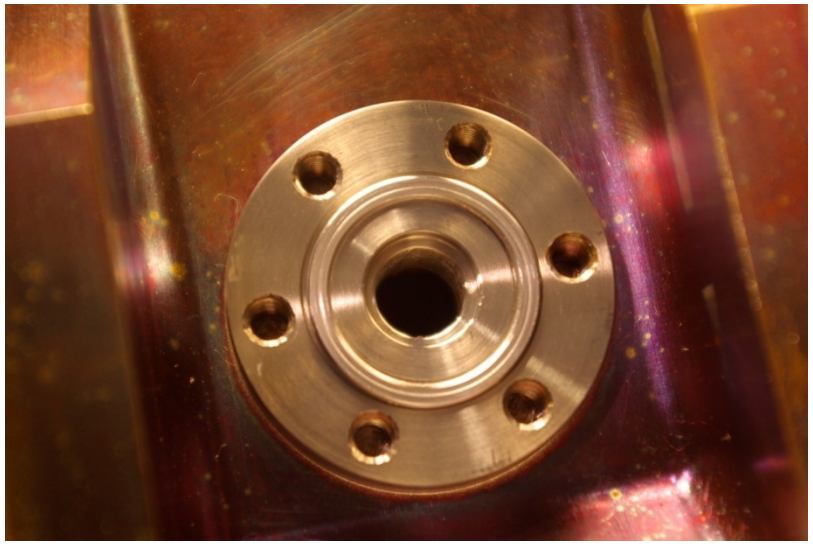
BPM head



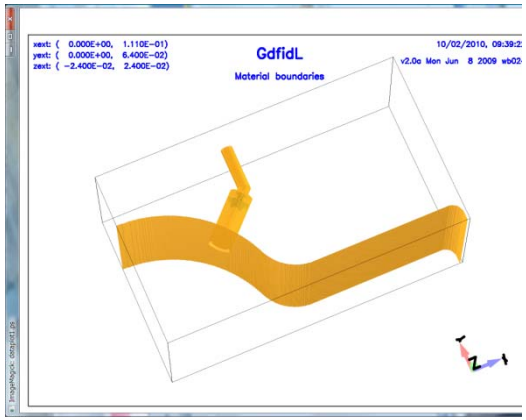


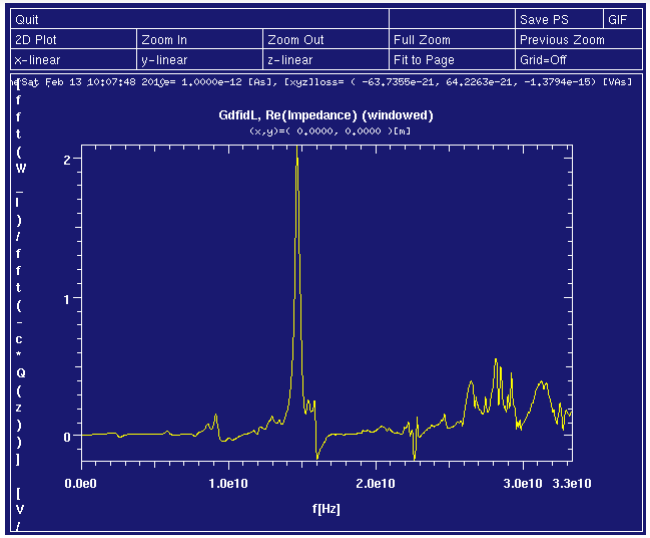
SuperKEKB用BPM model-E1
作図:M.Tobiyama 6/Oct/2006
修正:M.Tobiyama 8/Nov/2006

