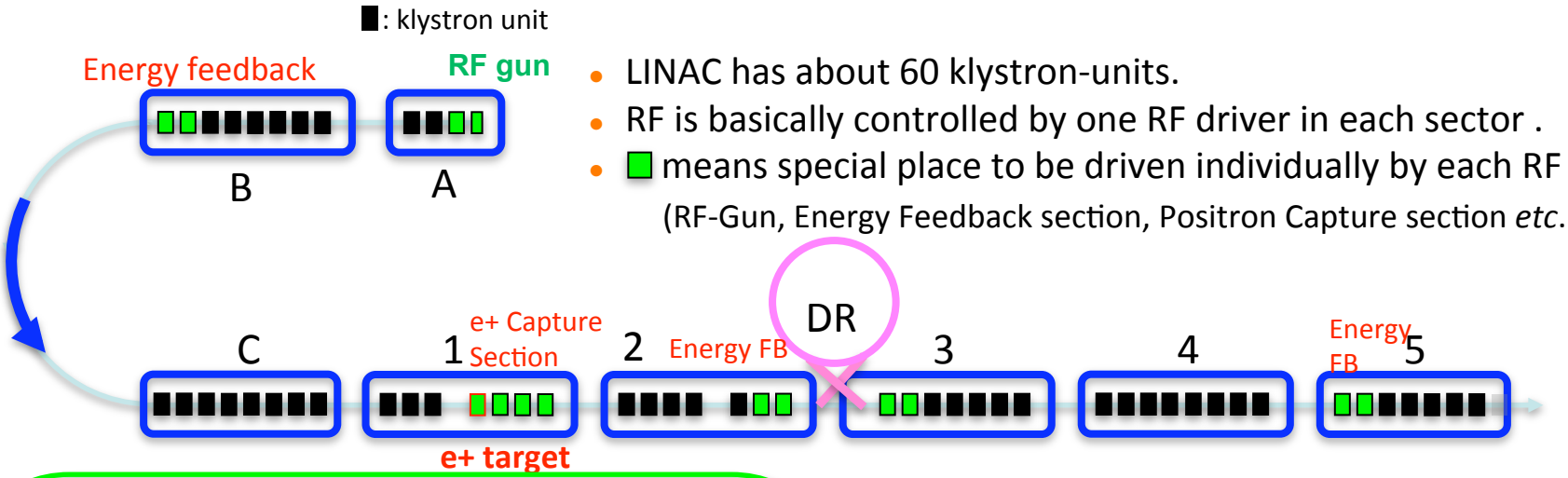
Low Level RF Development in e-/e+ Injector-LINAC

○Takako Miura, Hiroaki Katagiri, Shinichiro Michizono, Yoshiharu Yano

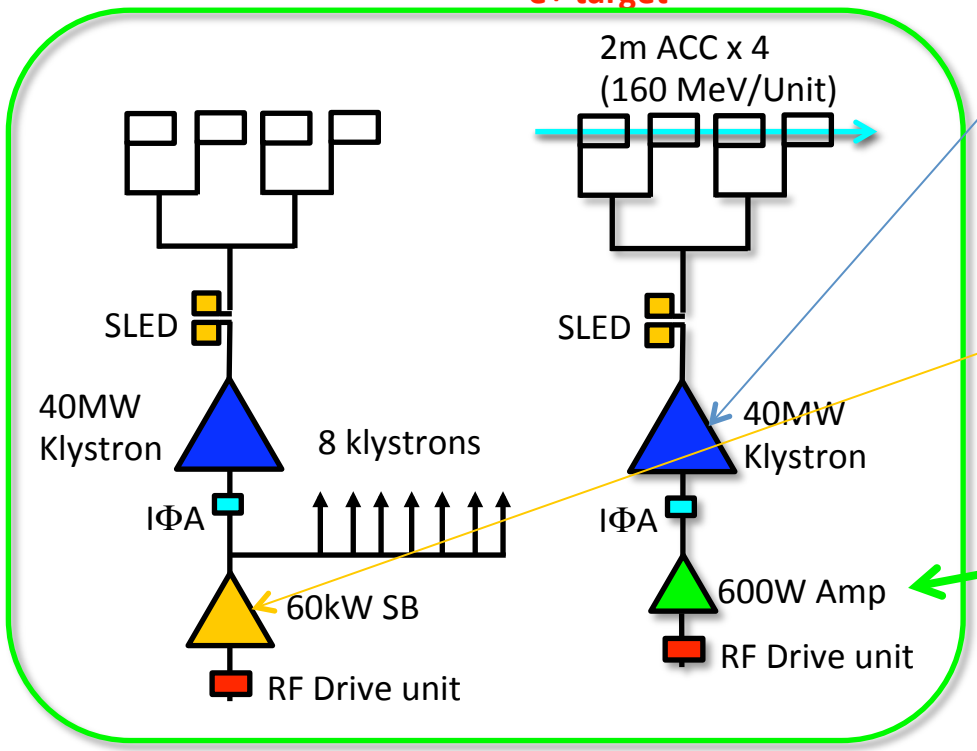
Contents

1. Overview of LINAC RF System
2. Estimation of LINAC RF Stability
3. Design of new RF DRIVER & RF MONITOR
4. Performance
5. Schedule

Introduction of LINAC RF System



- LINAC has about 60 klystron-units.
- RF is basically controlled by one RF driver in each sector .
- ■ means special place to be driven individually by each RF driver.
  (RF-Gun, Energy Feedback section, Positron Capture section *etc.*)

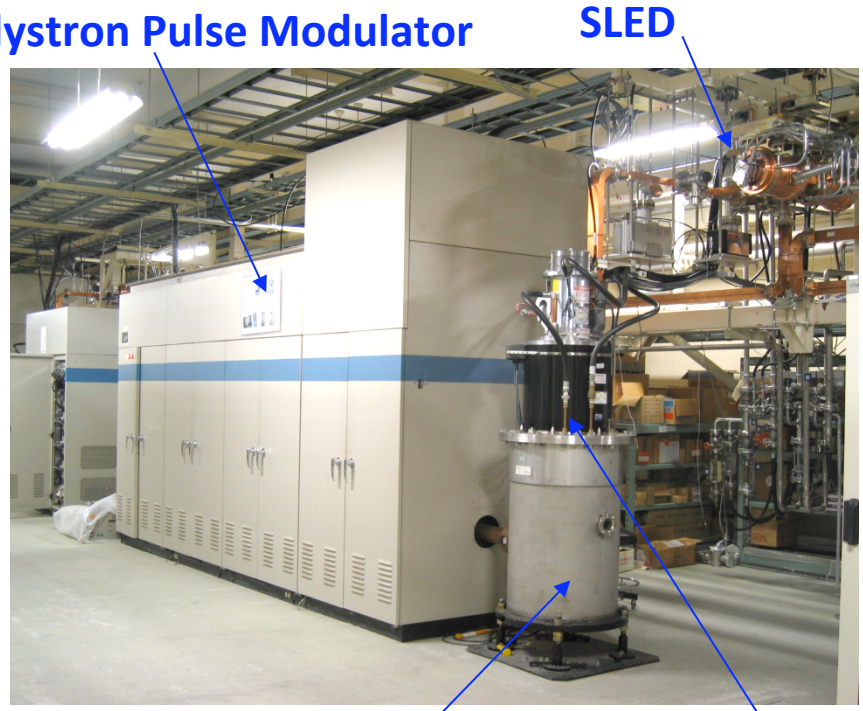


40 MW klystron feeds RF to 4 accelerating cavities. Acceleration gain is ~160 MeV per unit.

60 kW sub-booster klystron(SB) is installed in each sector as a driver amp.
1 SB drives max. 8 high power klystrons.

