RF Overview

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KEKB review committee

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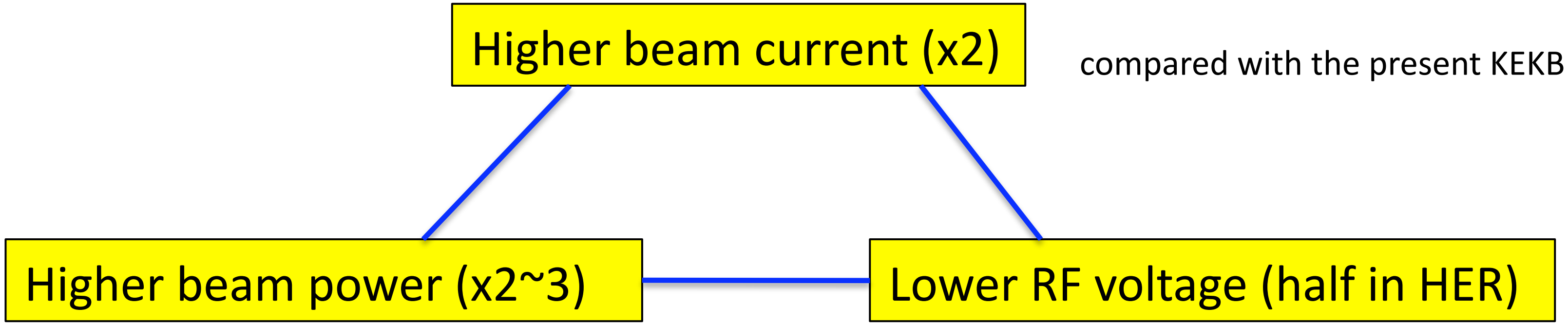
Present RF System for KEKB

- LER: 20 ARES cavities powered by 10 klystrons (2 cavities per 1 klystron).
- HER: 12 ARES cavities powered by 7 klystrons (2:1 for 10 cavities and 1:1 for 2 cavities) and 8 superconducting cavities powered by 8 klystrons.
- Each RF station consists of a 1MW CW Klystron, power supply for the klystrons, high-power RF system and low-level RF system.

Comparison of RF-related machine parameters

	KEKB		SuperKEKB	
	LER	HER	LER	HER
Beam Energy (GeV)	3.5	8.0	4.0	7.0
Beam Current (A)	1.8	1.4	3.60	2.62
Number of Bunches	1585	1585	2503	2503
Bunch Length (mm)	6 ~ 7	6 ~ 7	6	5
Energy loss/turn (MV)	1.5	3.5	2.15	2.50
Momentum compaction			2.74E-4	1.88E-4
Radiation Loss (MW)	2.7	4.9	7.74	6.55
Loss factor, assumed (V/pC)			25	40
Parasitic Loss (MW)			1.30	1.10
Total Beam Power (MW)	~ 3.5	~ 5.0	9.04	7.65
RF Voltage (MV)	8.0	15.0	8.4	6.7

Characteristics of the Nano-beam RF System



- Twice beam current is required.
- Three times RF power needs to be delivered to beam in LER.
- Lower RF voltage with higher beam current makes beam-loading effects much heavier, particularly in HER.

What if with the present RF system?

	unit	KEKB		SuperKEKB	
		LER	HER	LER	HER
Beam current	A	1.7	1.4	3.6	2.62
Total beam power	MW	3.0	5.0	9.04	7.65
Total RF voltage	MV	8.0	13.0	8.4	6.7
No. of cavities		20(ARES)	12(ARES)+8(SC)	20(ARES)	12(ARES)+8(SC)
No. of klystrons		10	7(A) + 8(S)	10	7(A) + 8(S)
Voltage /cavity	MV	0.4	0.3(A) / 1.2(S)	0.42	0.23(A) / 0.5(S)
Beam power /cavity	kW	150	210(A) / 310(S)	452	370(A) / 400(S)
Wall loss /cavity	kW	96	52(A) / -	106	33 / -
Input coupling for ARES		3.0	3.0	5.26	12.4
Loaded-Q for SCC			5 x 10^4		0.67 x 10^4
Detuning frequency	kHz	16	17(A) / 33(S)	31.2	39(A) / 112(S)
-1 mode growth time	ms	15			0.25
Klystron output power	kW	530	560(A) / 330(S)	1194	863(A) / 430(S)

(7% loss is included)

High current, large beam power and low voltage all together cause serious problems: too low operating voltage, too large coupling for ARES, too low QL for SC, detuning frequency exceeding the revolution, and too high klystron power.