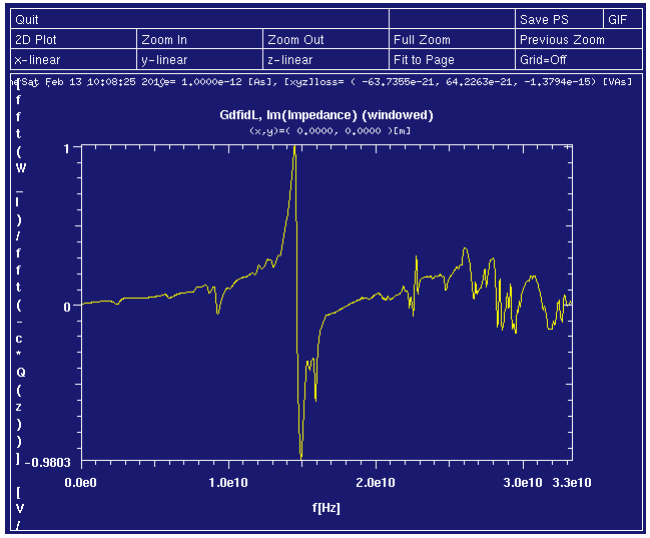


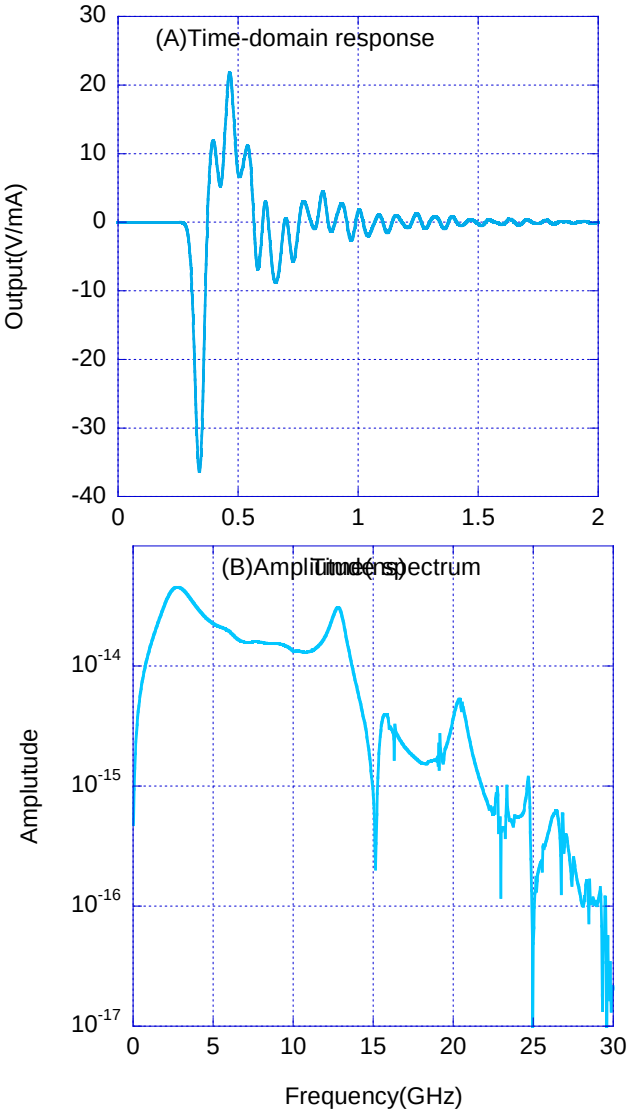


Impedance/button output simulation

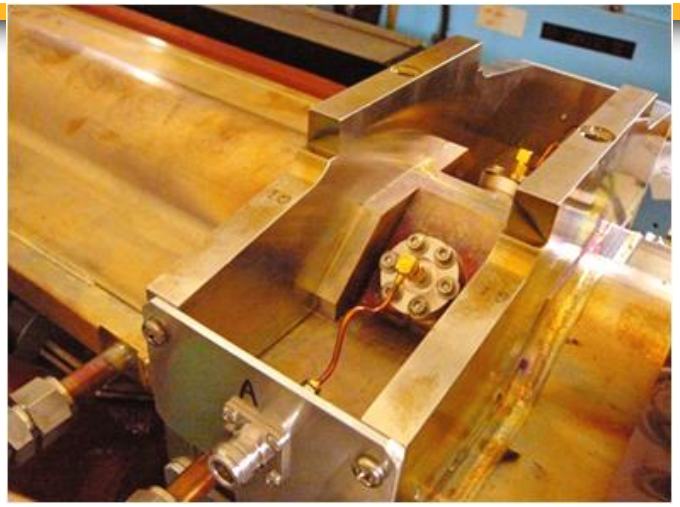


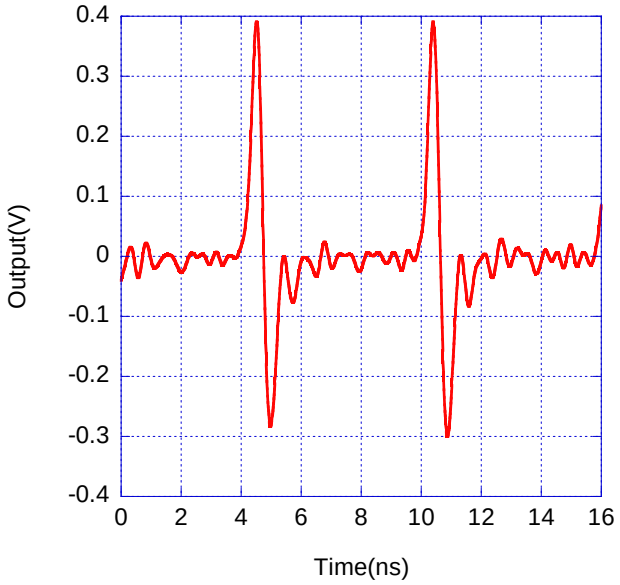




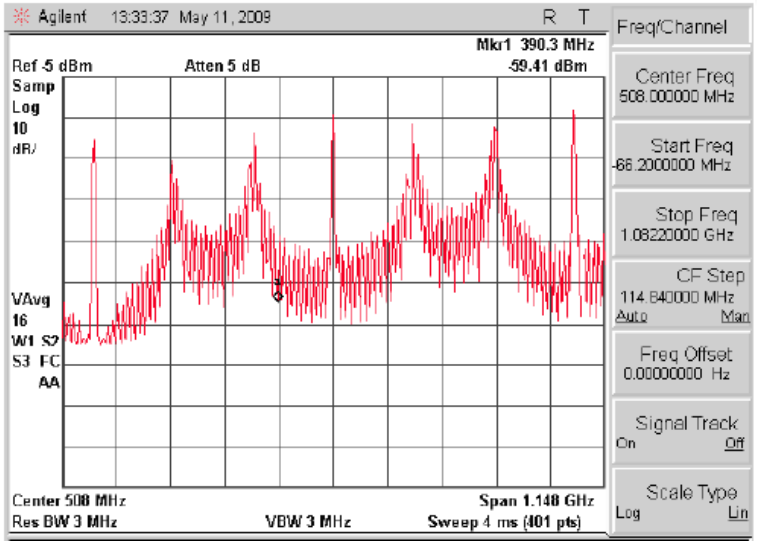


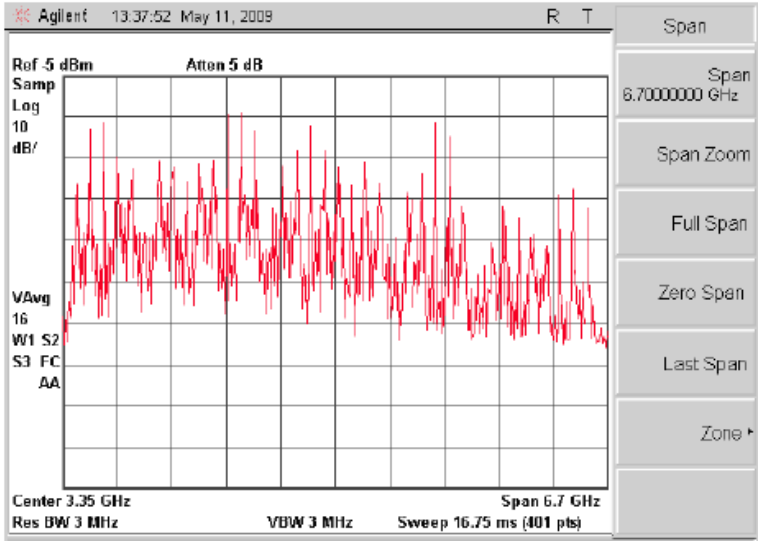
Beam signal



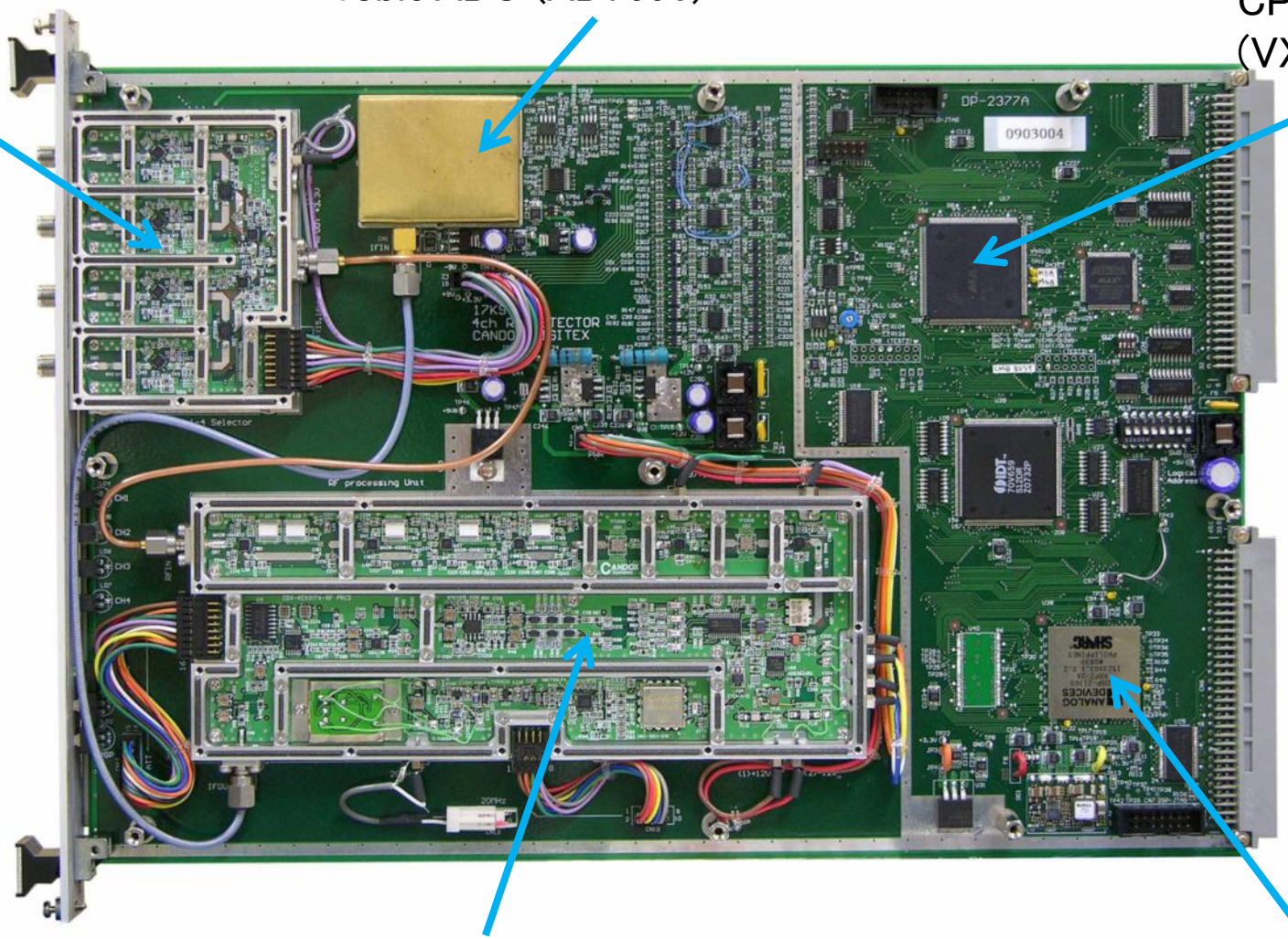


Temperature rise ~3deg @ 1.6A





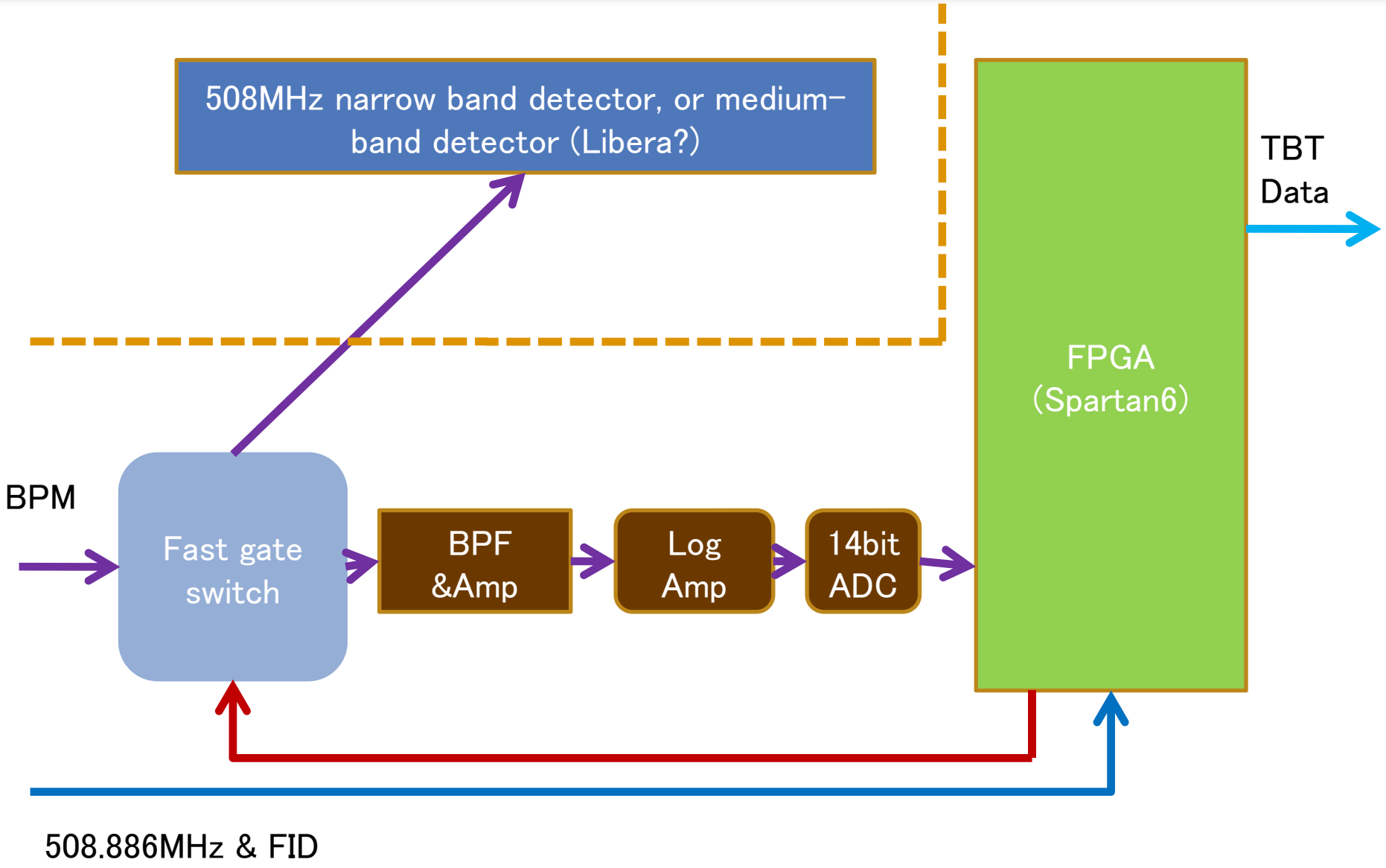
Digitex 17K94A 509MHz detector



Turn-by-turn monitor

- **Record the bunch position with turn-by-turn base.**
  - FFT the position data
    - Betatron phase advance between the monitors.
    - X-Y coupling
    - Low frequency oscillations and their source.
- **Need to share the same BPM signal with narrow-band or medium-band BPM detector.**
  - Should not disturb the signal to narrowband system.

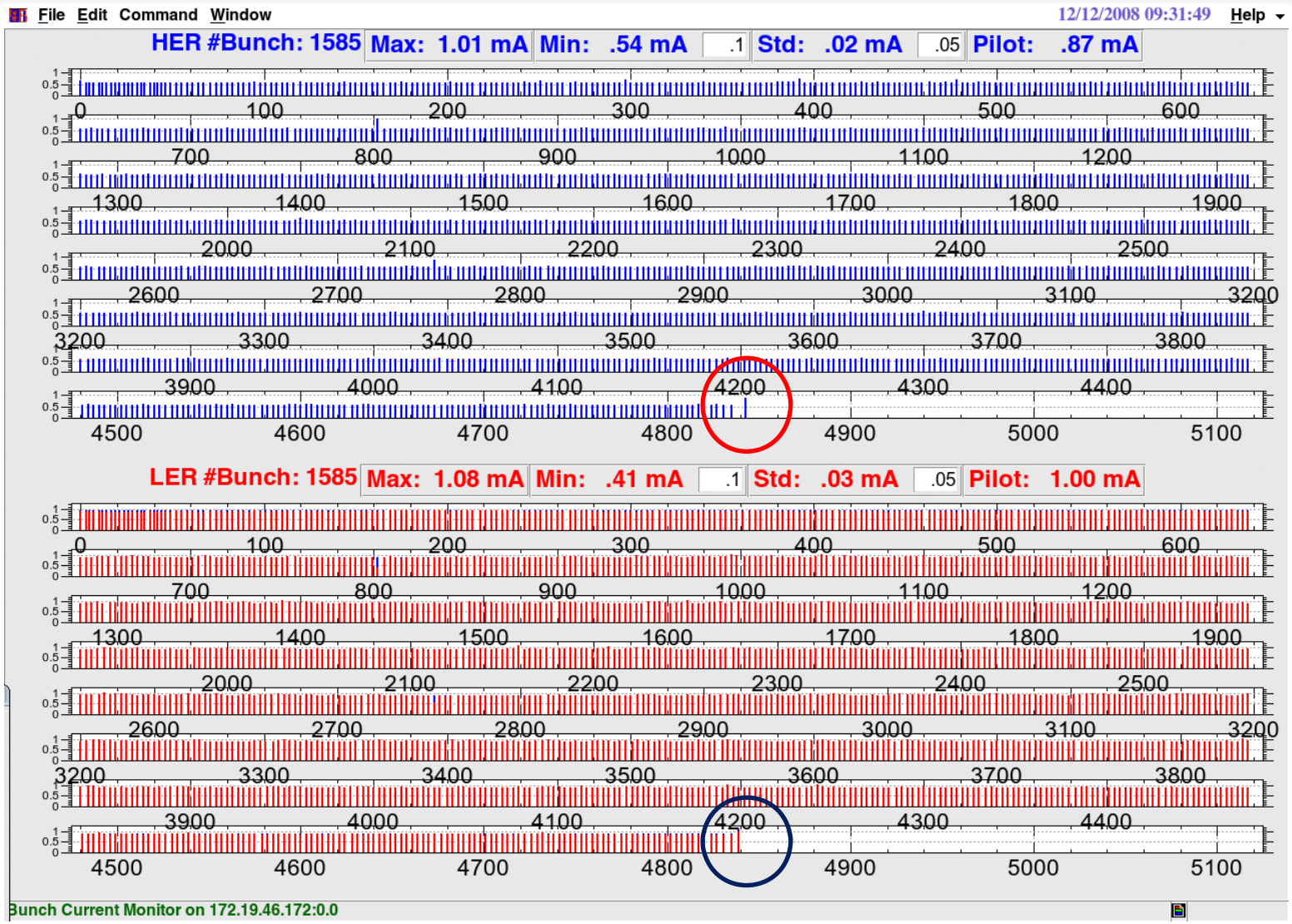
Gated turn-by-turn monitor



Gated optics measurements

- Excite betatron oscillation of pilot bunch (=non colliding bunch) with PLL
- Extract the signal of pilot bunch with fast beam switch , detect the signal with L/R detector to get the beam position of the pilot bunch, while most of the signal (2499/2500) is detected with narrow band COD detector.
  - FFT the signal to get the betatron phase advance.
  - Measure X-Y coupling
- Correct optics function, couplings with colliding condition.

Pilot bunch(KEKB)

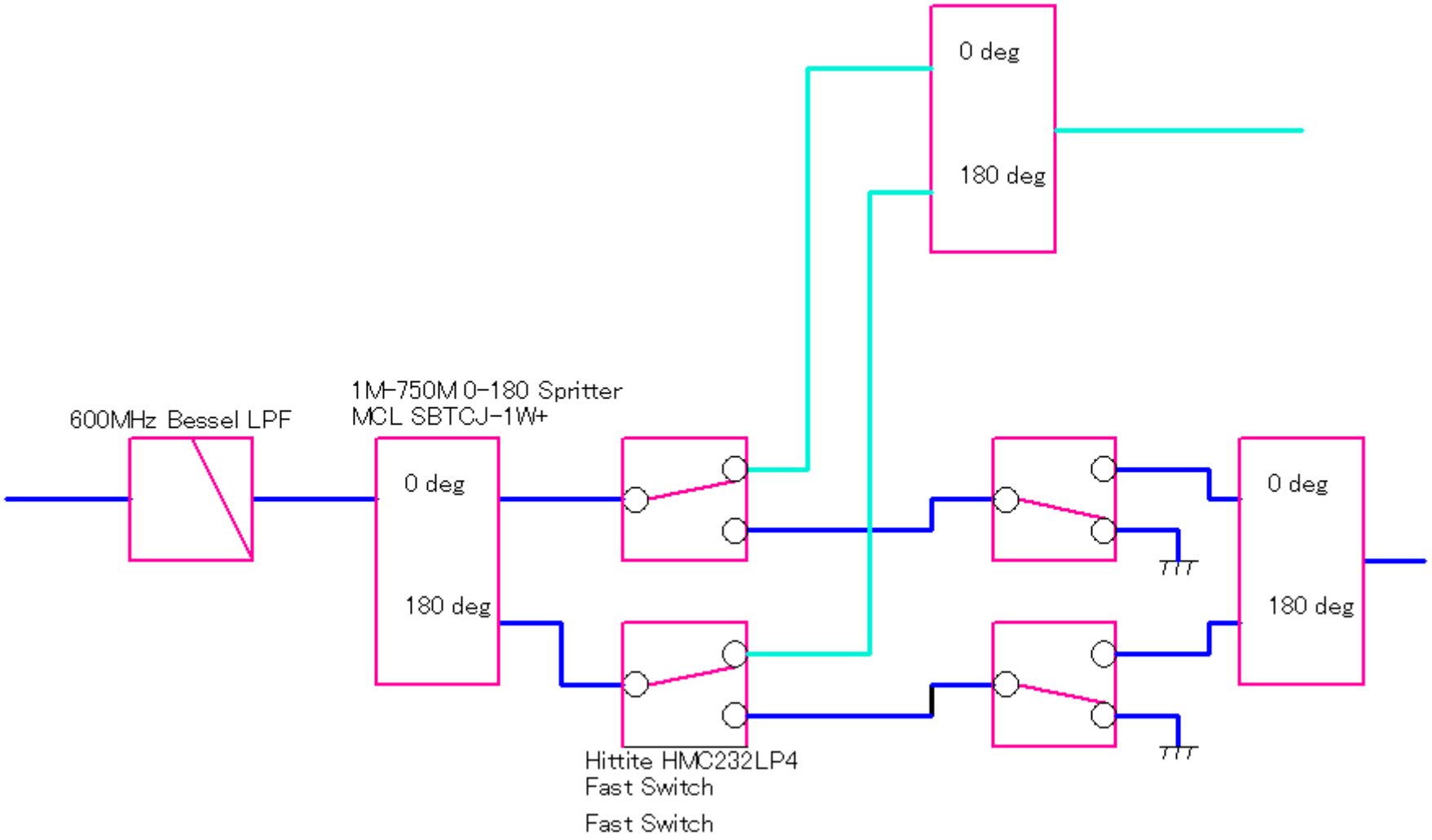


Fast gate switch

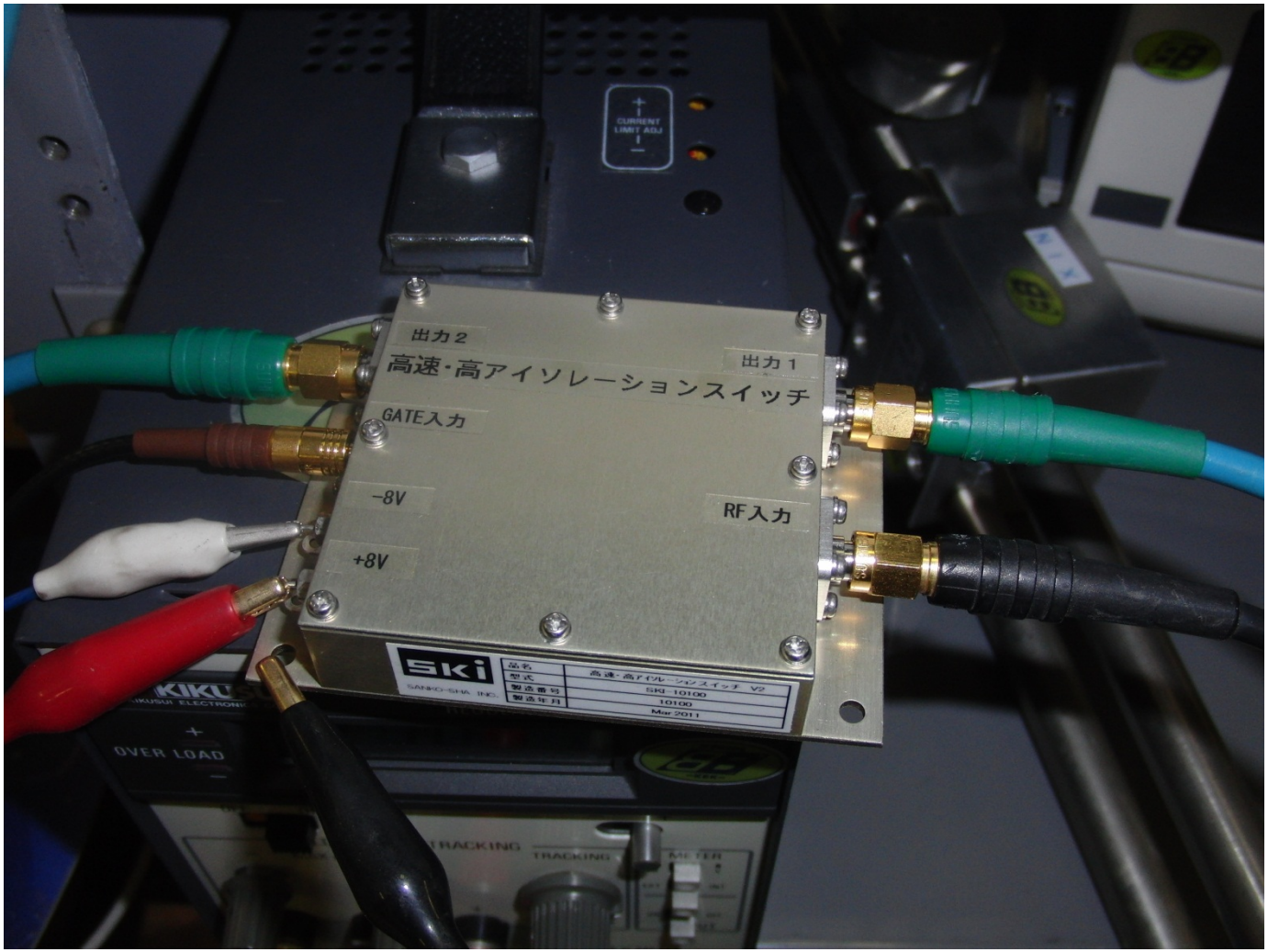
	Hittite HMC234C8	Tyco SW-283-PIN	Mini-Circuit M3SW-2-50DR+	Agilent HMMC-2027	AVAGO AMMC-2008
Input Power -1dB_c (dBm)	+26	+27	+25	+27	+14
Bandwidth (GHz)	DC - 8.0	DC - 3.0	DC - 4.5	DC - 26.5	DC - 50.0
Switching Time (ns)	3	2	5	< 1	0.1
Isolation (dB@2GHz)	52	25	50	55	46
Insertion Loss (dB@2GHz)	1.4	1.8	0.9	1.4	1.6
Control	0/-5 V	-8.5/+5 V	TTL	0/-10 V	0/-3.0 V

Switching noise

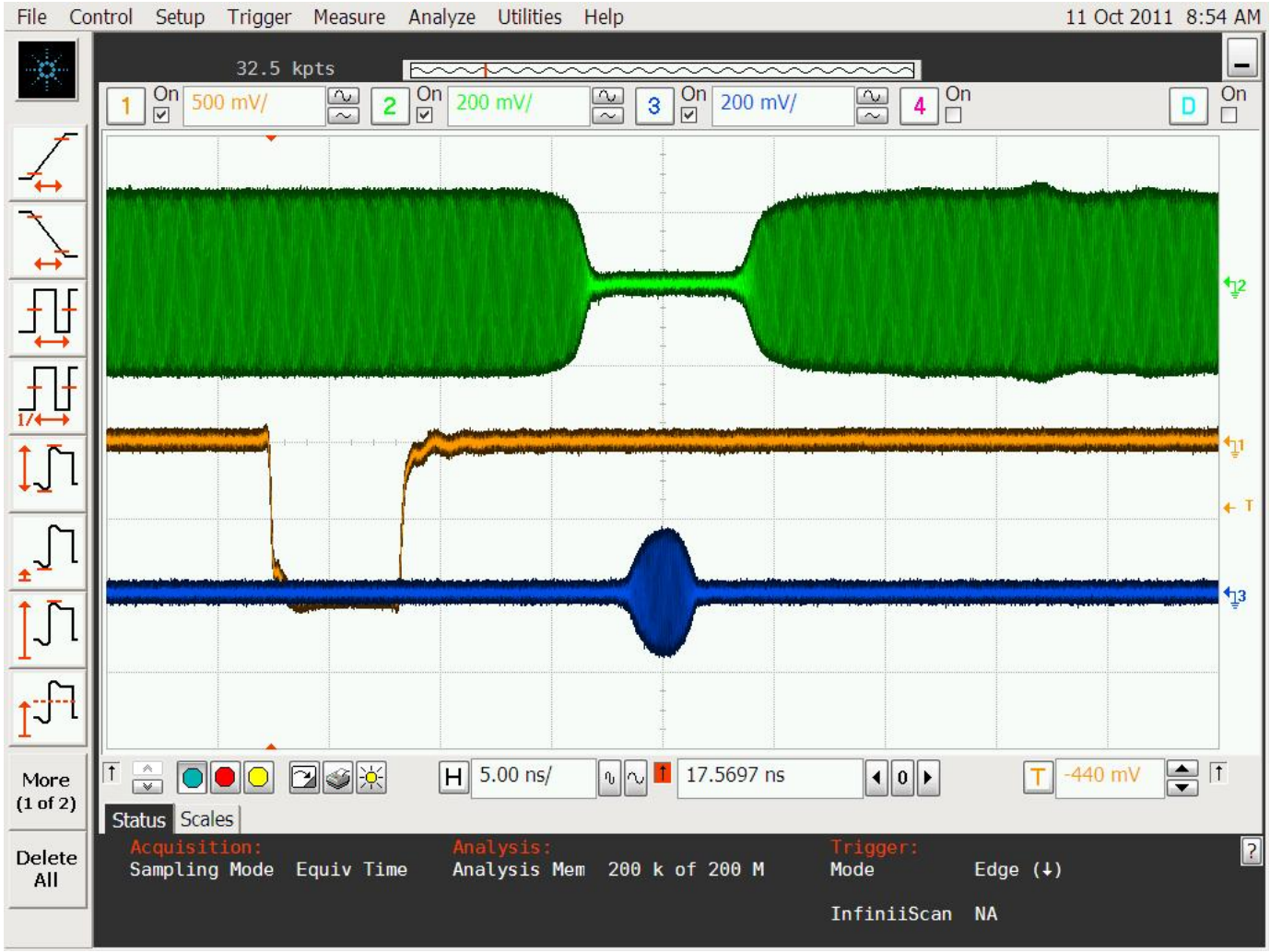
Better isolation and switching noise cancellation