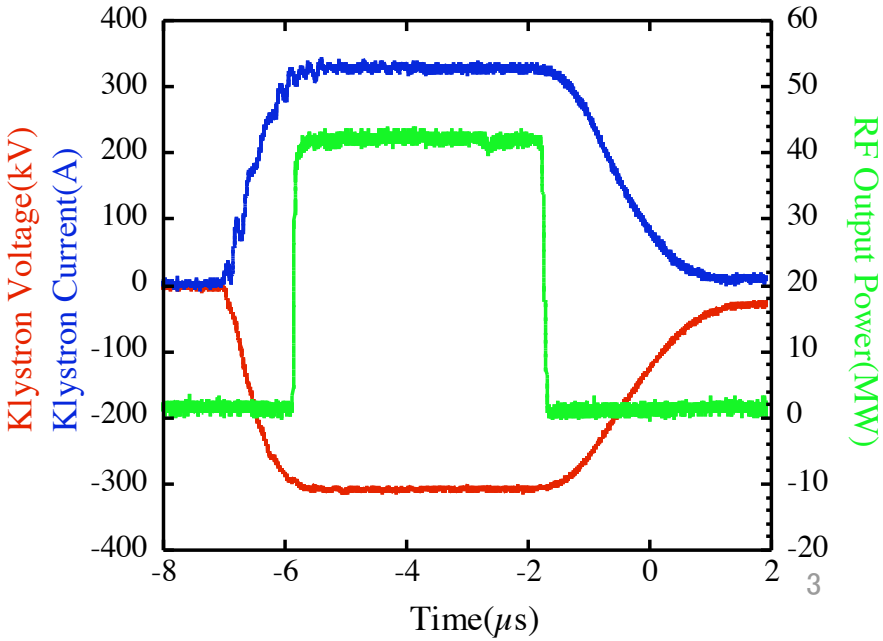
In the place to need to change RF phase individually, 600W solid state amp(SSA) has been installed per one unit.

High Power RF Source



Klystron Specifications

RF frequency	2856 MHz
RF pulse width	4 μs
Typical output power	40 MW
Perveance	2.1 $\mu A/V^{3/2}$
Beam Voltage	300 kV
Repetition Rate	50 Hz
efficiency	45 %



Estimation of RF Stability

< RF stability of Klystron>

Stability of Klystron High Voltage: $\Delta V/V$ (%)= 0.3 % p-p
(0.05% rms)

⇨ RF variation due to high voltage jitter per klystron:

Amplitude stability $\Delta A/A$(%)= 5/4 $\Delta V/V$(%)= 0.063% rms

Phase stability :$\Delta\theta$= -4deg*Δ V/V(%)= -/+0.2deg rms (from -4deg/%)

⇨ $\Delta V_{acc}/V_{acc}$ (%)=0.12 % rms at -10deg off-crest
0.15 % rms at -15deg off-crest

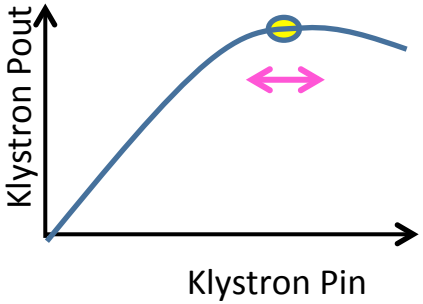
K(Perveance) = $I/V^{3/2}$
$P = \eta IV = \eta KV^{3/2}V = \eta KV^{5/2}$.
$\Delta P/P = 5/2\ \Delta V/V$.
$\Delta E/E = 5/4\ \Delta V/V$ $\leftarrow (E \propto \sqrt{P})$

$\cos(\theta\downarrow 0) - (1+\Delta V/V)\cos(\theta\downarrow$

Assuming there is no correlation to jitter between power supplies,
error of total energy is compressed to $1/\sqrt{N}$. (N : number of klystrons)

e.g. e-: N=50 -> δ=0.15/$\sqrt{50}$ =0.021% rms@ -15 deg off-crest
e+: N=30 -> δ=0.15 /$\sqrt{30}$ =0.033% rms@ -15 deg off-crest

<RF error caused by Low Level RF>



RF saturation point of klystron is adopted as RF operation point.

Input RF amplitude fluctuation becomes insensitive .

Phase jitter $\Delta\theta$ of input RF ~ 0.1deg rms per RF Drive Unit.

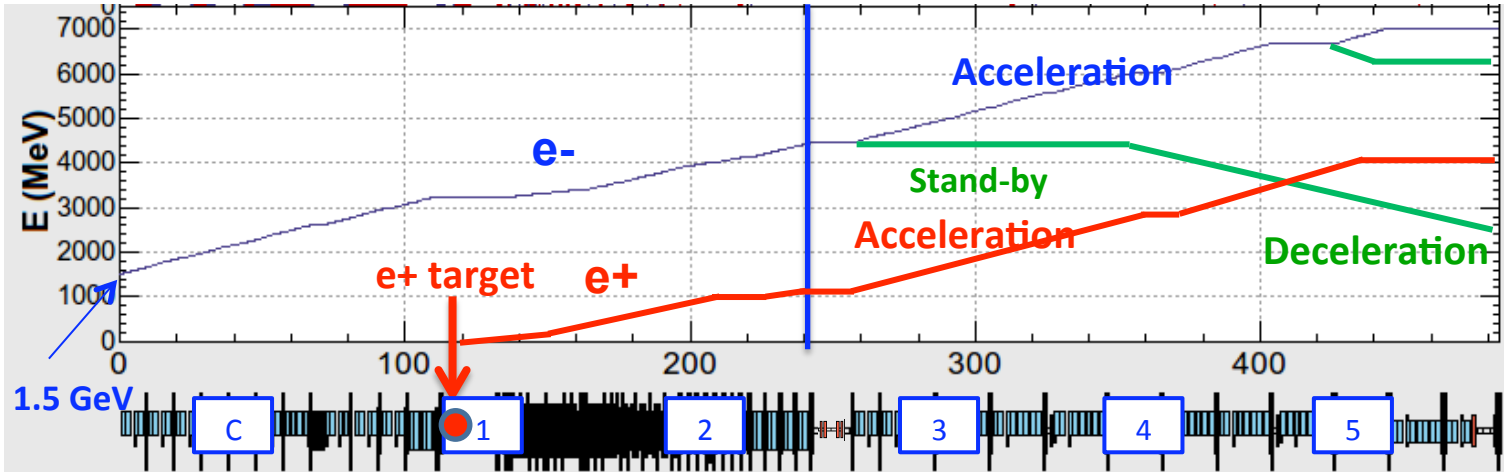
e.g. e-: N=8 -> δ=0.045/$\sqrt{8}$ =0.016% rms@ -15 deg off-crest
e+: N=4 -> δ=0.045 /$\sqrt{4}$ =0.023% rms@ -15 deg off-crest

Estimation : Error caused by RF system: 0.026 % rms for e- @ -15deg off-crest
0.040 % rms for e+ @ -15deg off-crest

Requirement of beam energy spread for SuperKEKB: 0.08% rms.