How to match the requirements (1)

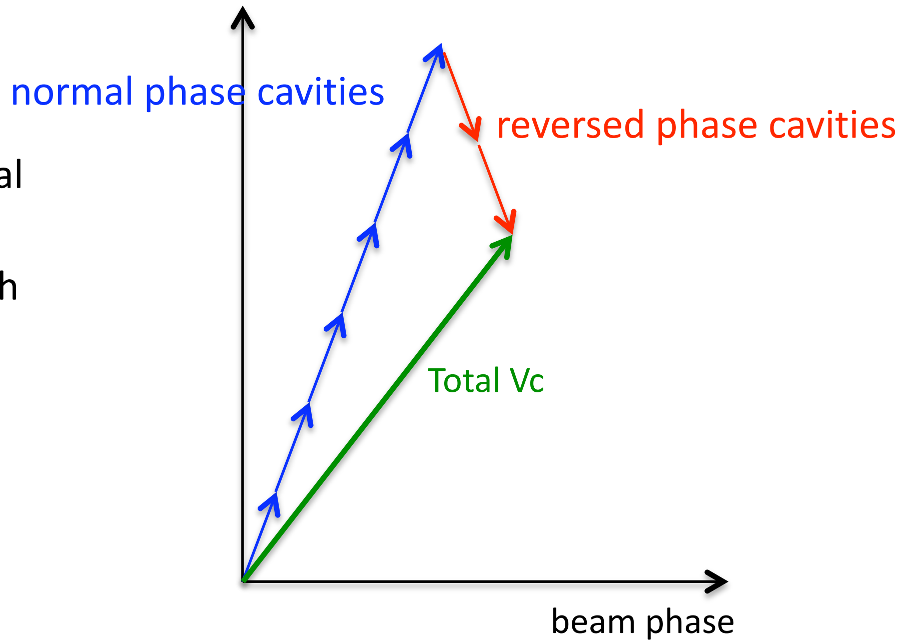
- To match the higher beam power with a low RF voltage, change the present scheme (one klystron drives two ARES cavities) to that one klystron drives one ARES.
  - Power delivered to beam by one klystron (800kW output power case)
    - Klystron: ARES = 1:2 station ---> 220x2=440kW /klystron
    - Klystron: ARES = 1:1 station ---> 600kW /klystron
    - By adding one klystron, beam power increases by 760kW.
  - At each RF station, operation at around 800kW is feasible.
    - Klystrons, power supplies and high-power RF system can be operated stably.
    - Existing components can be used without modifications.
    - Sufficient margin to saturation of klystron
- Increase the number of klystrons, but reduce the number of ARES cavities.

How to match the requirements (2)

- The low RF voltage and high beam power in HER can cause serious problems due to beam-loading effects as:
  - Too low operating voltage for SC cavities:
  - Input couplers need to be replaced with stronger coupling ones. This work can cause possible contamination on the SC cavity surface. And the tip of the couplers may have a heating problem.
  - Operating voltage of the ARES is also too low. Then the input couling of more than 10 is required. The R&D of input couplers to increase the coupling is being conducted. But feasibility of such a large couling has not been confirmed.
  - Detuning frequency of SCC exceeds the revolution frequency, and the growth time of the -1 mode longitudinal instability will be very fast.
- The problems can be solved by introducing Reversed-Phase Operation of SCC.

Reversed phase operation of SCC

- What is this scheme?
  - Phase of some SC cavities are set on the time-rising side (reversed phase), while others on the time-descending side (normal phase).
  - Low total RF voltage is obtained, while each cavity is operated at a high voltage.
  - Beam power is shared by all cavities, including the reversed phase ones.