Proposed and tested by Dr. T. Naito


出力２
高速・高アイソレーションスイッチ
出力１
GATE入力
−8V
RF入力
+8V
CURRENT LIMIT ADJ
OVER LOAD
TRACKING
METER

Switching


File Control Setup Trigger Measure Analyze Utilities Help
11 Oct 2011 8:54 AM
32.5 kpts
1 On 500 mV/
2 On 200 mV/
3 On 200 mV/
4 On
D On
H 5.00 ns/
17.5697 ns
T -440 mV
More (1 of 2)
Delete All
Status Scales
Acquisition:
Sampling Mode Equiv Time
Analysis:
Analysis Mem 200 k of 200 M
Trigger:
Mode Edge (↓)
InfiniiScan NA

SW noise


File Control Setup Trigger Measure Analyze Utilities Help
11 Oct 2011 8:56 AM
32.5 kpts
1 On 500 mV/
2 On 10.0 mV/
3 On 10.0 mV/
4 On
D On
H 5.00 ns/
17.5697 ns
T -430 mV
More (1 of 2)
Delete All
Status Scales
Acquisition:
Sampling Mode Equiv Time
Analysis:
Analysis Mem 200 k of 200 M
Trigger:
Mode Edge (↓)
InfiniiScan NA


File Control Setup Trigger Measure Analyze Utilities Help
11 Oct 2011 11:41 AM
20.0 kpts
1 On 500 mV/
2 On 200 mV/
3 On 100 mV/
4 On
D On
H 2.00 ns/
19.5582 ns
T -430 mV
More (1 of 2)
Delete All
Status Scales
Acquisition:
Sampling Mode Equiv Time
Analysis:
Analysis Mem 200 k of 200 M
Trigger:
Mode Edge (↓)
InfiniiScan NA


File Control Setup Trigger Measure Analyze Utilities Help
11 Oct 2011 11:47 AM
32.0 kpts
1 On
2 On 200 mV/
3 On 200 mV/
4 On
D On
H 5.00 ns/
22.9628 ns
T -620 mV
More (1 of 2)
Delete All
Status Scales
Acquisition:
Sampling Mode Equiv Time
Analysis:
Analysis Mem 200 k of 200 M
Trigger:
Mode Edge (↓)
InfiniiScan NA

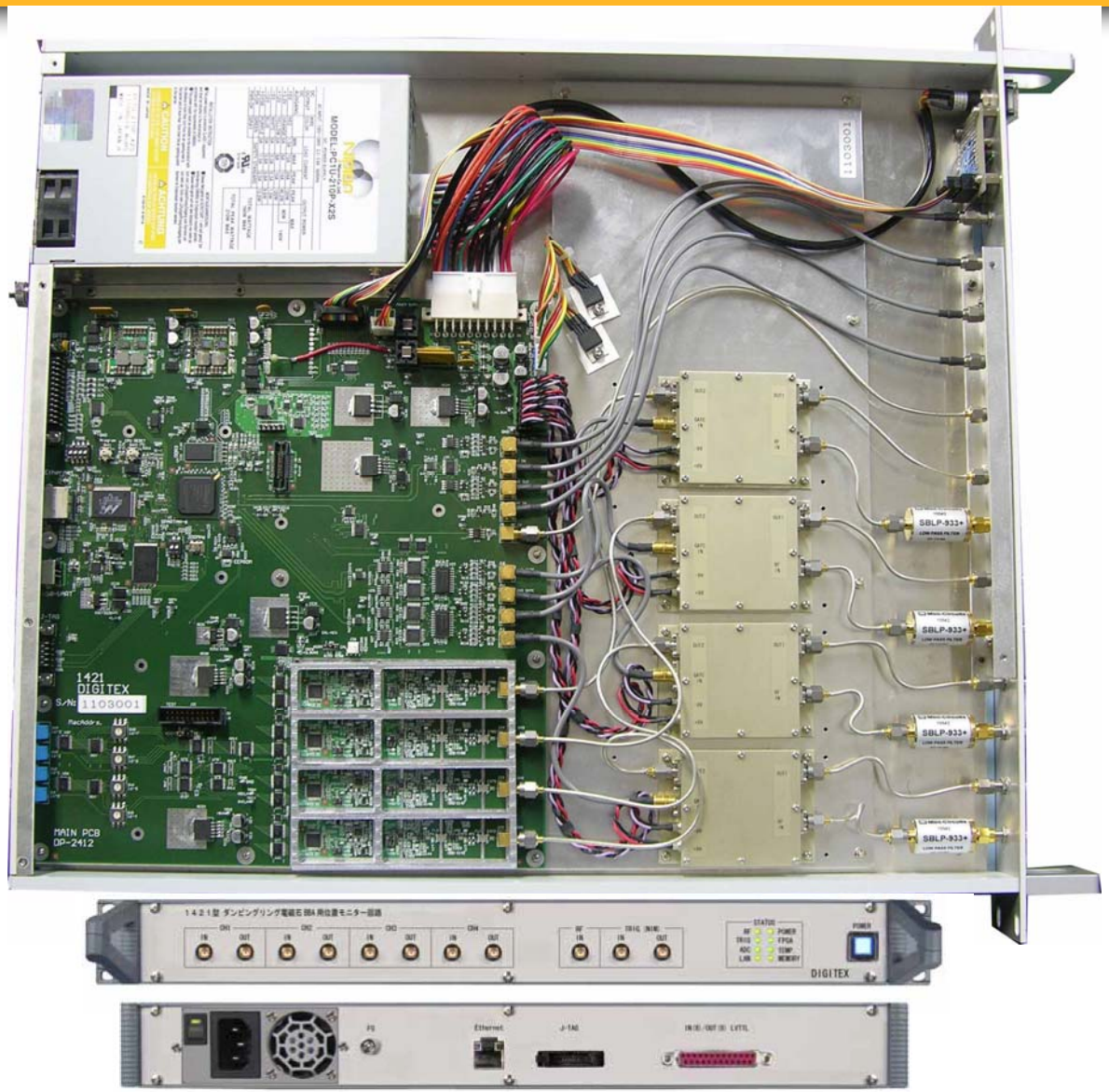
RF to No.1 (SW off)

RF to No.1 (SW ON)

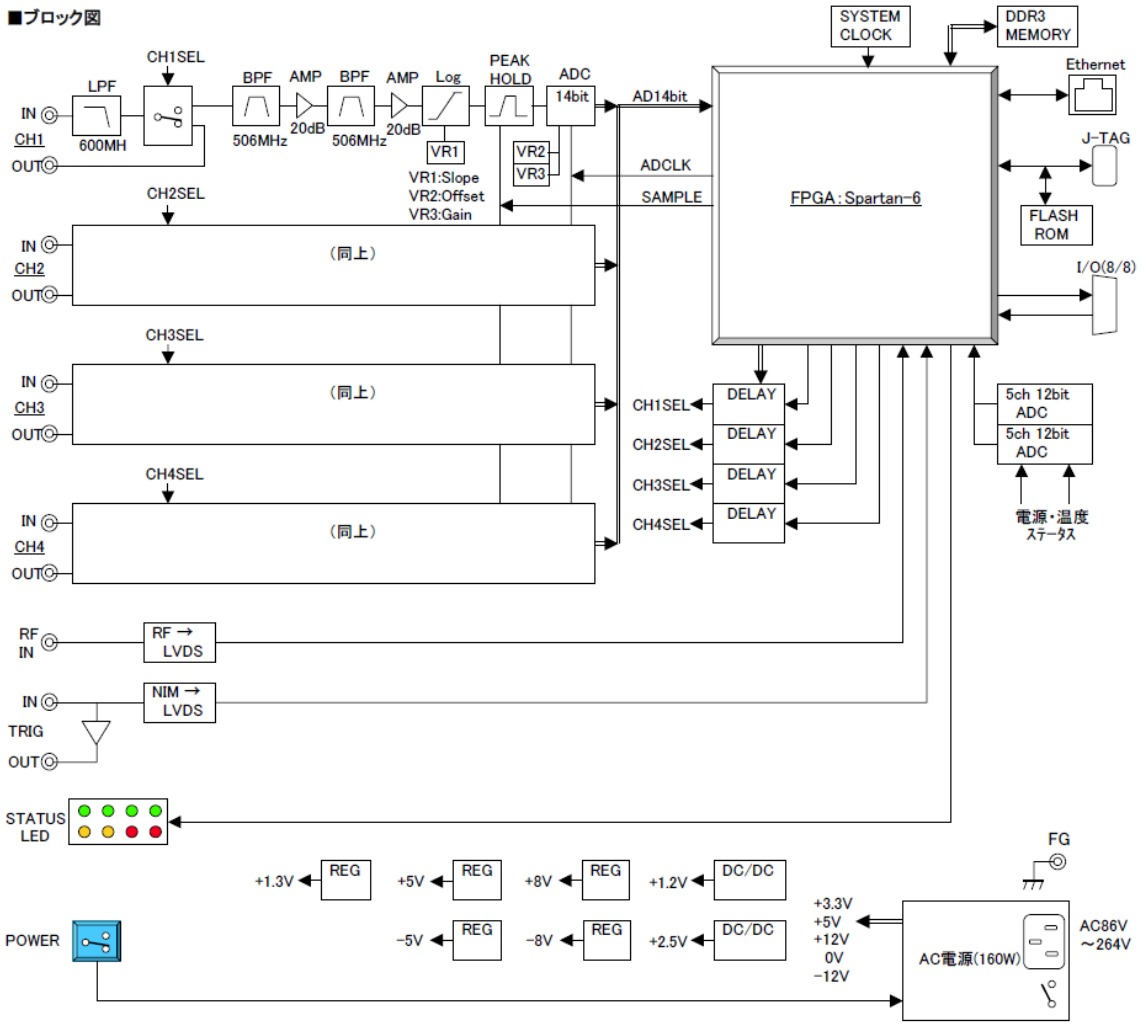
RF to No.2 (SW ON)

RF to No.2(SW OFF)

Circuit


1421
DIGITEX
S/No 1103001
MAIN PCB
DP-2412
SBLP-933+
SBLP-933+
SBLP-933+
SBLP-933+
DIGITEX

Block Diagram



Log ratio detector

- 506MHz BW 24MHz SAW filter
- ADL5521 20dB Low noise amplifier x 2
- ADL5513 Log amplifier
- Peak-hold circuit
- ADS850 14bit 10MSPS BW 270MHz ADC

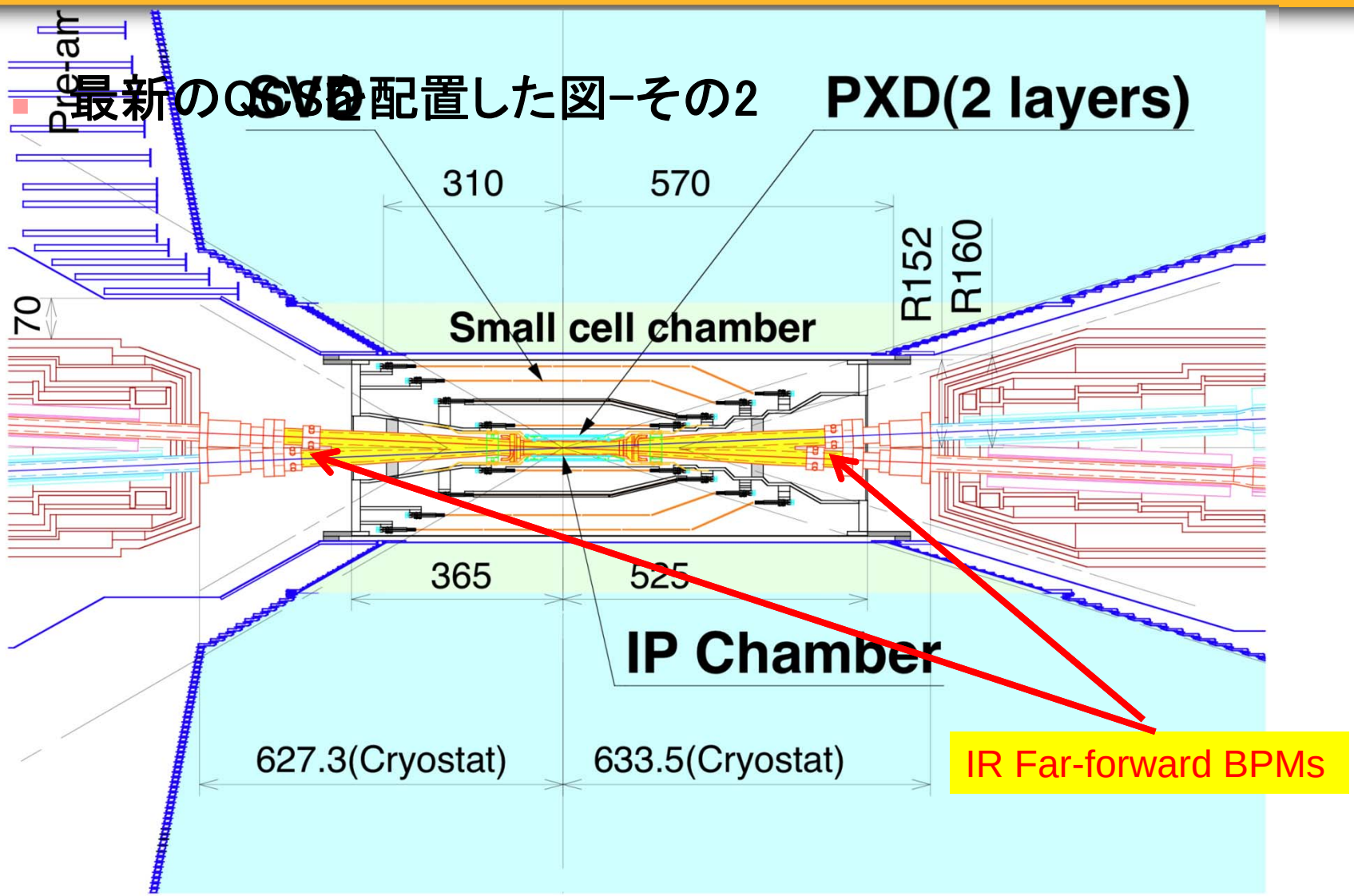
Digital control

- **Based on SP605 evaluation board**
  - Spartan-6 XC6SLX45T FPGA
  - DDR3-1066 128M memory
  - GbE and UART interface