Towards 4-Ring Simultaneous Injection

Injector-LINAC provides the beams to 4-different rings with different energies.



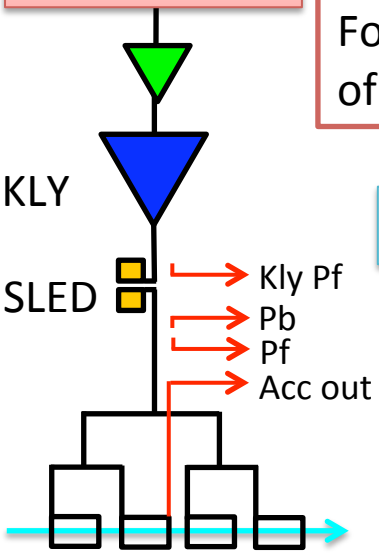
HER: 7 GeV e-

AR: 6.5 GeV e-

LER: 4 GeV e+

PF: 2.5 GeV e-

RF Drive Unit



RF phase change is necessary according to the "Beam Mode" in 50 Hz. For high stability, RF modulation timing should be synchronize the clock of "Timing System" (114.24 MHz).

RF Monitor

Data taking and identification of "Beam Mode" in 50 Hz are necessary.

Development of new RF Drive Unit & RF Monitor

IQ digital control

IQ Modulator / IQ Demodulator

I ⇕ Q

ADC/DAC

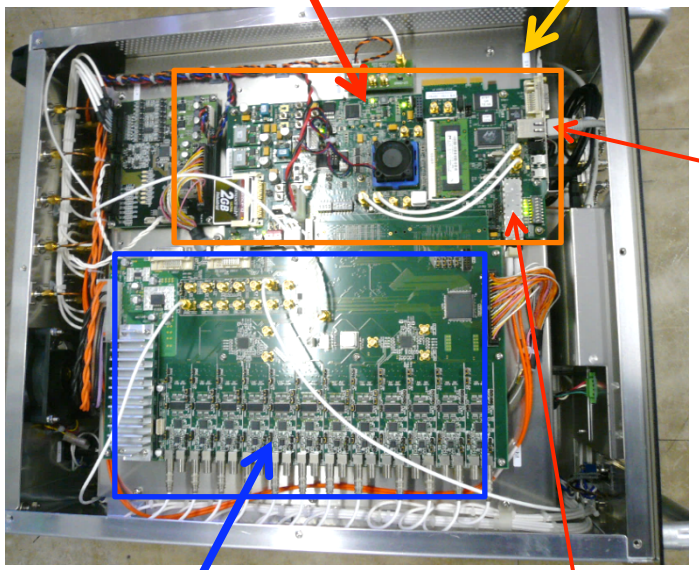
Digital processing with “FPGA”

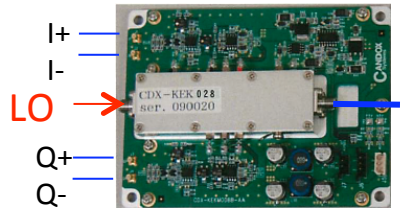
Touch panel

Common design is adopted

Xilinx ML605 FPGA evaluation board

IQ-modulator or IQ-demodulator are mounted on rear side.





Ethernet

Data are sent to EPICS IOC server

Parameter setting is possible from front touch panel.

14bit ADC/DAC board
Clock : 114.24 MHz

Sampling clock synchronize to “Event Timing System”

SFP Optical Transceiver

Reception of Event mode and phase information from event generator

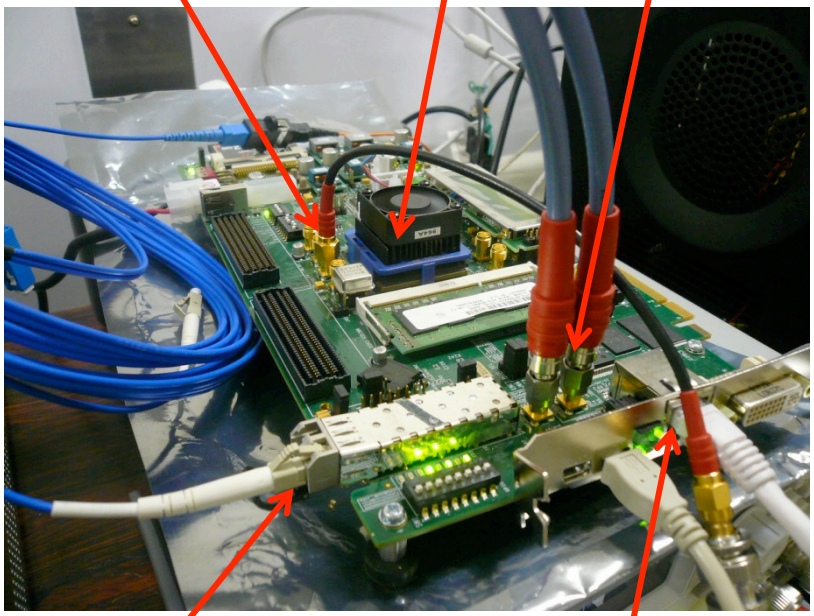
Reception Test of Event Data

ML605 Xilinx FPGA board

114.24 MHz reference clock of Event System

Input 50-Hz Trigger

FPGA



SFP(Optical Transceiver)
Serial signal of 2GHz
Event data are sent from Event-Generator via optical fiber

GbE
Data is sent to a server using GbE via SiTCP

Receive of beam mode and phase from "Event System" has been confirmed.

Mode : PFe- 2Hz

50 Hz counter

Event code obtained

1	182	26	182
2	182	27	182
3	182	28	182
4	52	29	52
5	182	30	182
6	152	31	152
7	182	32	182
8	182	33	182
9	182	34	182
10	182	35	182
11	182	36	182
12	182	37	182
13	182	38	182
14	182	39	182
15	182	40	182
16	182	41	182
17	182	42	182
18	182	43	182
19	182	44	182
20	182	45	182
21	182	46	182
22	182	47	182
23	182	48	182
24	182	49	182
25	182	50	182

52 : PF e-
182: No Injection Mode

Phase data taking test

SD EV DB EV	
00 00 01 00	1
00 BC 00 00	
00 00 02 00	2
00 BC 00 00	
00 00 03 00	3
00 BC 00 00	
00 00 04 00	4
00 BC 00 00	
00 00 05 00	5
00 BC 00 00	
00 00 06 00	6
~	
00 00 03 00	996
00 BC E4 00	
00 00 03 00	997
00 BC E5 00	
00 00 03 00	998
00 BC E6 00	

"2K Byte Data Buffer" is used for sending phase data information

Specification of RF Drive Unit

Functions :

1. RF Modulation
2. VSWR measurement for Klystron output
3. Fast Interlock output for Klystron protection
4. RF-monitor 1ch
5. Analog video out

Modulator specification

Setting resolution: 0.1 %, 0.1deg

Reproducibility(Accuracy of phase)