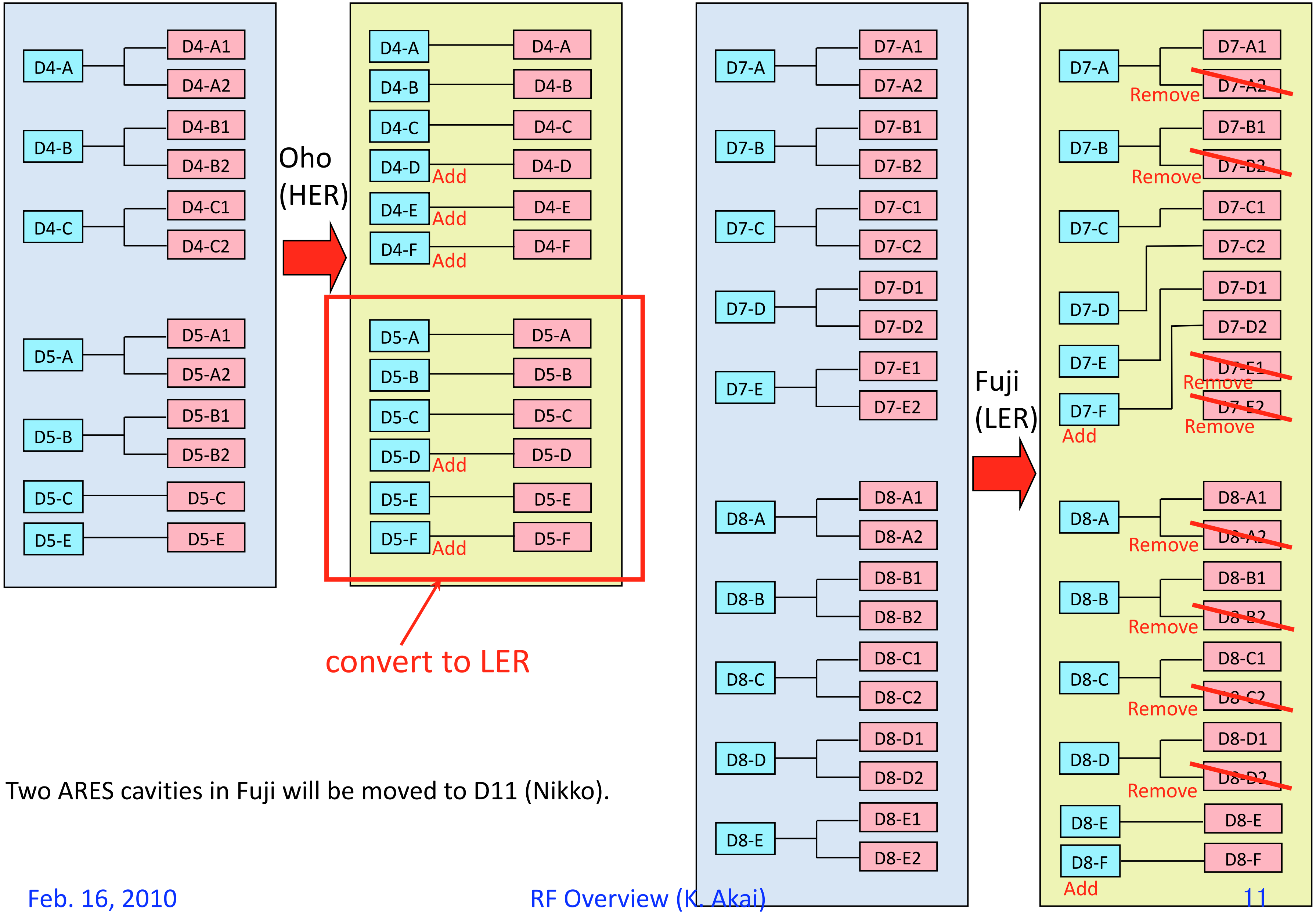
- Merits
  - No need to change the input coupling.
  - Detuning frequency is relatively small. Furthermore, the impedance of the reversed-phase cavities cancels that of normal phase ones. Then the -1 mode instability growth rate becomes acceptably small.
  - Gap transient also cancels out.

Details will be given by Y. Morita.