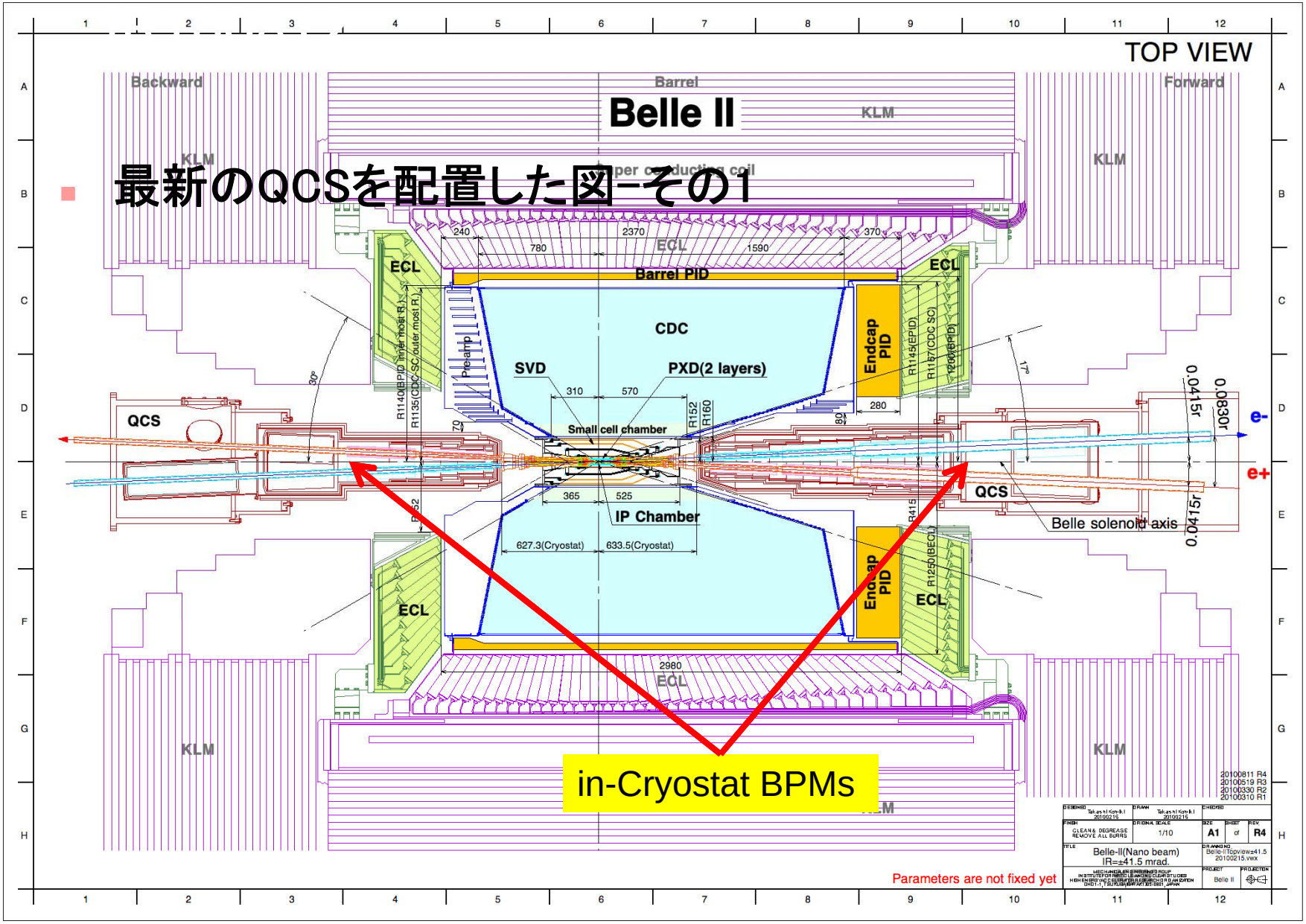
- **Timing control (508MHz /5120, delay (2ns step), fine delay tuning through EP195 (10ps step)) to fast gate SW**
- **Power and temperature monitor**
- **Using MicroBlaze to control and communicate.**

IR100812

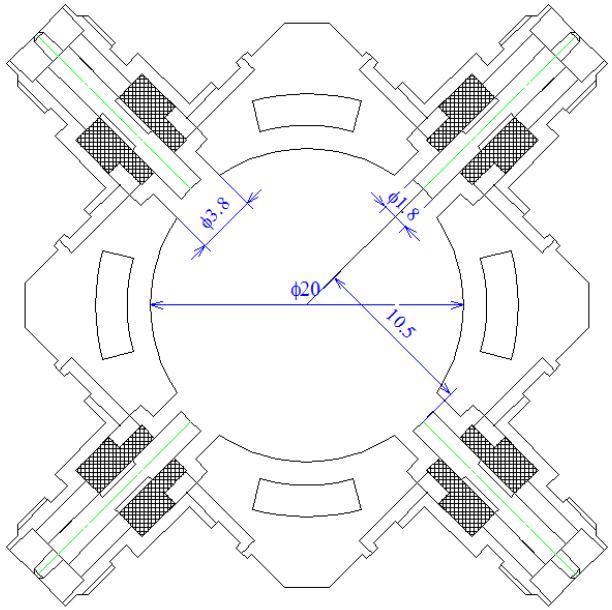
- 最新のQCSを配置した図−その2



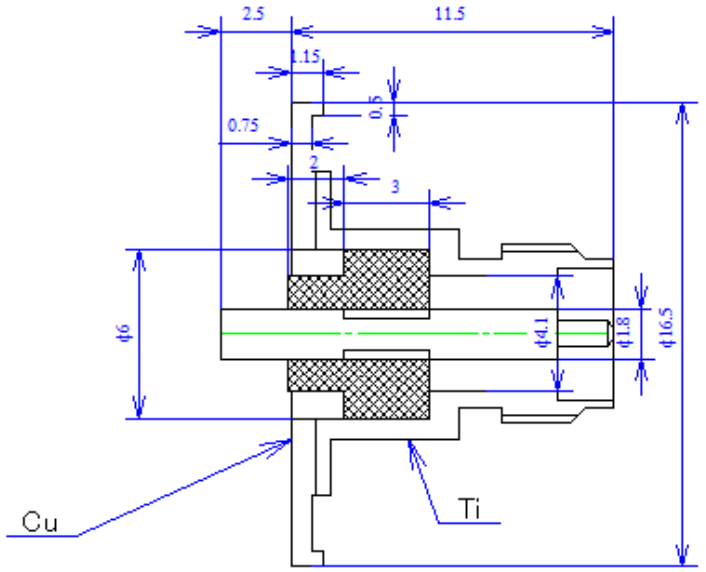
- 最新のQCSを配置した図−その1



IR far-forward BPM



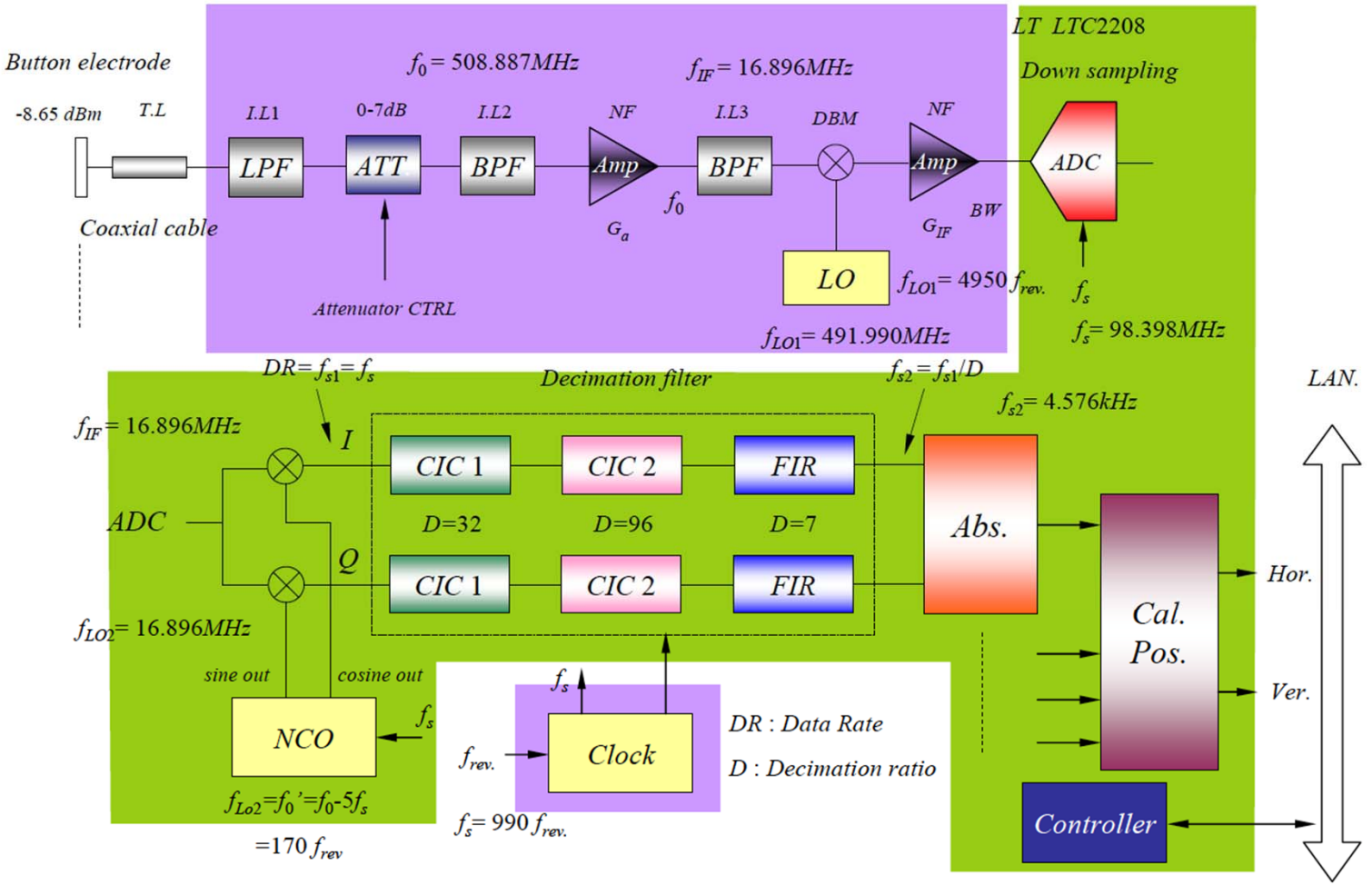
IR先端用BPM御提案図(Ver.2.0)
縮尺:4:1(for A4)
作図:M.Tobiyama 9/Jul/2009
修正:M.Tobiyama 16/Jul/2009(ver.0.2)
修正:M.Tobiyama 31/Jul/2009(ver.1.0)
修正:M.Tobiyama 13/Aug/2009(ver.2.0)



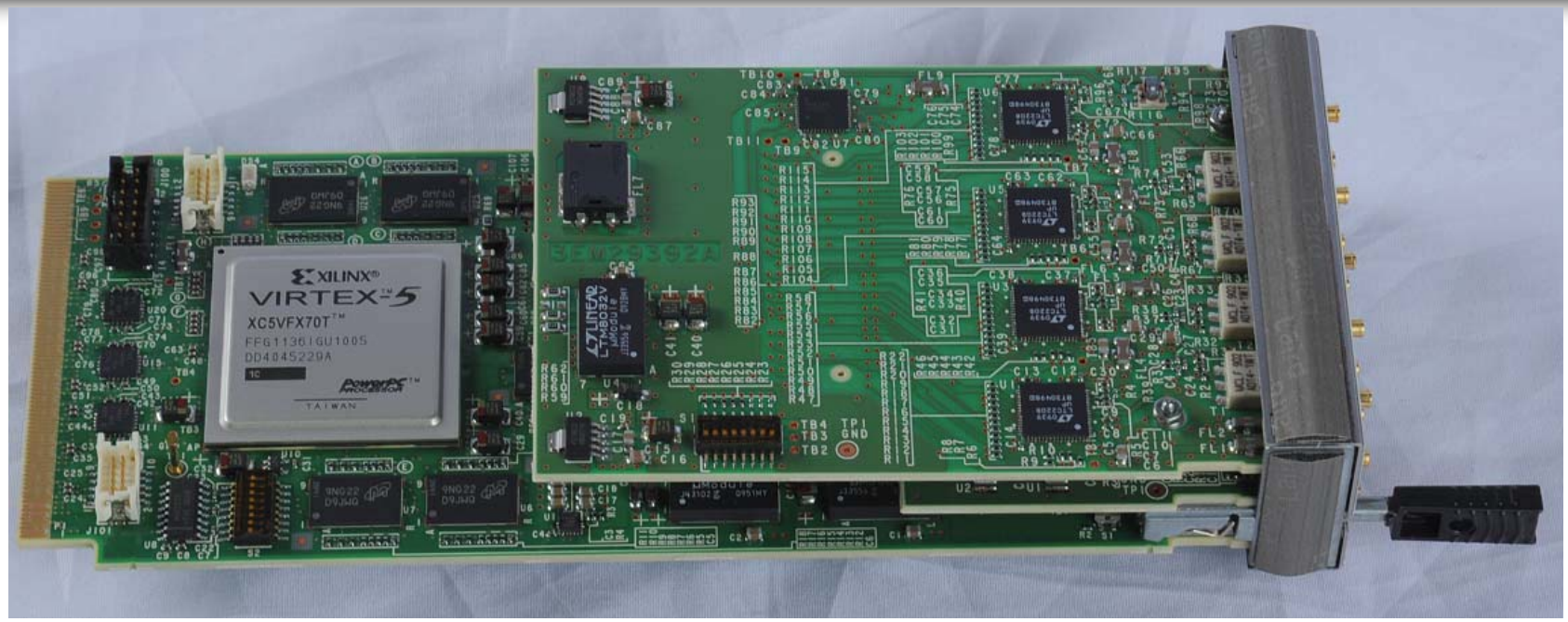
衝突点用SMAフィードスルーS2型概略図

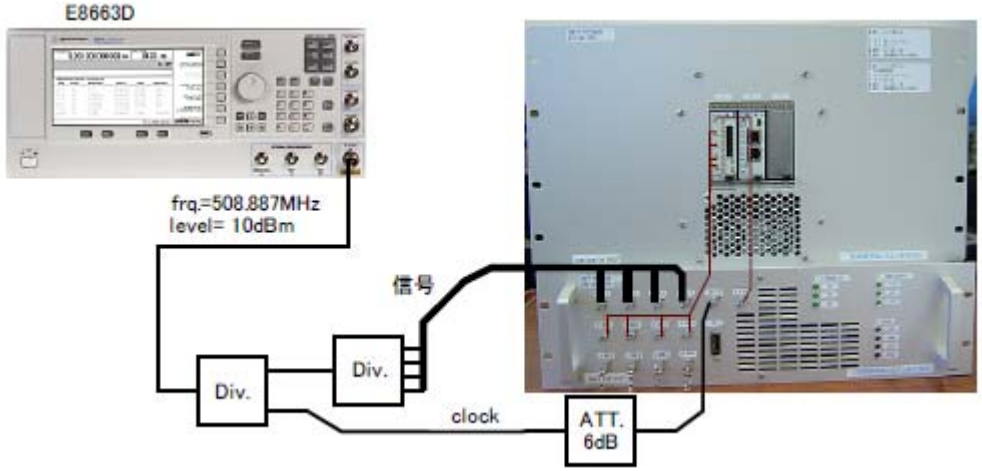
IR far-forward BPM

IR feedback detector



micro-TCA size board

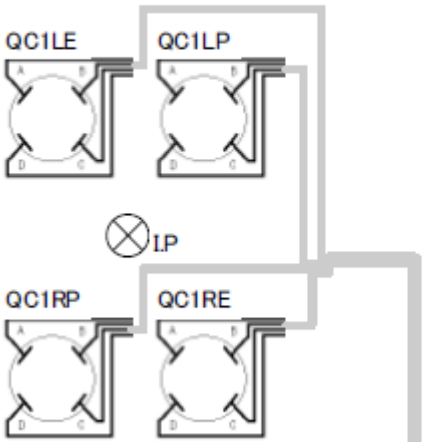




軌道フィードバックBPM　データ転送・軌道演算システム　Ver.1.01

2011/07/12

BPMはQC1に付いている4台

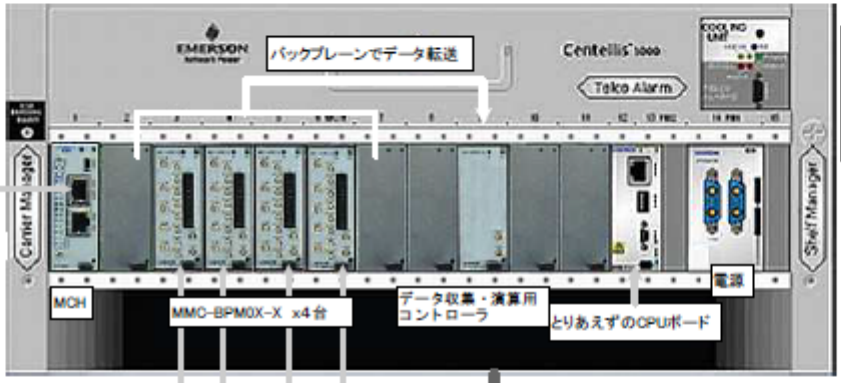


BPM信号処理回路（MMC-BPM01-B)データ出力形式

・出力データ	X,Yビーム位置（mm）
・データ出力レート	5kHz
・データフォーマット	?
・データビット数	固定小数点で24bits以上
・データ出力	シリアル
・出力インターフェース	GbE、PCI Express μTCA Back planeを使用
・測定の同期	?