: < 0.2% rms, <0.2 deg rms

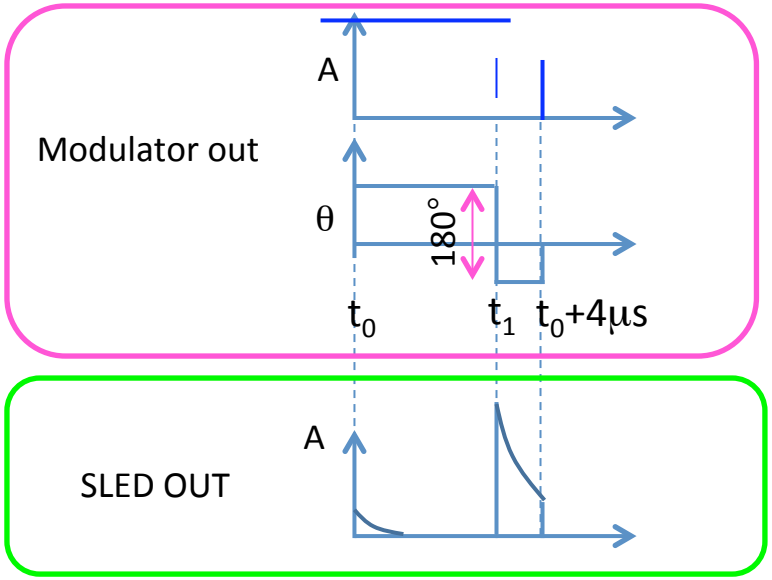
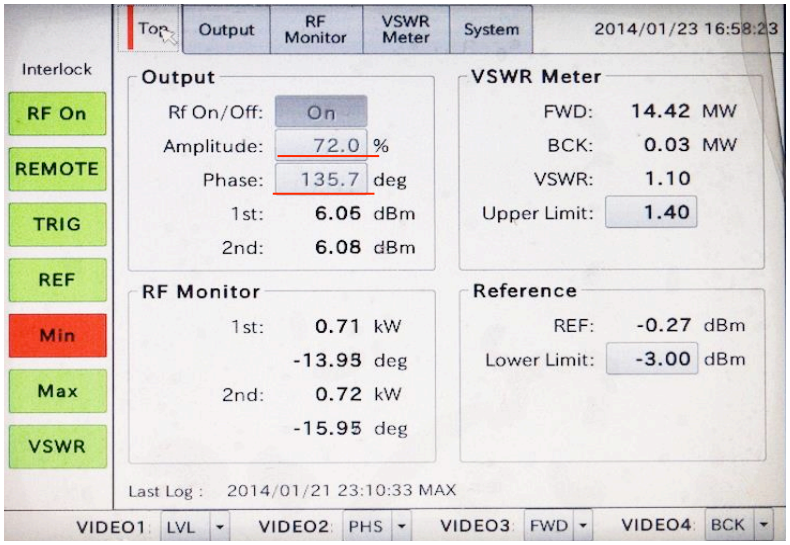
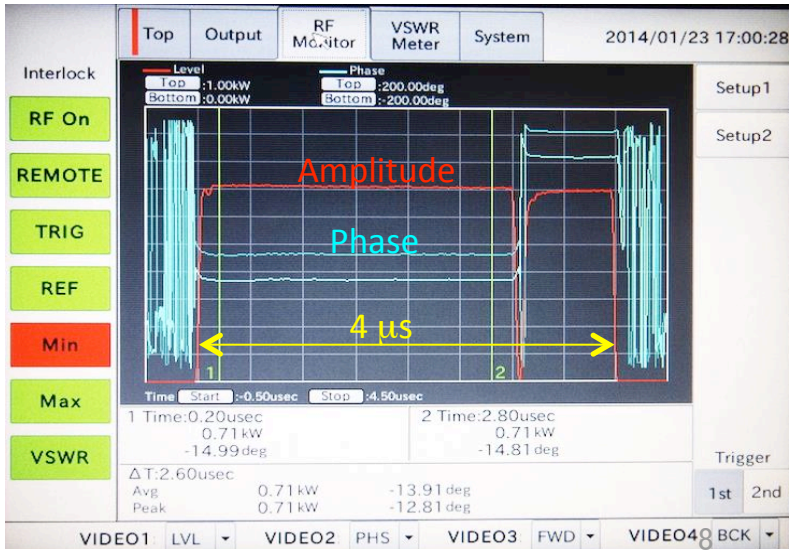


Photo of the front touch panel

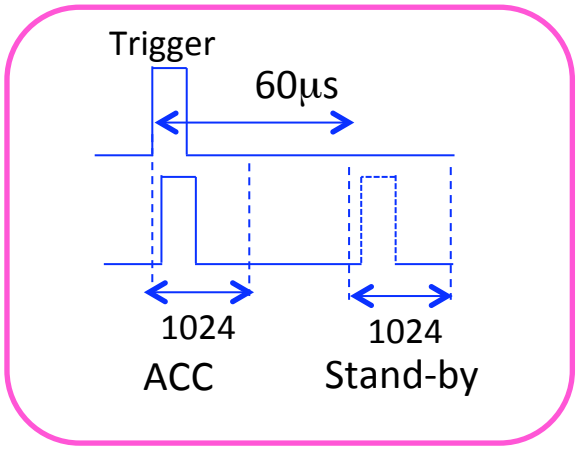




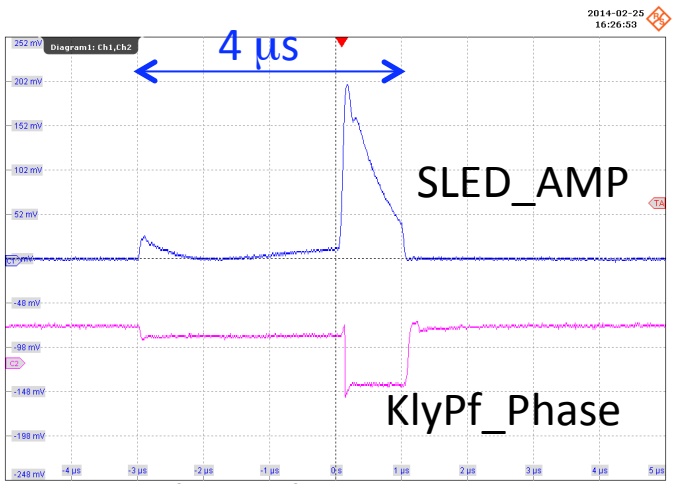
Specification of RF Monitor

	Previous RF Monitor for KEKB	RF Monitor for SuperKEKB
ADC	8 bit, 1GHz, 2 RF	14 bit, 114MHz, 5 RFs
Measurement region	< 40deg., 2μs	360deg, ACC 9μs / STB 9μs
50Hz data acquisition	NG (Max 25Hz)	OK
Identification of the events	NG	OK
Precision	0.15%rms, 0.2deg rms	0.1% rms, 0.1 deg rms

New RF-Monitor can take whole RF waveform, and can identify the event mode.



Pulse is always output in either the ACC or STB.