RF parameters for SuperKEKB

	unit	LER	HER	
Beam Current	A	3.60	2.62	
Energy loss/turn	MV	2.15	2.50	
Radiation Loss	MW	7.74	6.55	
Parasitic Loss	MW	1.30	1.10	
Total Beam Power	MW	9.04	7.65	
Total RF Voltage	MV	8.4	6.7	
Number of cavities		18 ARES	8 ARES + 8 SCC (3 reversed phase)	
		(ARES)	(ARES)	(SCC)
RF Voltage	MV	0.467	0.48	1.3
Wall loss	kW	131	139	-
Beam power	kW	502	556	400
Input coupling		4.84	5.01	QL~5E4 (no change)
Klystron output (7% loss in waveguides included)	kW	677	744	428
Detuning frquency	kHz	28.1	18.4	47.4
-1 mode growth time	ms	5.3	11.3	

Convert RF stations (Oho and Fuji)



Two ARES cavities in Fuji will be moved to D11 (Nikko).

Reinforcement of RF stations: summary

(number of klystrons / number of cavities)

	KEKB		SuperKEKB		Change
Building	LER	HER	LER	HER	
D4		3 / 6		6 / 6	add 3 klystrons
D5		4 / 6	6 / 6		add 2 klystrons, convert from HER to LER
D7	5 / 10		6 / 6		add 1 klystron, remove 4 ARES
D8	5 / 10		6 / 6		add 1 klystron, remove 4 ARES
D11				2 / 2	add 2 klystrons, install 2 ARES for HER
Total (ARES)	10 / 20	7 / 12	18 / 18	8 / 8	Add 9 stations in total
D10		4 / 4S		4 / 4S	
D11		4 / 4S		4 / 4S	
Total (SCC)		8 / 8S		8 / 8S	

("S" denotes SC cavities)

Back-up scheme for HER

- 14 ARES cavities alone without SCC also work.
- But we choose the SC/ARES hybrid system as baseline scheme because:
  - The existing SC cavities and cryogenic system can be used without big changes.
  - Keep progress in KEK's world-leading technology and experience of SCC for high current application.
    - The KEKB-type cavity is used in BEPC-II in IHEP, and also considered to be adopted in other laboratories.
  - No problems have been seen with the reversed-phase operation.
- We consider the 14 ARES scheme as a back-up option.

	unit	HER
Beam Current	A	2.62
Energy loss/turn	MV	2.50
Radiation Loss	MW	6.55
Parasitic Loss	MW	1.10
Total Beam Power	MW	7.65
Total RF Voltage	MV	6.7
Number of cavities		14 ARES
		(ARES)
RF Voltage	MV	0.479
Wall loss	kW	137
Beam power	kW	546
Input coupling		4.98
Klystron output (7% loss in waveguides included)	kW	732
Detuning frquency	kHz	19.9
-1 mode growth time	ms	20.4

Instability due to RF cavities and cure

Ring	Direction	Cause	Frequency (MHz)	Growth time (ms)	Cure
LER	Longitudinal	ARES-HOM	1850	15	B-by-B FB
LER	Longitudinal	ARES-0/pi	504	29	(B-by-B FB)
LER	Longitudinal	-1 mode	508.79	5	-1 mode damper
LER	Transverse	ARES-HOM	633	9	B-by-B FB
HER	Longitudinal	ARES-HOM	1850	75	(no need)
HER	Longitudinal	SCC-HOM	1018	58	(no need)
HER	Longitudinal	-1 mode	508.79	11	-1 mode damper
HER	Transverse	ARES-HOM	633	48	(no need)
HER	Transverse	SCC-HOM	688	14	B-by-B FB

ARES 0/pi mode will be presented in detail by T. Kageyama.