データ収集・演算用コントローラ（信号処理回路のディジタル部分を使用する）

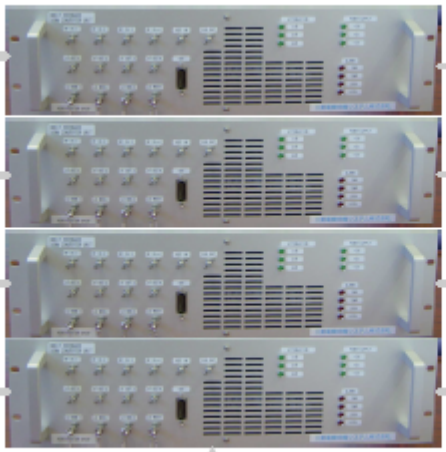
・信号処理回路とのインターフェース	GbE、PCI Express　μTCAの μTCA Back planeでデータをやり取り
・OS	IOC化するならLinux？
・EPICSは動作させるのか	IOC化するなら
・要求演算性能	データ収集、出力、演算を5kHzの Ratenoyで行なえる必要あり？
・演算結果出力レート	5kHz
・必要演算精度	固定小数点で24bitsi以上？
・BPM何台分演算するのか	最初は4台
・演算式、パラメータ	簡単自由に動作中にも変更可能なこと
・記憶する項目と容量	?
・出力インターフェース	?
・ファームウエア書き換え	リモートでFlashROM書換可？



データ収集・演算用コントローラの
外部との通信

遠いIOC測定（KEKBでいう所のIOC）へ
演算結果、Bump情報を通知する必要あり
データ収集・演算用コントローラの処理に
余裕がある場合、IOCを実装しEPICSにて
必要な通信を行なうのがよいか？

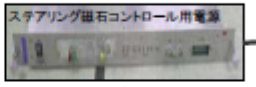
アナログ信号処理部



RF clock供給　508.887MHz

どうデータ送信するか
全く不明

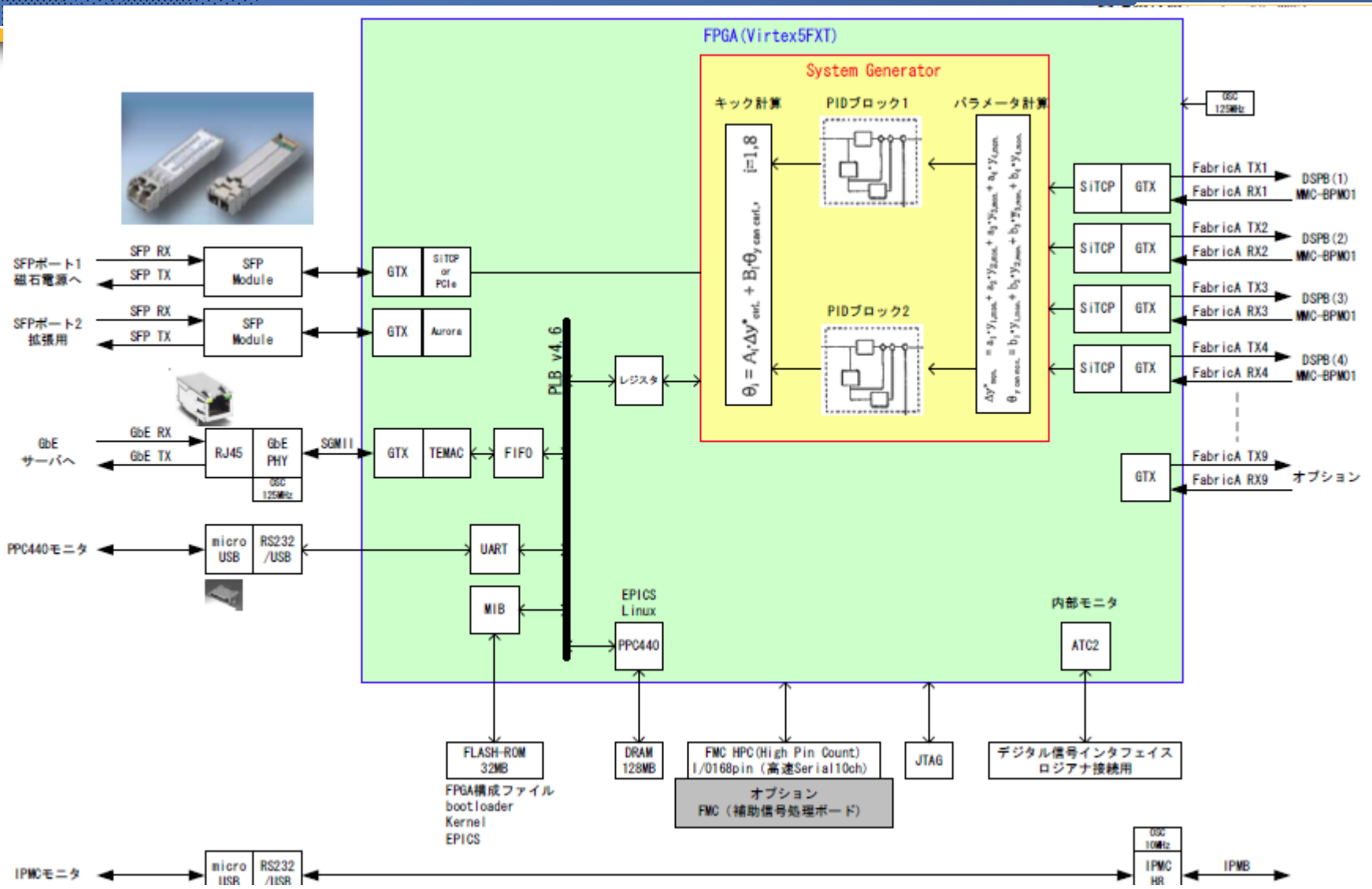
HER Hor. 4台
Ver. 4台



LER Hor. 4台
Ver. 4台

電源へのデータ設定

・出力データ種類	?
・データ設定レート	5MHz
・データフォーマット	?
・データビット数	?
・出力インターフェース	?

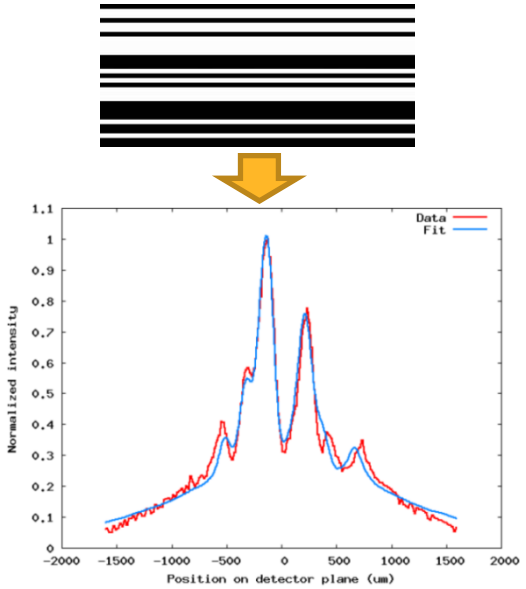

FPGA(Virtex5FXT)
System Generator
キック計算
PIDブロック1
パラメータ計算
PIDブロック2
i=1,8
OSC 125MHz
SiTCP
GTX
FabricA TX1
FabricA RX1
DSPB(1) MMC-BPM01
FabricA TX2
FabricA RX2
DSPB(2) MMC-BPM01
FabricA TX3
FabricA RX3
DSPB(3) MMC-BPM01
FabricA TX4
FabricA RX4
DSPB(4) MMC-BPM01
FabricA TX9
FabricA RX9
オプション
SFPポート1 磁石電源へ
SFPポート2 拡張用
SFP RX
SFP TX
SFP Module
GTX
SiTCP or PCIe
Aurora
PLB v4.6
レジスタ
GbE サーバへ
GbE RX
GbE TX
RJ45
GbE PHY
SGMII
TEMAC
FIFO
PPC440モニタ
micro USB
RS232 /USB
UART
MIB
EPICS Linux
PPC440
内部モニタ
ATC2
FLASH-ROM 32MB
FPGA構成ファイル
bootloader
Kernel
EPICS
DRAM 128MB
FMC HPC(High Pin Count) I/O168pin (高速Serial10ch)
オプション
FMC (補助信号処理ボード)
JTAG
デジタル信号インタフェイス
ロジアナ接続用
IPMCモニタ
OSC 10MHz
IPMC HR
IPMB

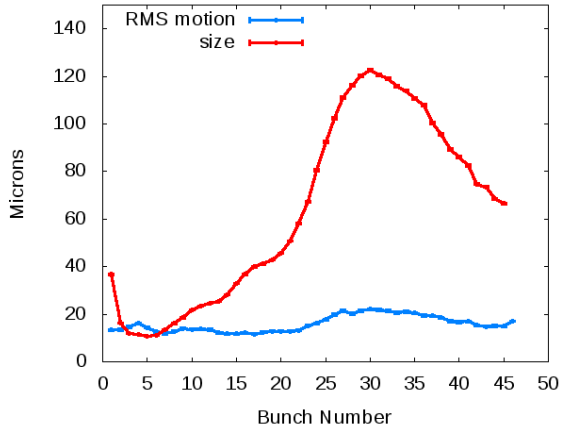
Medium-band detector???

X-ray size monitor using Coded Aperture (KEK, Hawaii U., Cornell U.)

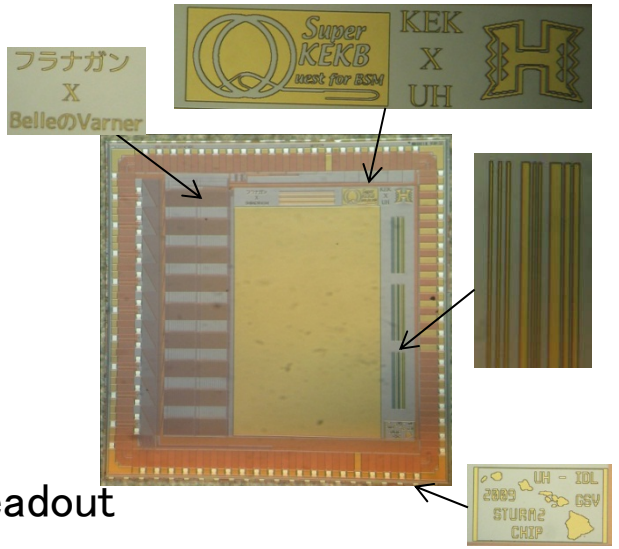
Goal: Bunch-by-bunch, turn-by-turn size/profile measurements of low-emittance beams.

- X-ray astronomy technique: multiple pinholes in pseudo-random pattern
- Reconstruction requires simulation of full diffraction and absorption characteristics of mask, plus detector response, over spectrum.
- Pseudo-random pattern gives relatively flat spatial frequency response. (Good for reconstruction).
- **Large aperture and spectral bandwidth enables single-shot measurements at resolutions somewhat better than a pinhole camera.**



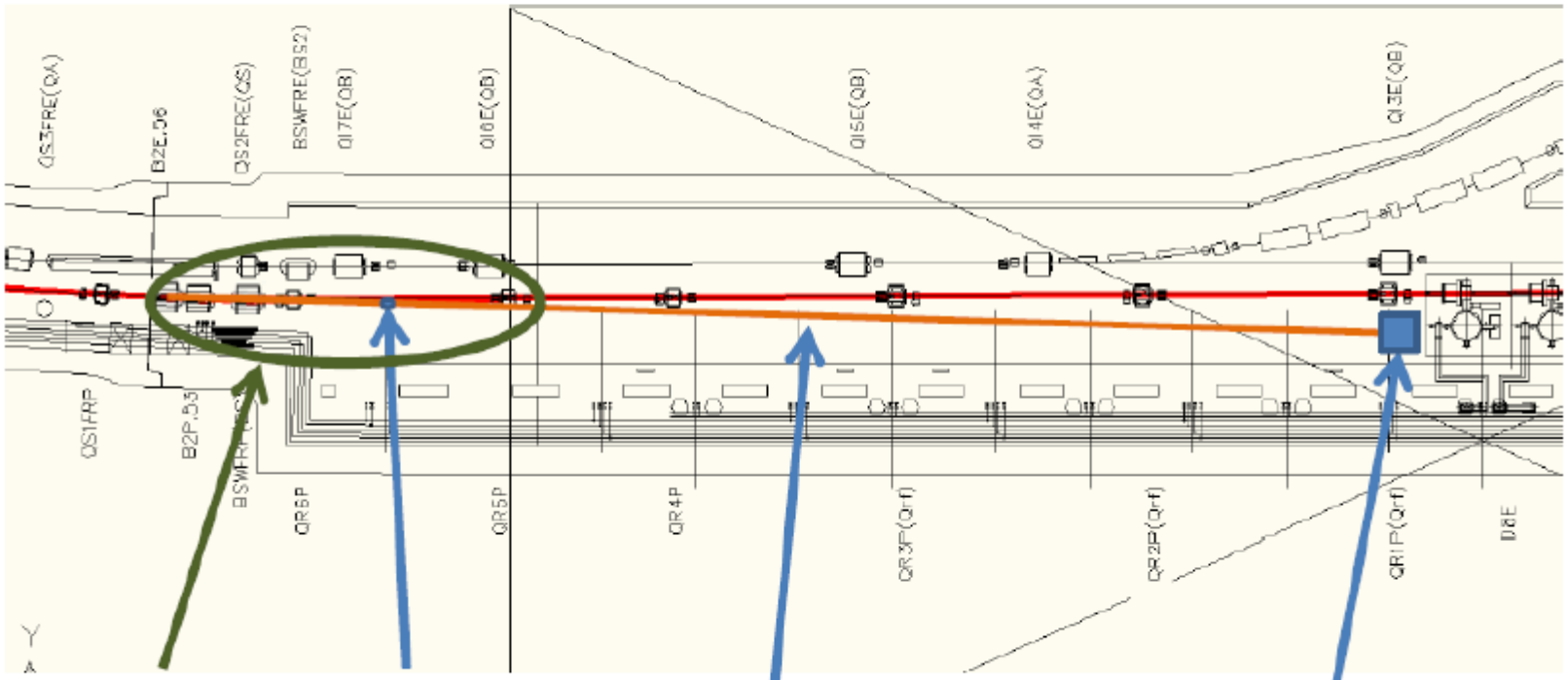


Example of bunch-by-bunch data (electron-cloud blow-up study data at CesrTA). Single-shot data averaged for each bunch.