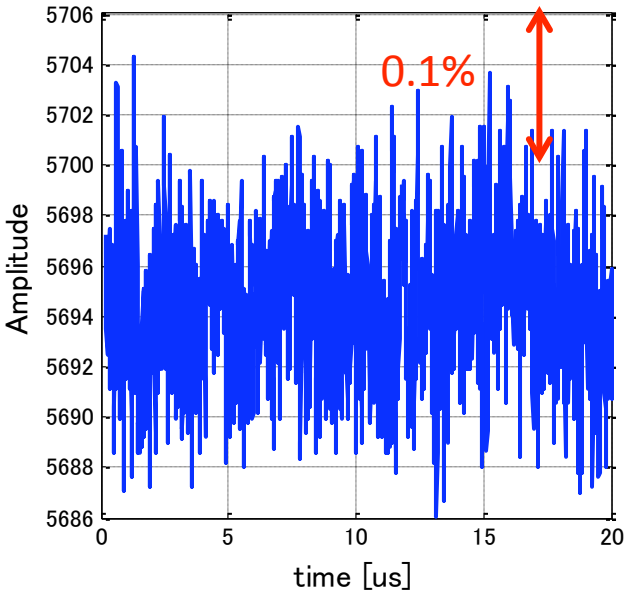


Analog video out

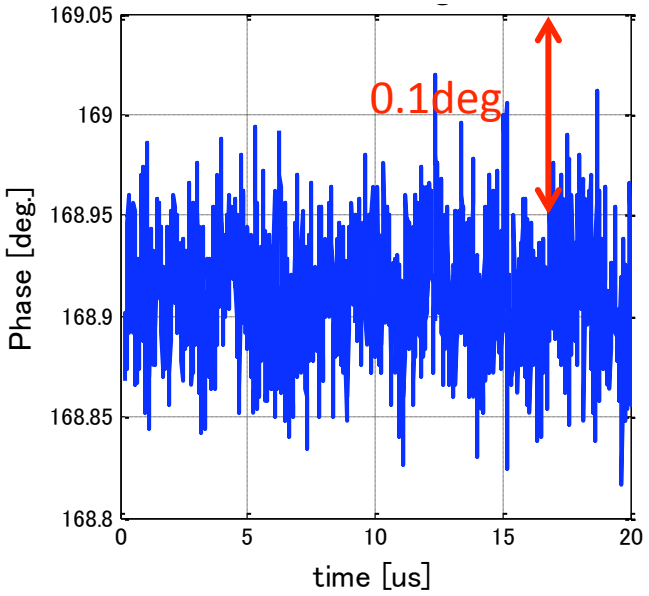
Performance of ADC board

Monitor input : CW 2856 MHz

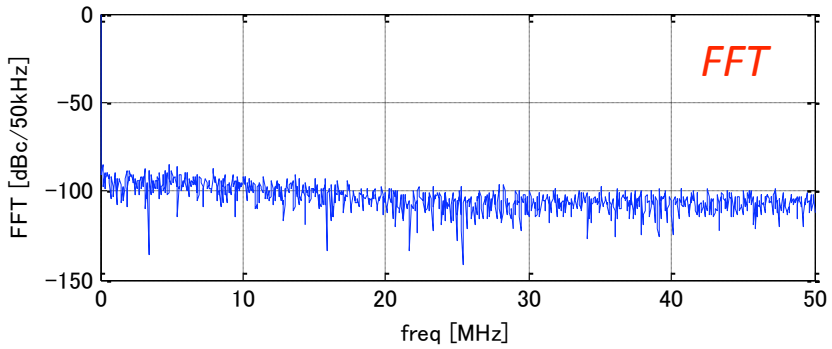
Amplitude: 0.05 % rms



Phase : 0.03 deg. rms



@100MHz sampling

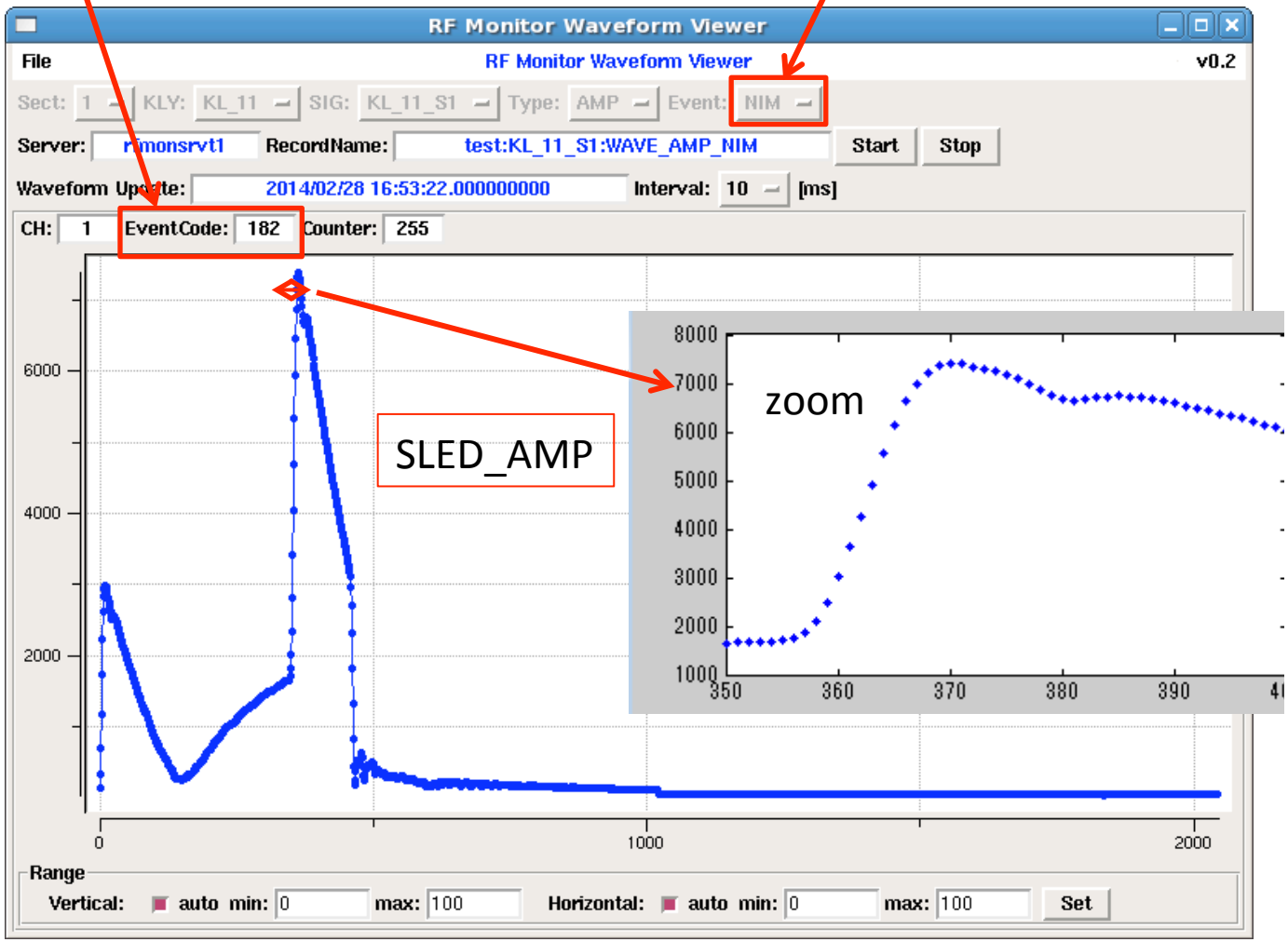


No spurious

RF Monitor Data Taking Test

Event Code=182 (No injection mode)