Bunch gap transient

- Phase modulation along a bunch train caused by an abort gap

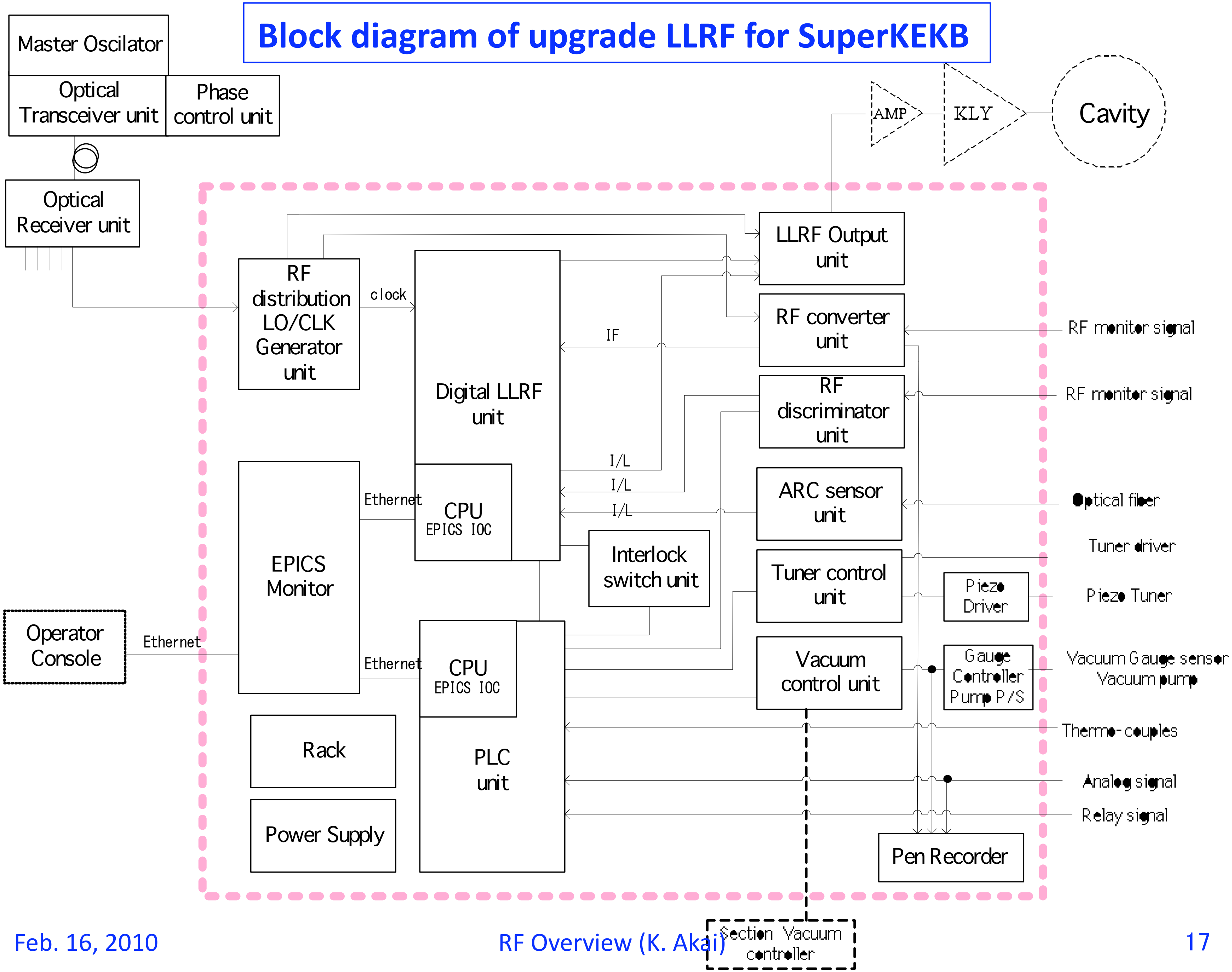
$$\Delta\phi = \frac{\omega_{rf}}{2V_c}\left(\frac{R}{Q}\right)\times I_b\Delta t = \frac{P_b\Delta t}{2\cos\phi_s U}$$