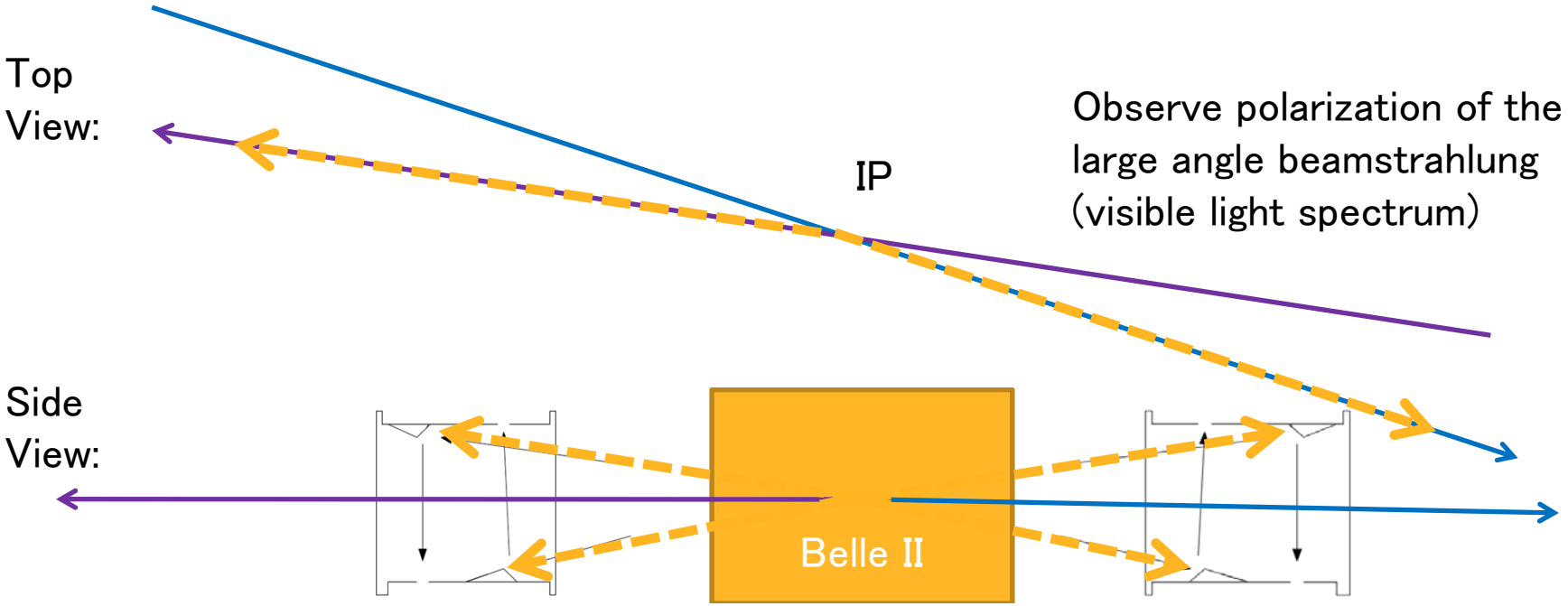
STRUM2 ASIC for readout

XRM:LERのX線ビームライン（富士D8）

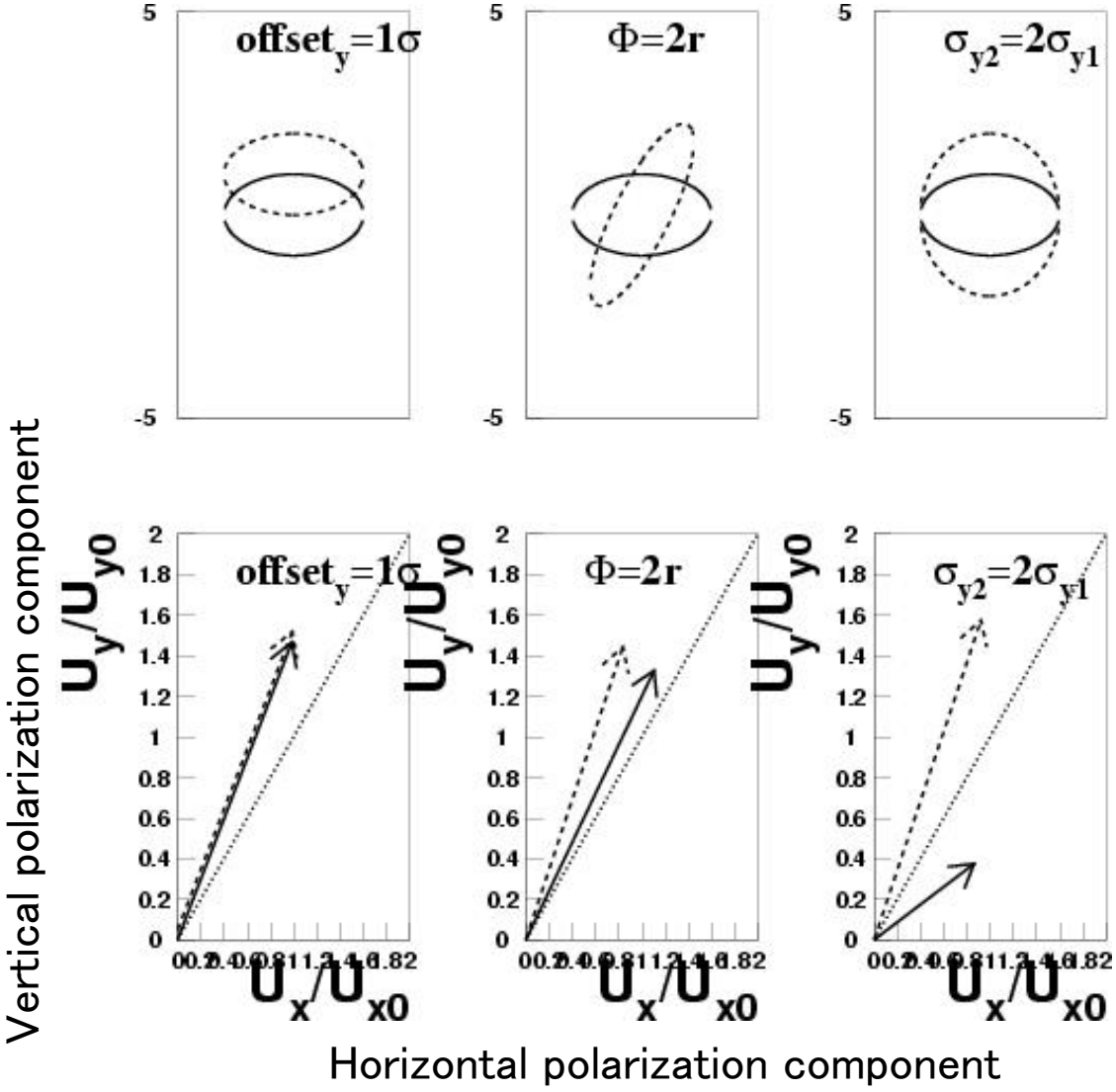


Beamstrahlung monitor for SuperKEKB (Wayne State U.)

- Beamstrahlung: Radiation emitted by the particles in one beam due to the bending force of the EM field of the other colliding beam. Many similarities with SR but also some substantial difference due to very short "magnet".
- Beamstrahlung polarization at specific azimuthal points provides unique information about the beam–beam geometry.



Examples of Large Angle BMST pattern



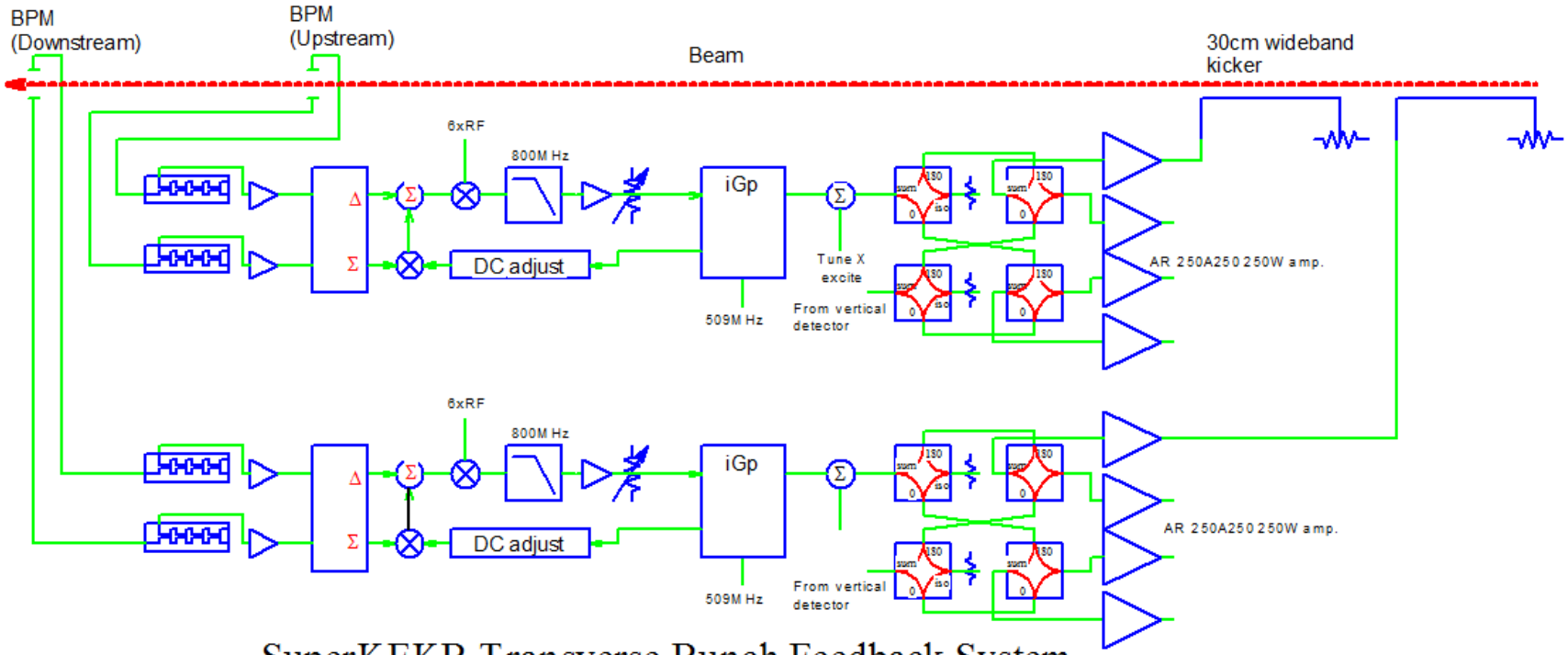
The observation of transverse beam-beam overlap function, directly and passively at the IP, is unmatched by any other device.

SuperKEKB BxB feedback

- **We need to**
  - prepare longitudinal feedback systems on both rings.
  - improve the performance of the transverse feedback systems
  - design and prepare much durable vacuum components such as BPM electrode or feedback kickers to stand higher beam current..

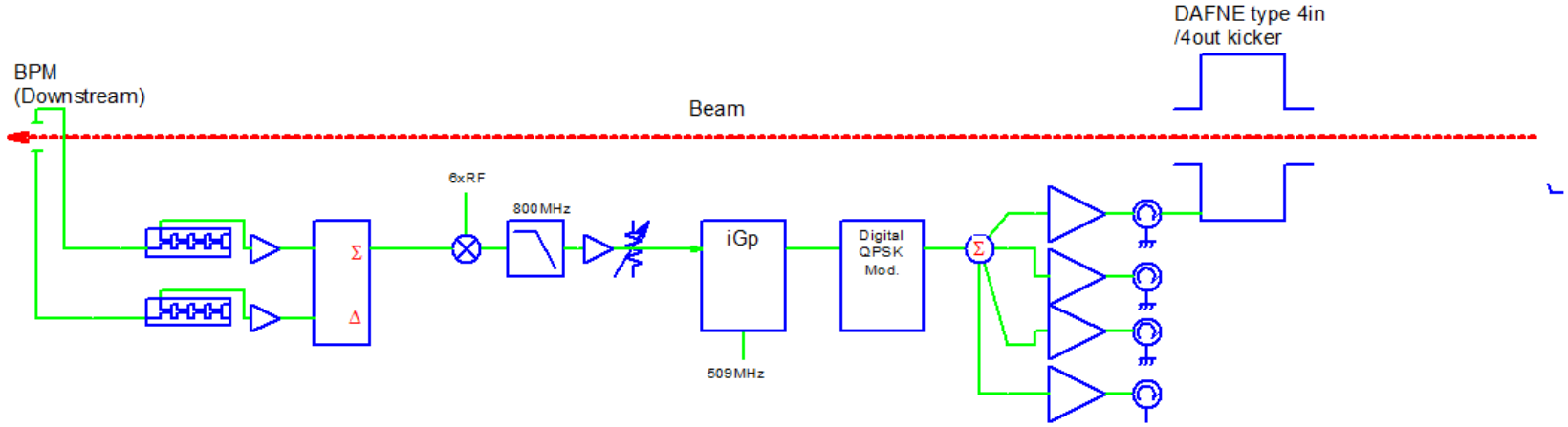
- **Use general purpose feedback signal processing system– iGp or iGp12**
- **Development of BPM electrode with improved time response using glass–type seal**
- **Development of better bunch detection circuit**

SuperKEKB Transverse FB plan



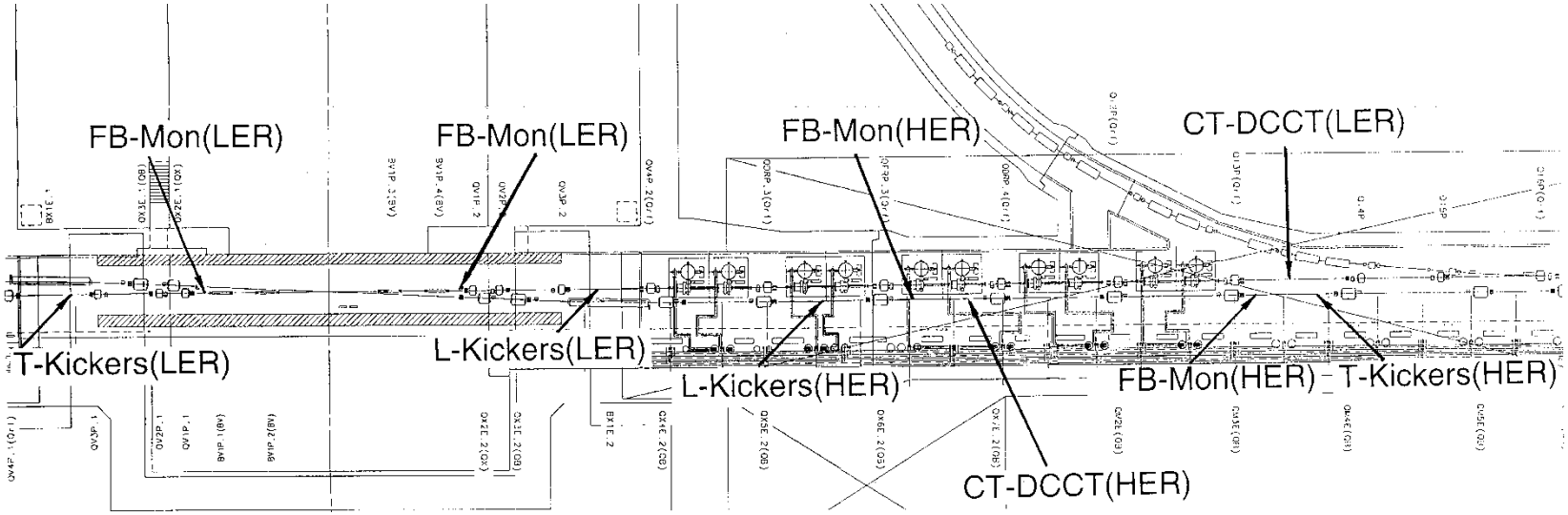
SuperKEKB Transverse Bunch Feedback System

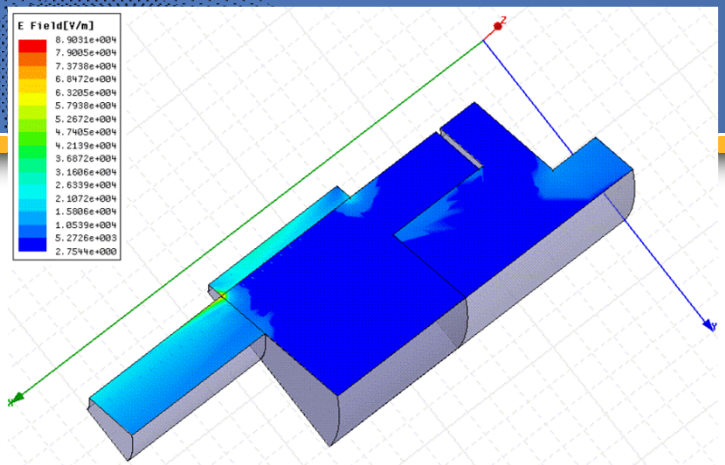
SuperKEKB Longitudinal FB plan



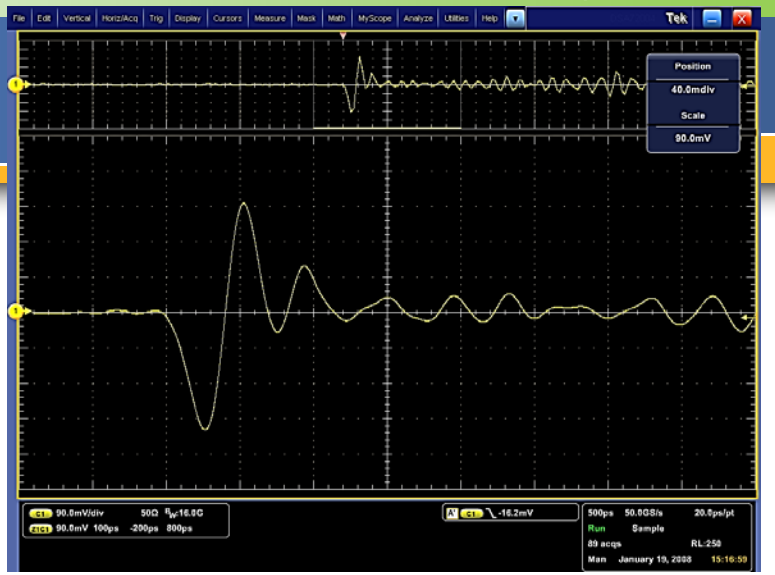
SuperKEKB Longitudinal Bunch Feedback System

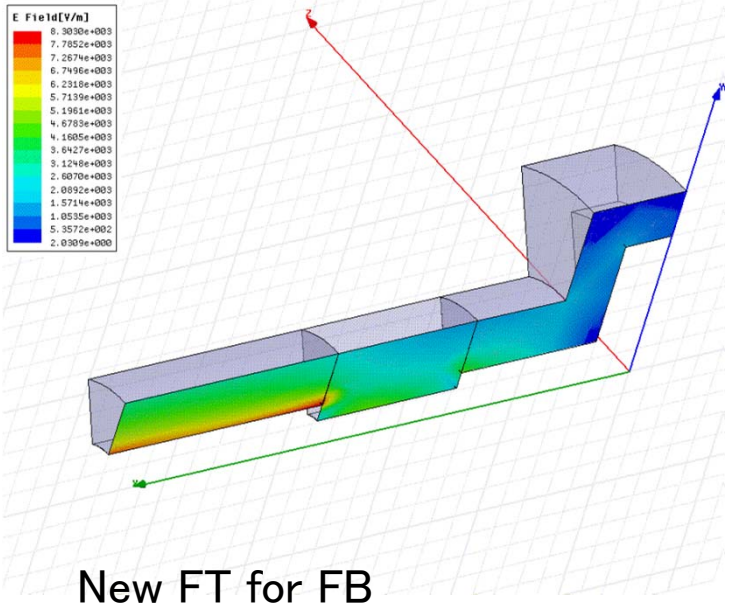
Placement of BxB FB (Fuji)