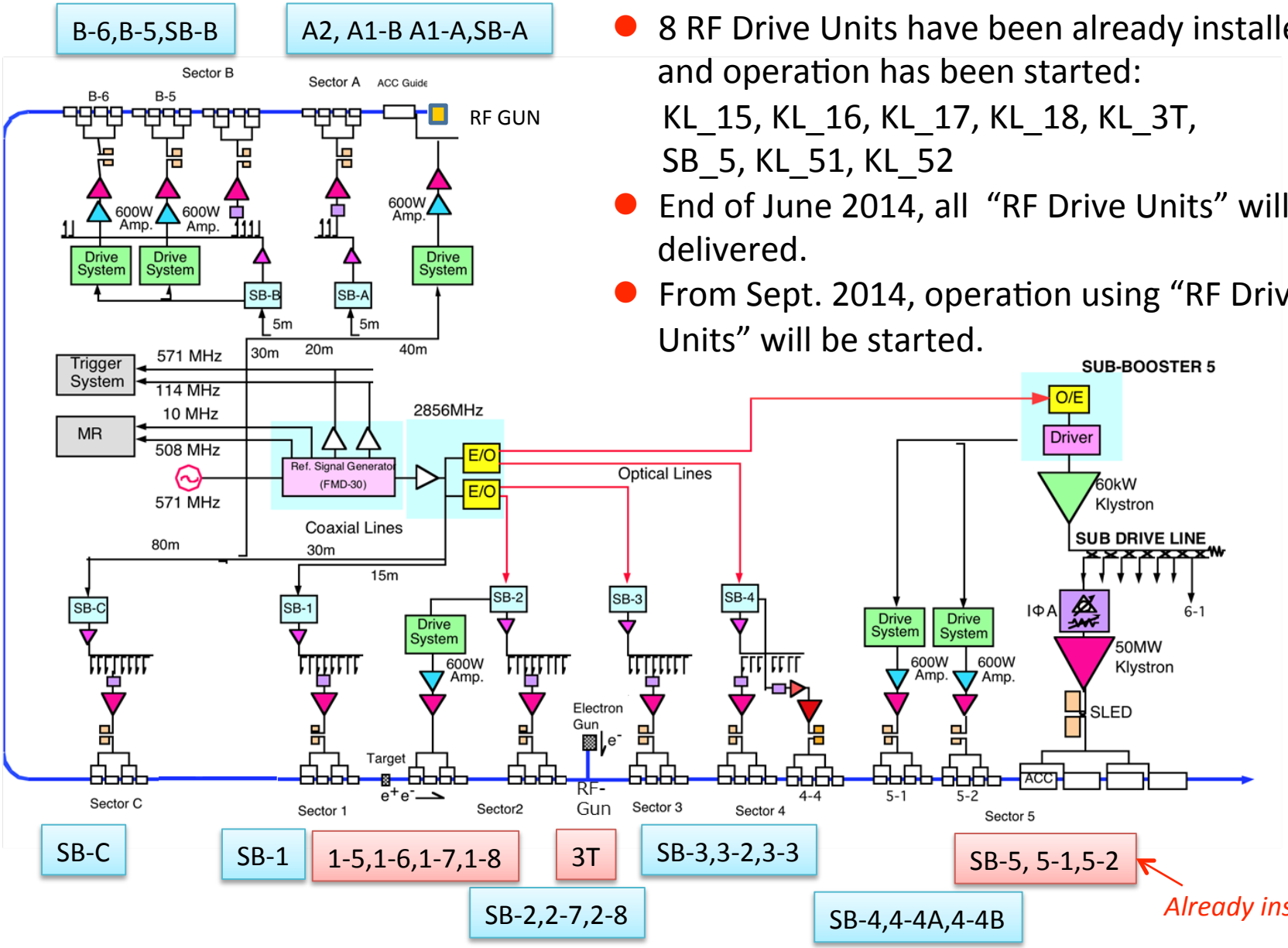
NIM: no injection mode is selected



Data taking and event mode identification has been achieved.

Data correction will be performed in PC server(EPICS IOC).

Schedule of RF Drive Unit

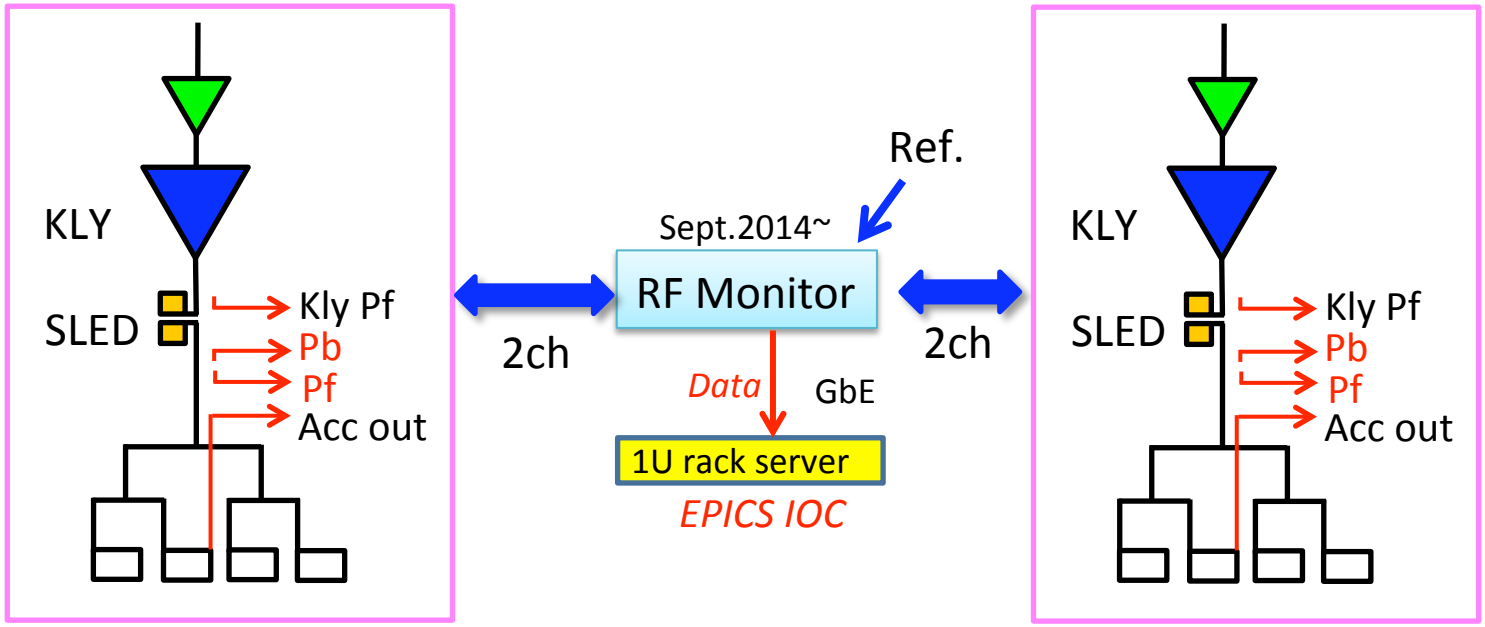


- 8 RF Drive Units have been already installed and operation has been started:
  KL_15, KL_16, KL_17, KL_18, KL_3T, SB_5, KL_51, KL_52
- End of June 2014, all "RF Drive Units" will be delivered.
- From Sept. 2014, operation using "RF Drive Units" will be started.