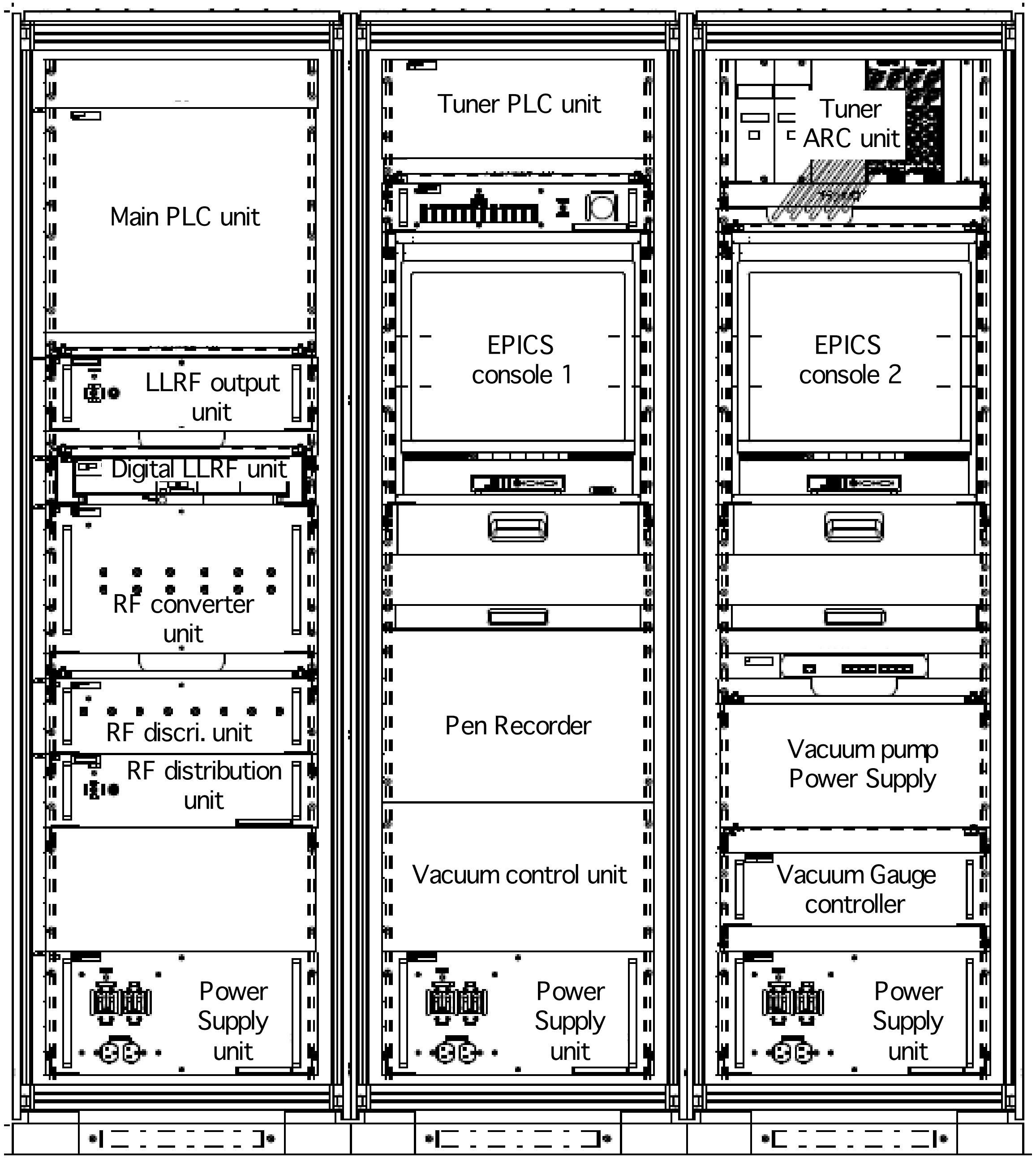
- KEKB
  - Owing to high stored energy of the ARES and SCC, transient phase modulation (also longitudinal position change of beam) is small, about 3 to 5 degrees. No luminosity degradation along a train is observed.
  - Calculation and measurements agree well.
- SuperKEKB
  - Since the beam current is twice, the gap length should be reduced less than half (500ns --> 200ns). Rise time of the abort kicker will be improved.