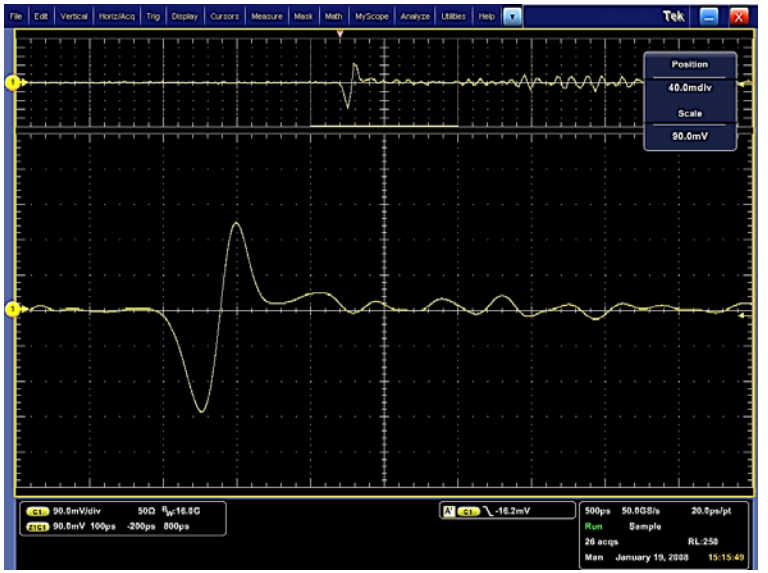


Present feedthrough for FB



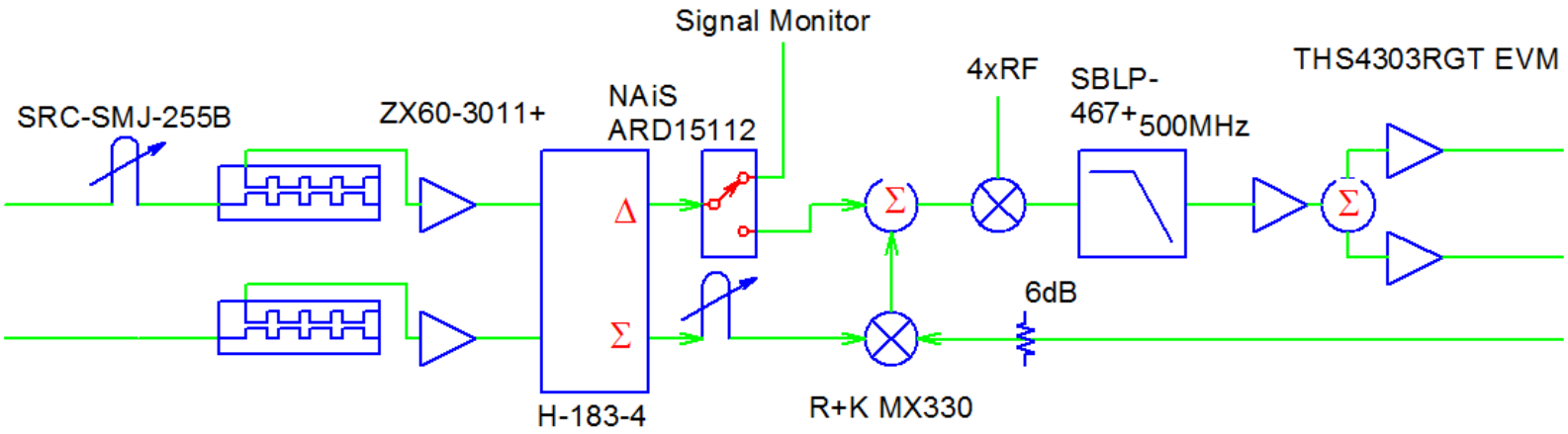


New FT for FB

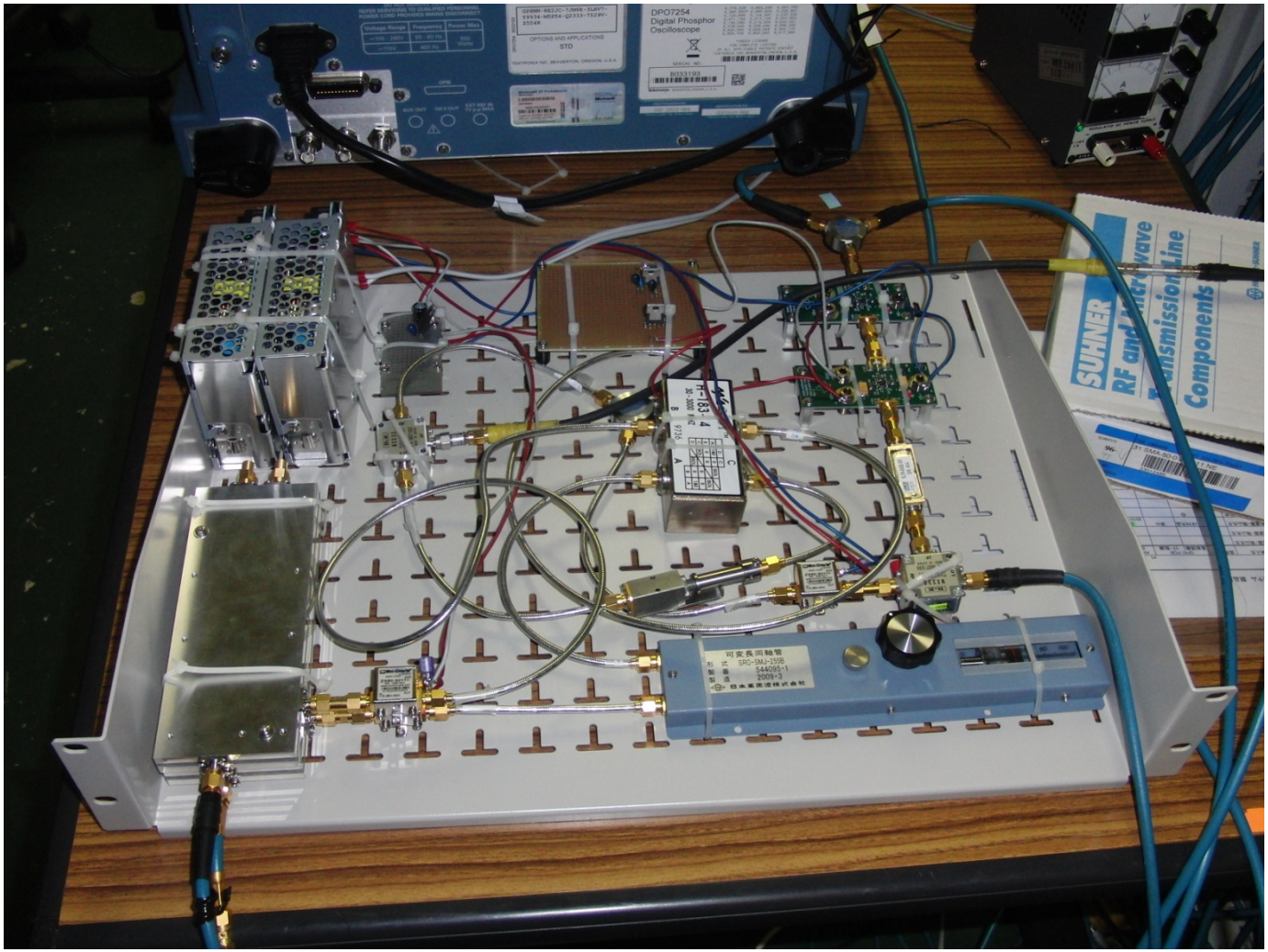


Bunch position detector

- Comb filter (fc=2GHz, or 2.5GHz, or 3GHz)
- Low noise, high isolation
- DC-coupled amplifiers



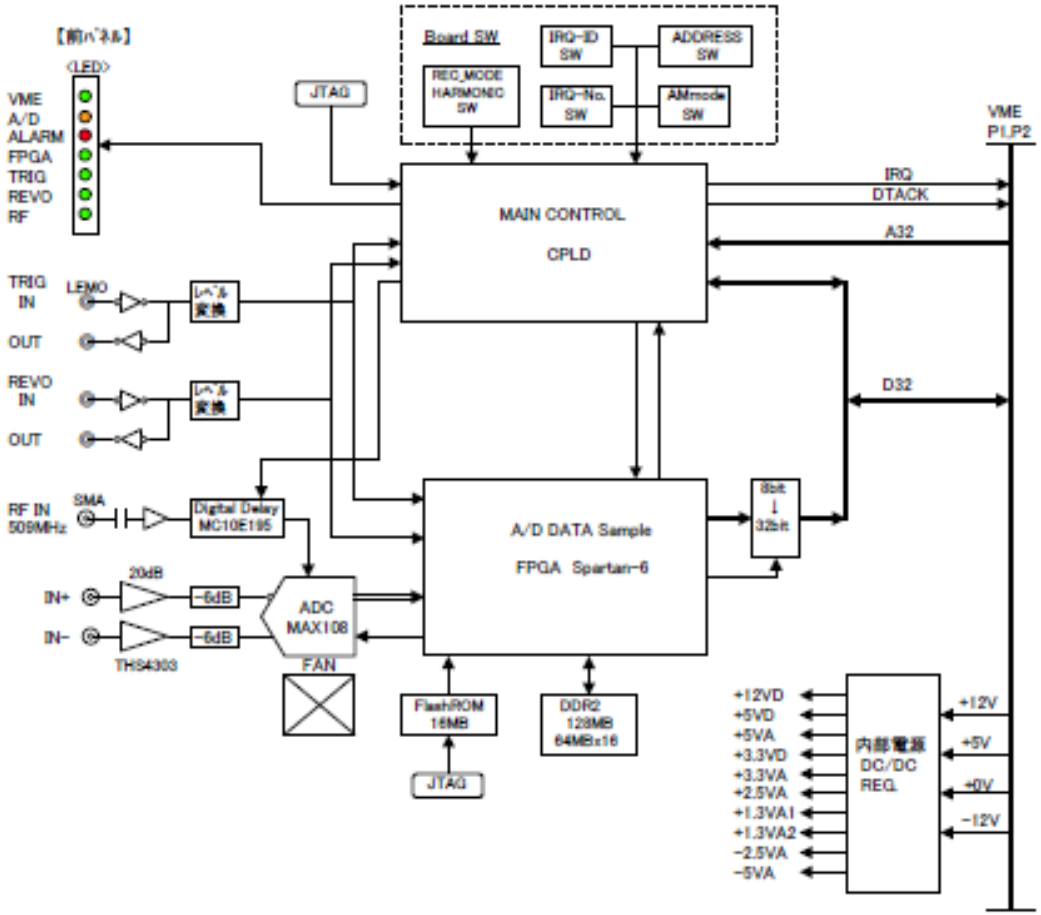
Bunch position detector



Digital filter

- **We have six iGp8**
  - two of them will be used for damping ring FB.
- **We’ve bought two iGp12 for evaluation:**
  - 8 tap FIR max. Should be enough for SuperKEKB transverse feedback system.
  - Might consider to replace FPGA by the largest one to realize much longer tap (32 tap?) for SuperKEKB longitudinal feedback.

Bunch current monitor



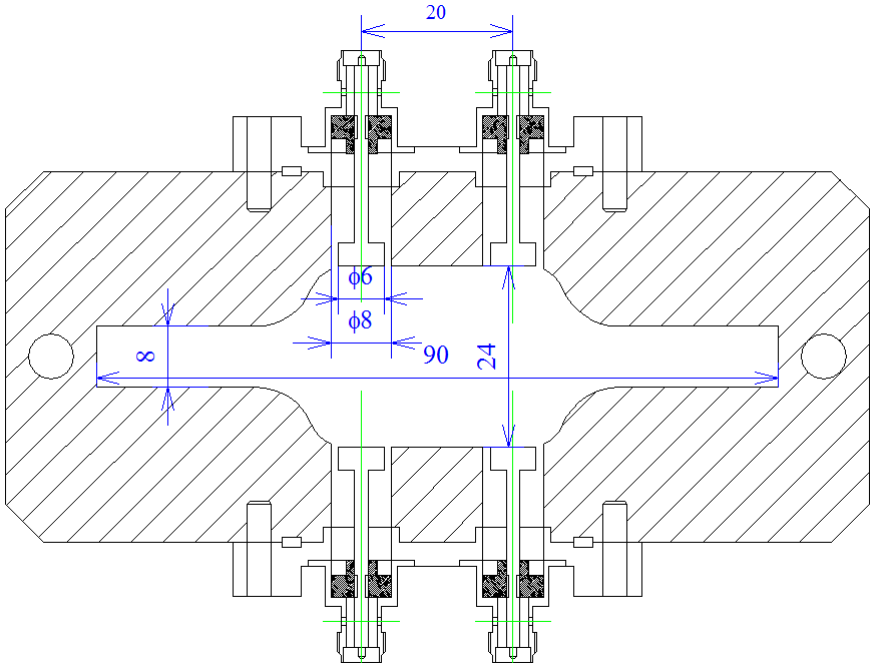
SO-DIMM type FPGA(SP6-LX45)

http://www.enclustra.com/en/products/fpga-modules/mars-mx1/

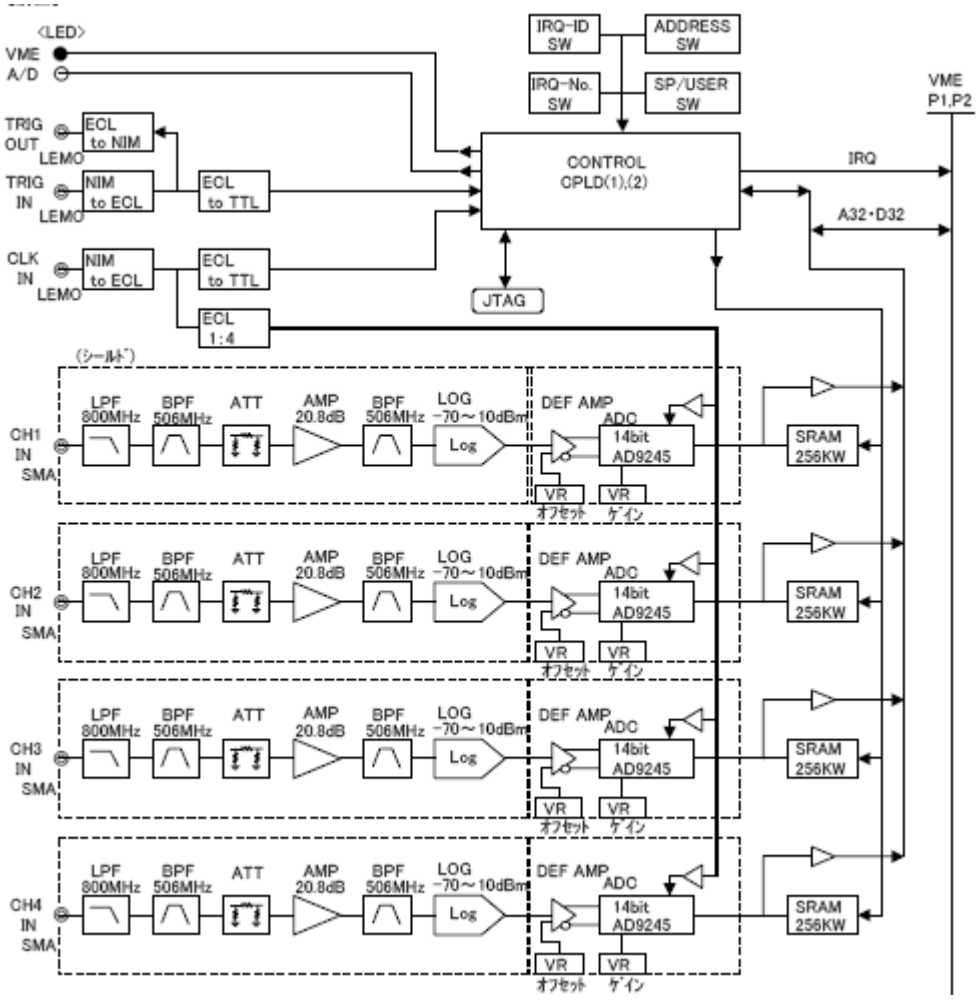
Beam instrumentation for DR

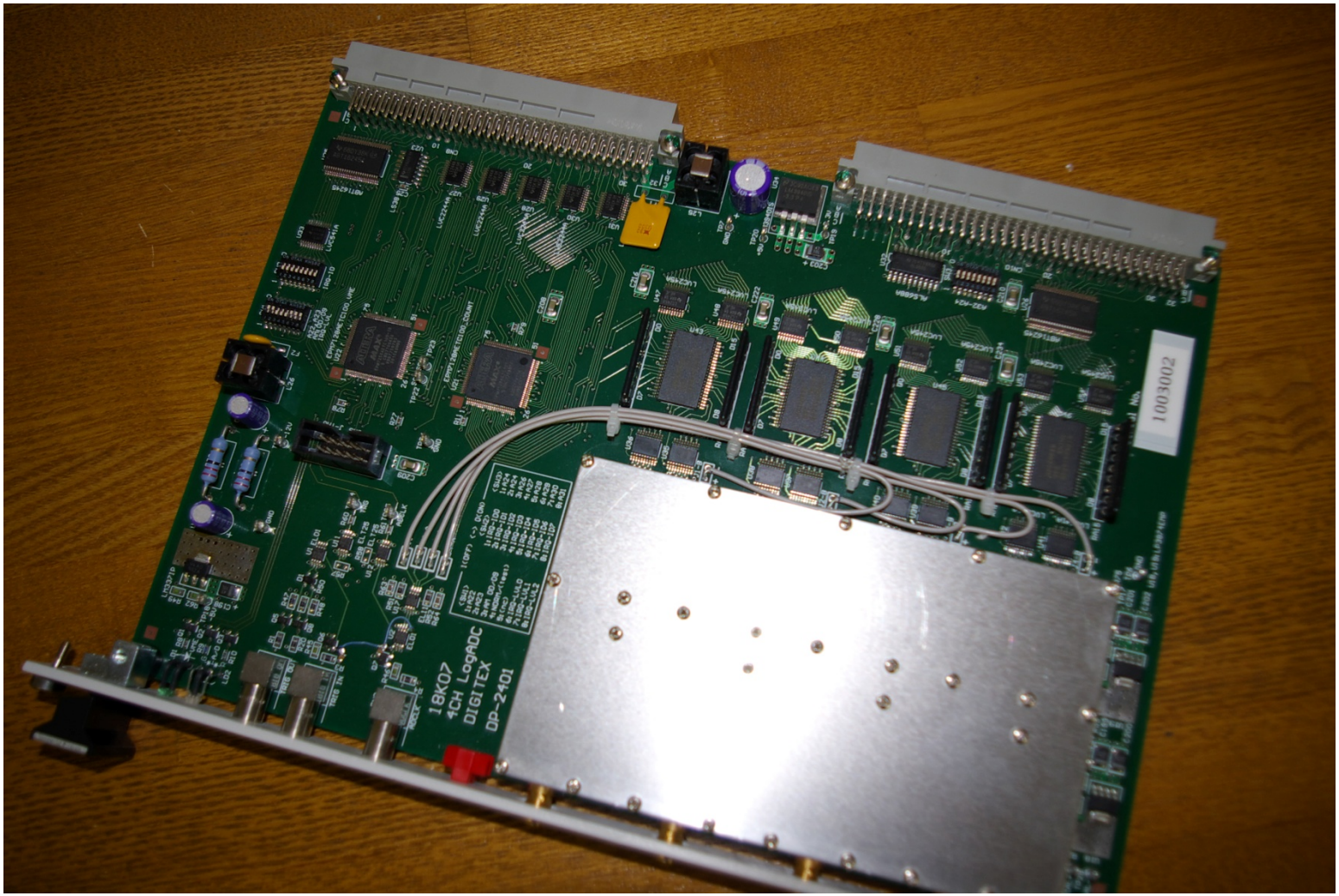
- BPM : 84
- DCCT
- SR monitor (beam size, bunch length)
- Beam loss monitor
- Bunch-by-bunch feedback system (to damp the residual kick of the extraction/injection kickers)
- Bunch current monitor
- Betatron tune monitor