Schedule of RF Monitor

Total=70 set

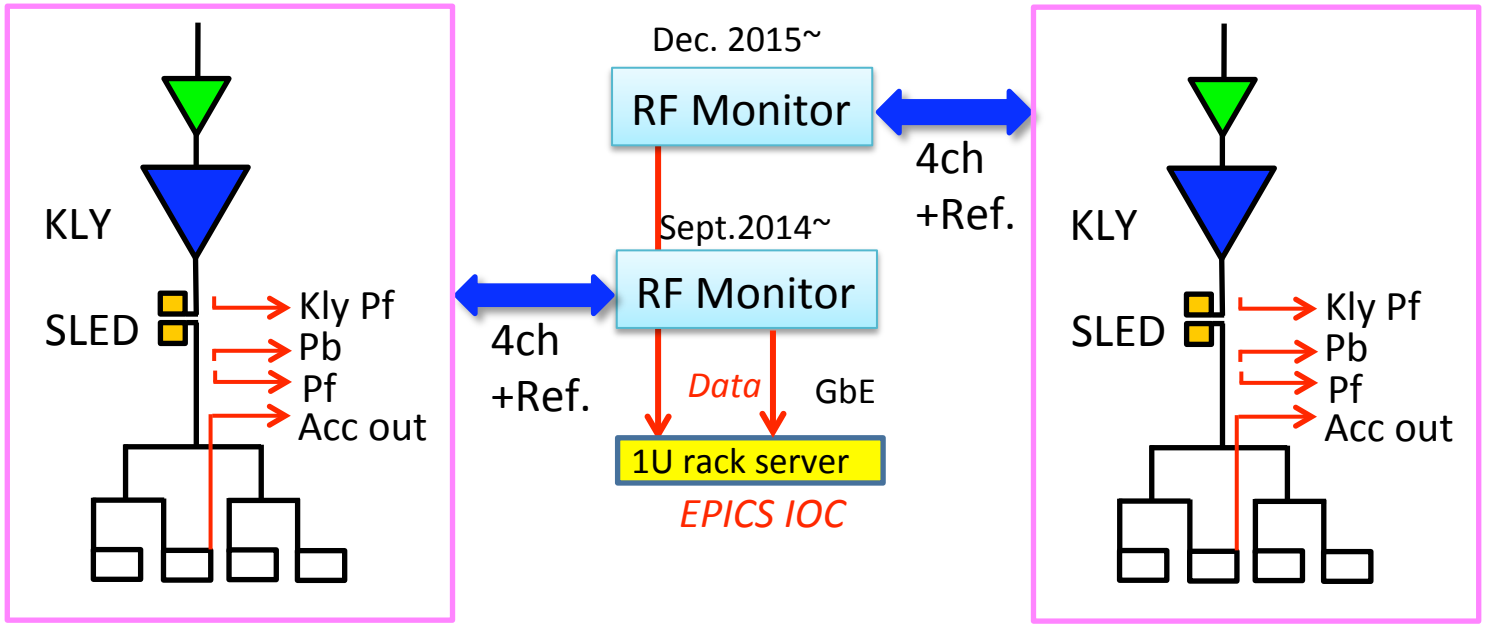
June 2014: 35 RF Monitors will be delivered.
RF Monitor will be installed per each 2-Klystron Units, respectively.
(Tentatively, whole area of LINAC will be covered.)
Sept. 2014: Operation of RF monitor system will be started.



Schedule of RF Monitor

Total=70 set

June 2014: 35 RF Monitors will be delivered.
RF Monitor will be installed per each 2-Klystron Units, respectively.
(Tentatively, whole area of LINAC will be covered.)
Sept. 2014: Operation of RF monitor system will be started.
Feb. 2015: Another 35 RF monitors will be delivered.
Dec. 2015:RF Monitor will be installed per each Klystron Unit.



Summary

New RF Drive Unit & RF Monitor have been developed for SuperKEKB.

Reception of event code and phase data from Event Generator have been tested.

Performance of ADC board was confirmed.

Data taking of RF Monitor via EPICS IOC has already performed.

About long term stability and data correction, the study has been continued.

Backup Slides

Klystron Phase Variation due to High Voltage Error

Phase changes depending on electron drift time from input cavity to output cavity of klystron.

$$m_0 \gamma c^2 = m_0 c^2 + eV$$
$$\gamma = 1 + eV / m_0 c^2$$
$$\Delta\gamma = e\Delta V / m_0 c^2 = eV / m_0 c^2 \ \Delta V / V$$

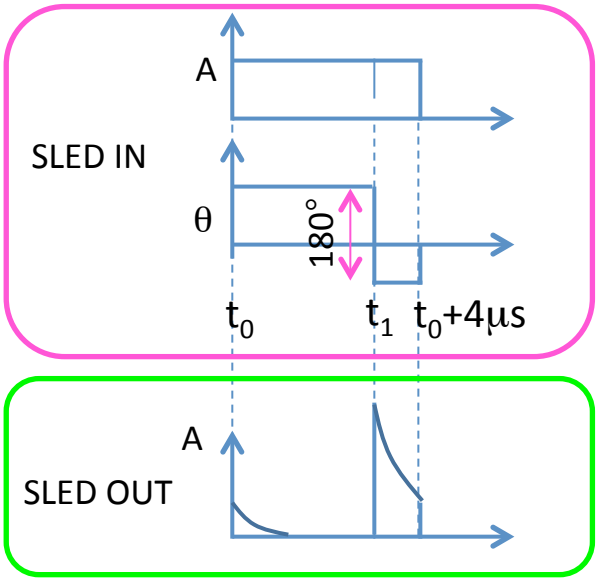
$$\theta = L / \beta c \cdot f \cdot 360°$$
$$\Delta\theta = -360° \cdot fL / c \ \Delta\beta / \beta^2 = -360° \cdot fL / c \ \Delta\gamma / \gamma^3 \ 1 / \beta^3 = -360° \cdot fL / c$$
$$\Delta\gamma / (\gamma^2 - 1)^{3/2} = -360° \cdot fL / c \ [(1 + eV / m_0 c^2)^2 - 1]^{-3/2}$$
$$eV / m_0 c^2 \ \Delta V / V$$

L=403mm, V=300 kV => $\Delta\theta$= -3.99 deg/%

Specification of RF Drive Unit

Setting resolution: 0.1 %, 0.1deg
Reproducibility: < 0.2% rms, <0.2 deg rms

Functions : IQ Modulation / RF-monitor 1ch/
VSWR meter/Interlock out / Analog video out



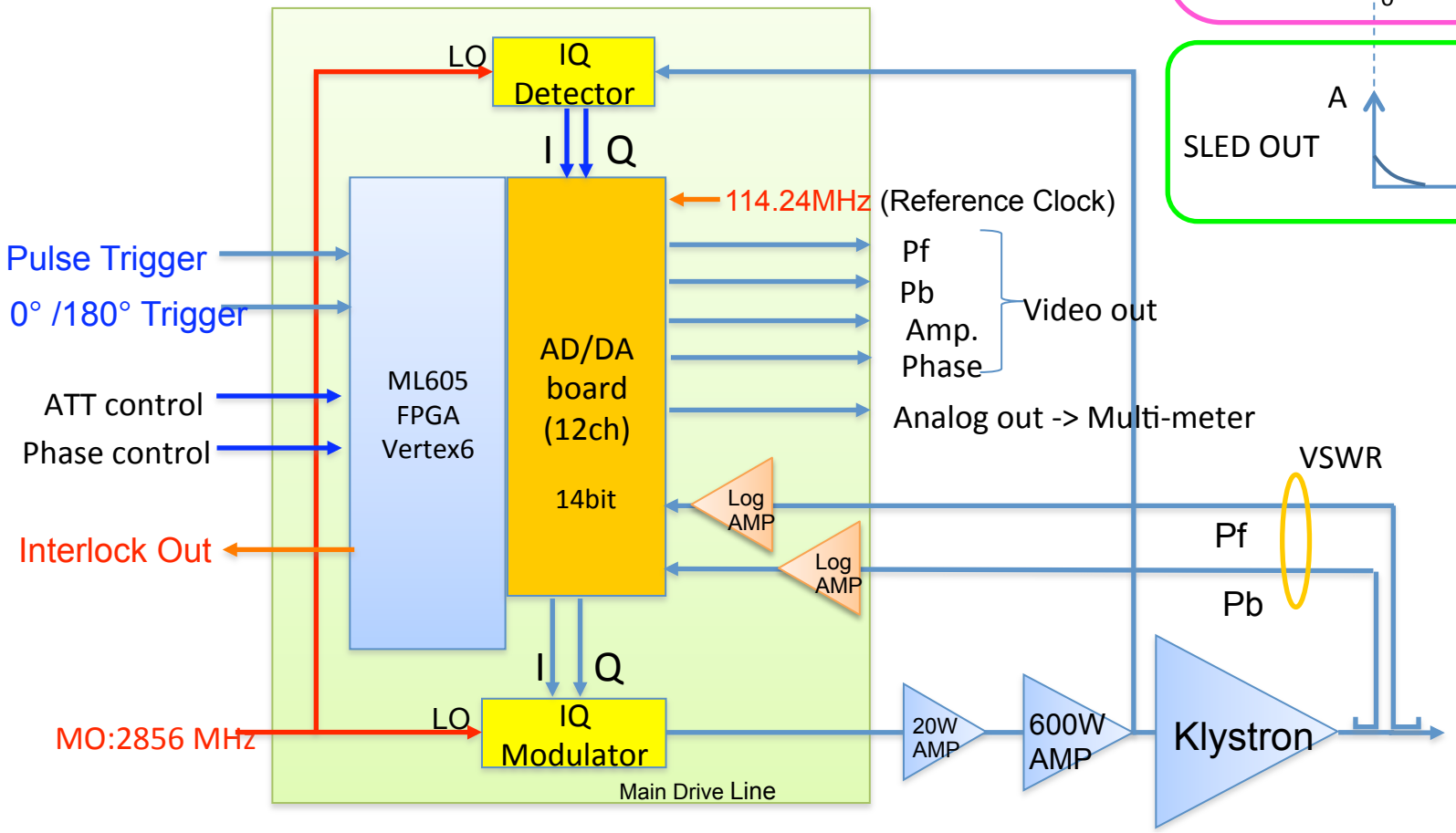
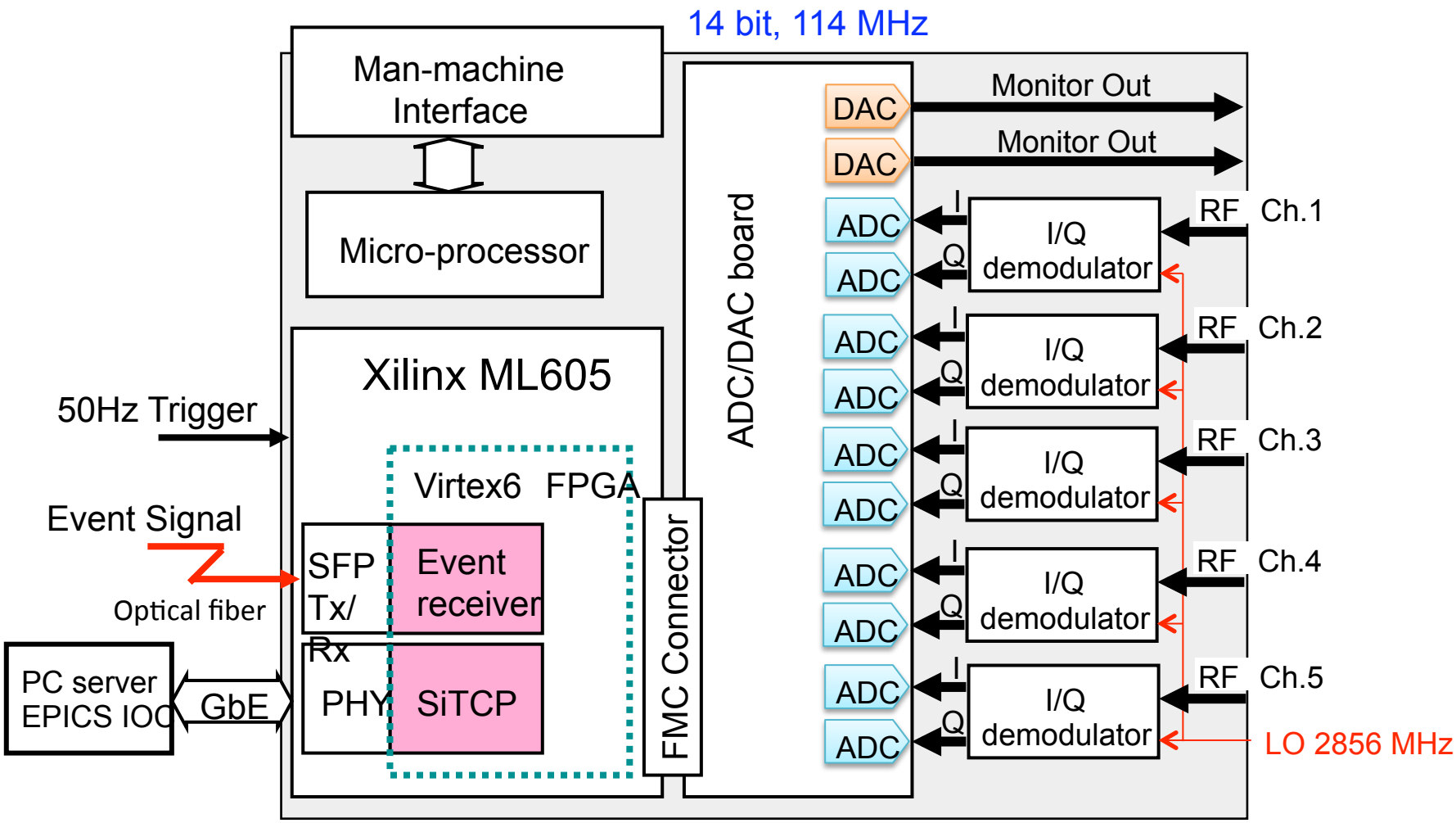


Diagram of RF Monitor



ANALOG DEVICES, AD9254 (14bit, max 150 MHz)