BPM chamber

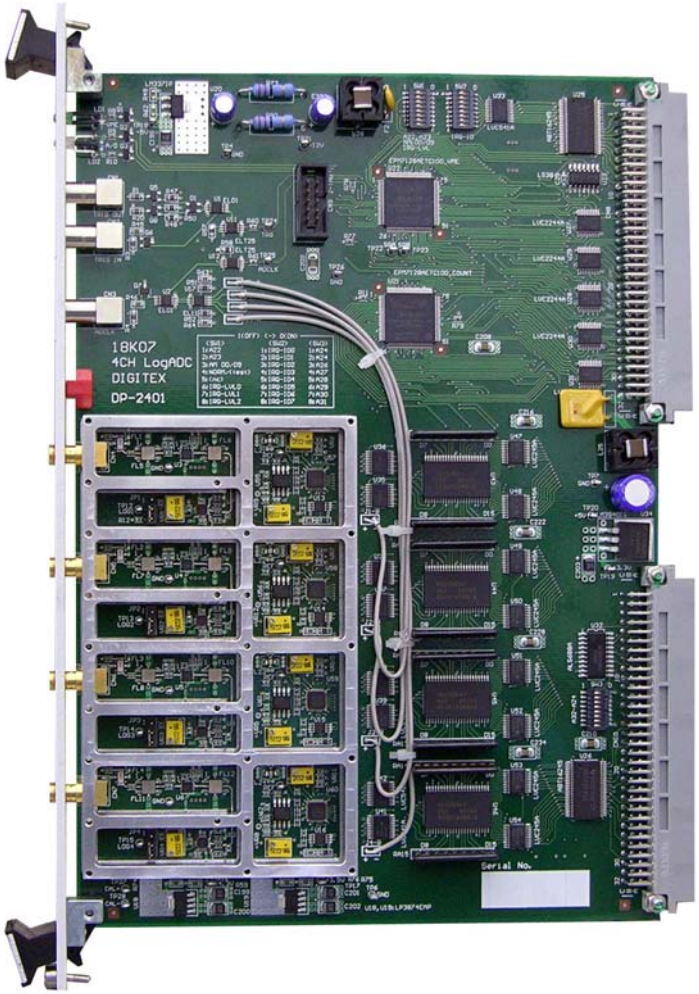


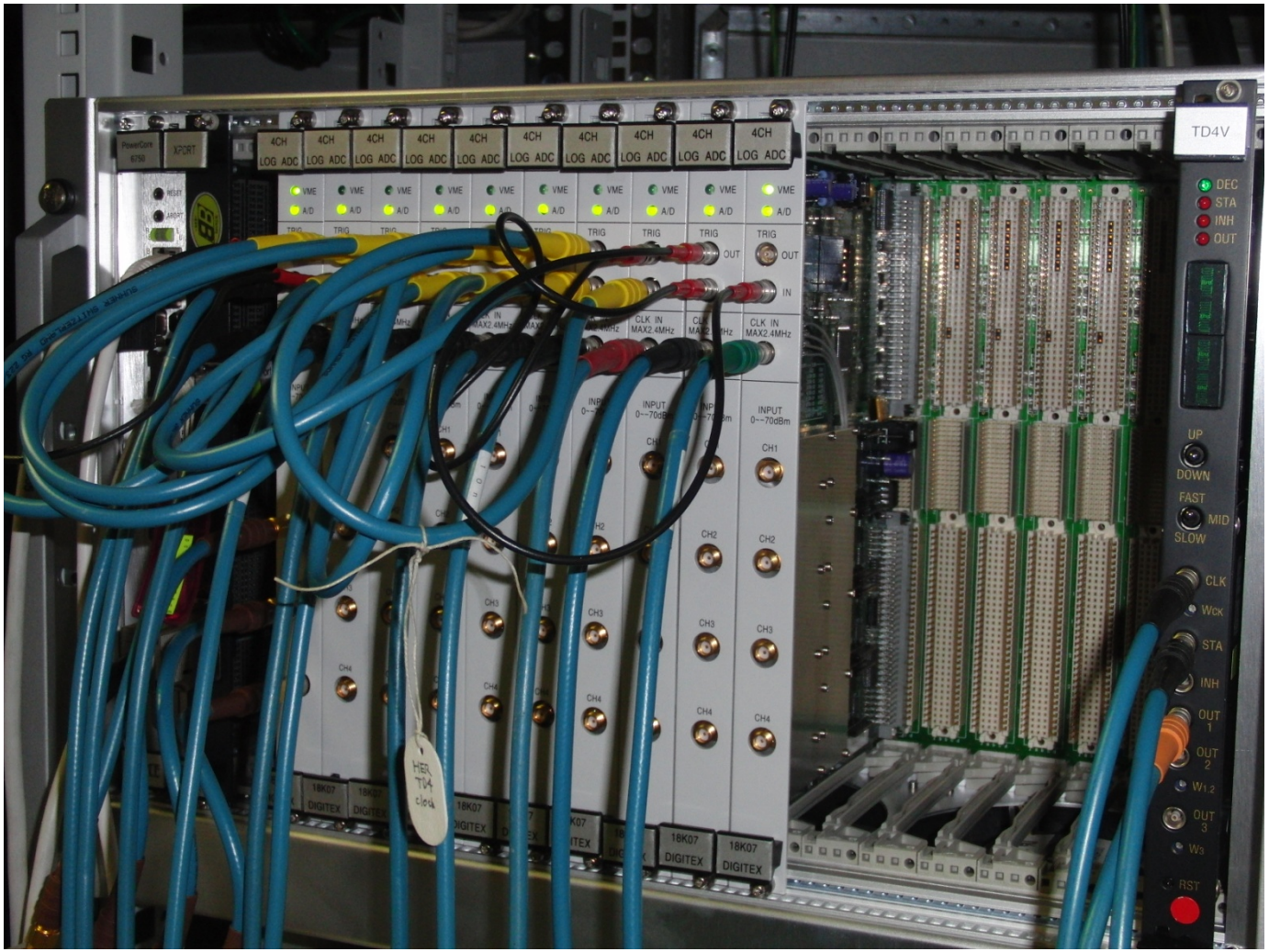
4ch L/R detector (VME)



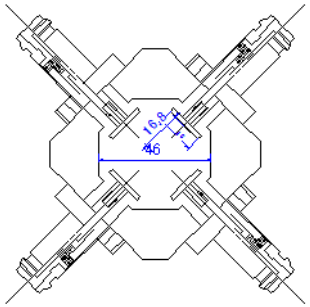

18K07
4CH LogADC
DIGITEX
DP-2401
1003002

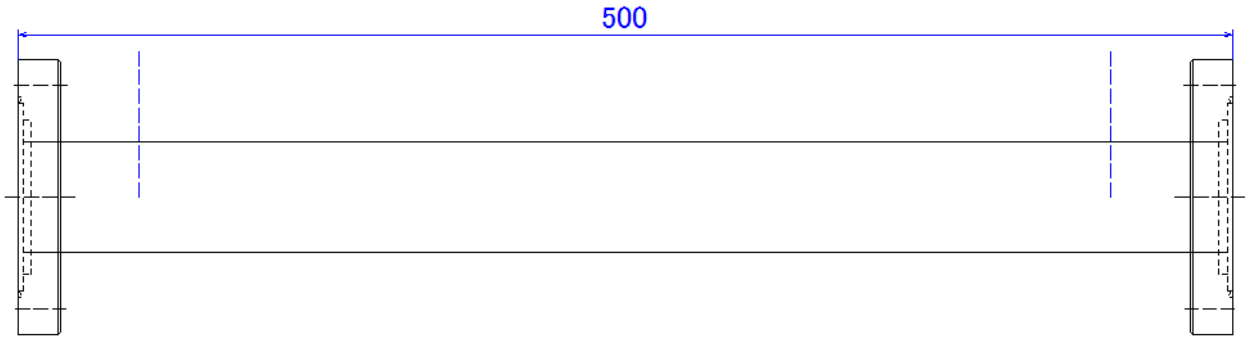

4CH
LOG ADC
VME
A/D
TRIG
OUT
IN
CLK IN
MAX2.4MHz
INPUT
0--70dBm
CH1
CH2
CH3
CH4
18K07
DIGITEX

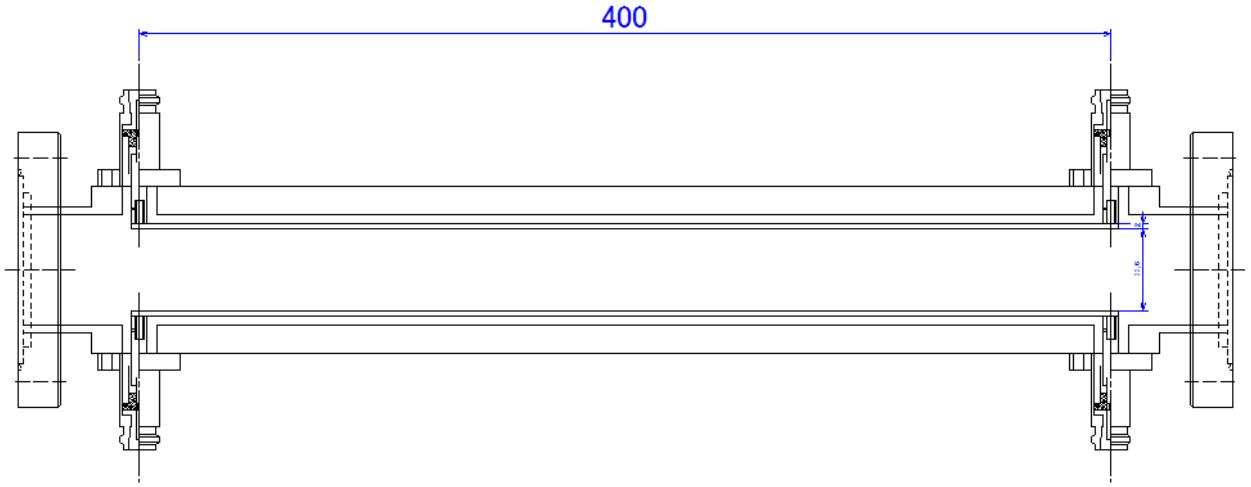

18K07
4CH LogADC
DIGITEX
DP-2401


TD4V
4CH LOG ADC
DEC
STA
INH
OUT
UP
DOWN
FAST
MID
SLOW
CLK
Wck
STA
INH
OUT 1
OUT 2
W1,2
OUT 3
W3
RST
18K07 DIGITEX

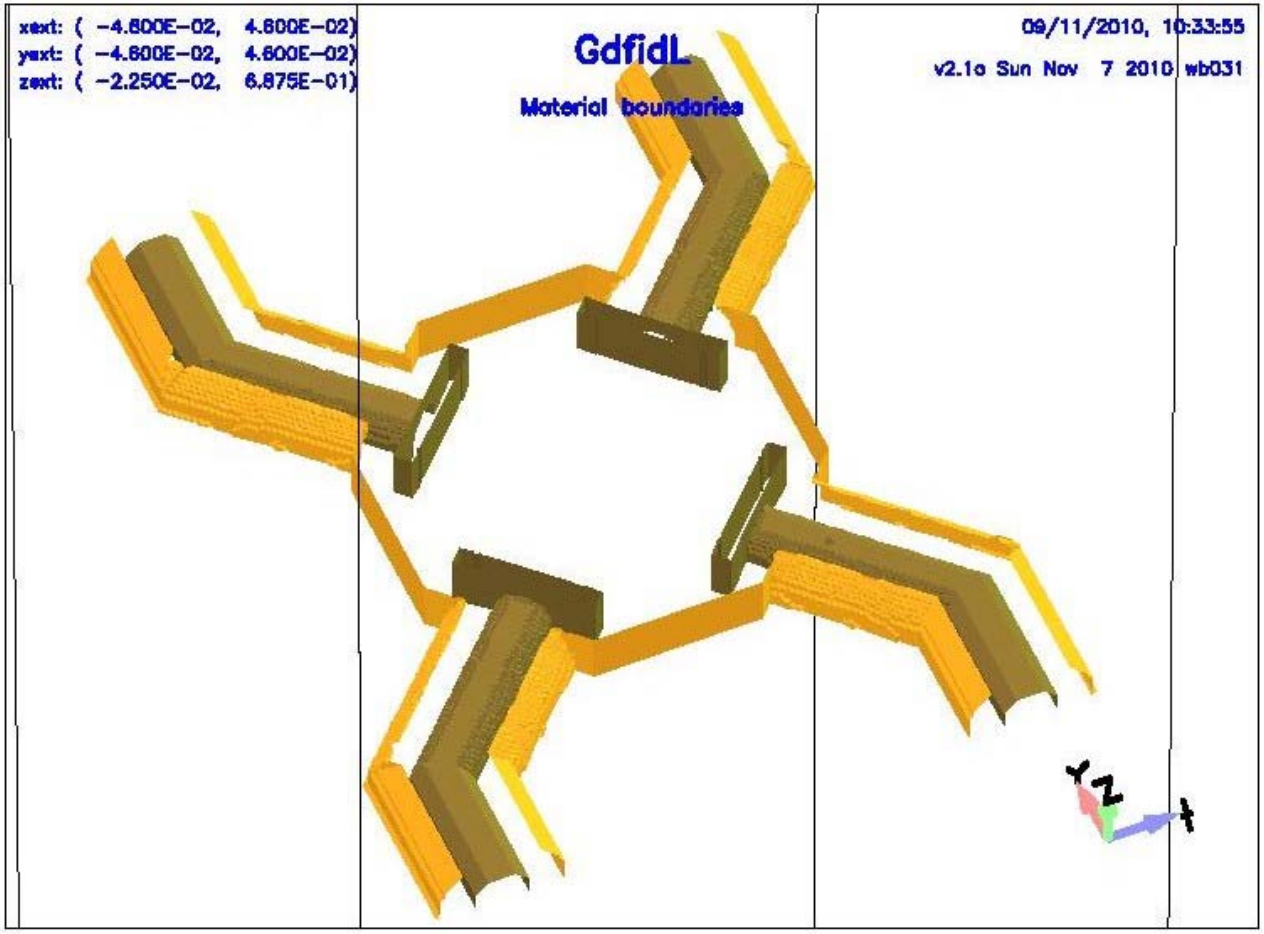
FB-Kicker







1/1 model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yext: (-4.600E-02, 4.600E-02)
zext: (-2.250E-02, 6.875E-01)
GdfidL
Material boundaries
09/11/2010, 10:33:55
v2.1c Sun Nov 7 2010 wb031
Y
Z

Schedule

- **BPM heads**
  - 1/2 of necessary BPM is under production. The rest will be fabricated on the next FY.
- **508MHz narrowband detector (VXI)**
  - Final tuning in progress
  - Mass production will be start on next fiscal year
- **Gated turn-by-turn monitor**
  - Prototype test in progress
  - 2nd trial might be needed
  - Waiting for the decision of the optics group for the place (and the total number) of the monitor

Schedule (cont.)

- **Fast orbit feedback**
  - Detector: 2nd trial-set will be ready soon.
  - Feedback processor unit will also be ready soon.
  - Simulation work using Simulink/Matlab is in progress.
  - Will also test Libera Brilliance+ (with orbit feedback unit).
- **X-ray size monitor and Beammstrahlung monitor**
  - Progressing under US-Japan collaboration (Cornell U., U. Hawaii, PNNL, Wayne state U.)

Schedule (cont.)

- **Bunch by bunch feedback**
  - Feedthoughs (button, high-power feedthroughs) will be delivered soon.
  - Need to wait for the decision of the chamber structure around the feedback systems.
  - Additional iGp12 will be ordered in next FY.
- **Damping ring**
  - Engineering works started (tunnel digging, power supply buidlings)
  - Mass production after decision of vacuum chamber (after estimate of CSR effects)