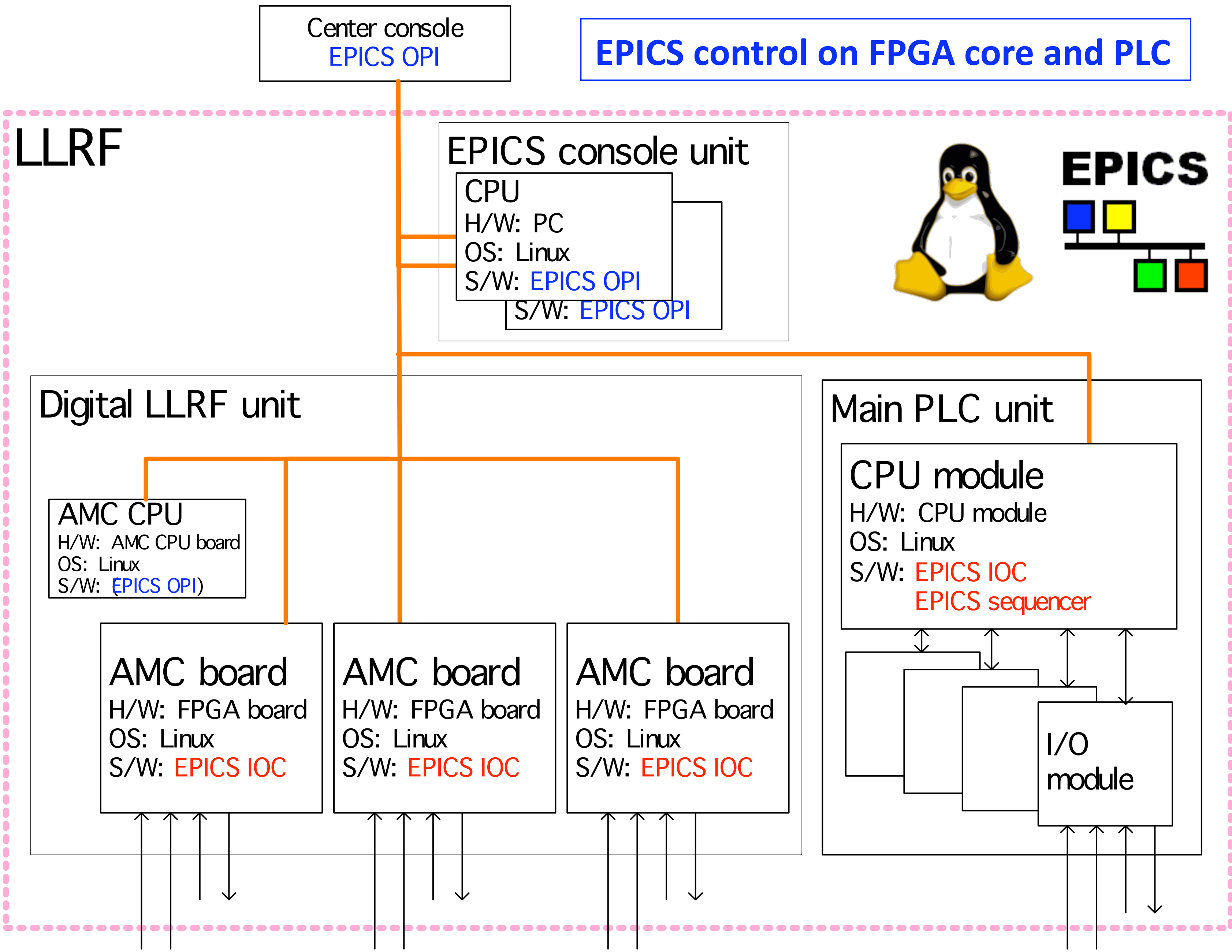
Upgrade LLRF for SuperKEKB

- Development
  - Development of new LLRF for SuperKEKB with full digital control started in 2008. Hardware design is almost done.
  - First production is underway in JFY2009. It will be installed at D4-A station in late 2010 for system adjustment and performance check.
- Contribution from other groups and company
  - KEKB/Linac control group (EPICS on FPGA core and PLC)
  - cERL-LLRF group (Digital board is common for SuperKEKB and cERL.)
  - Mitsubishi Electric TOKKI Systems Corporation (manufacture)
- Construction plan
  - New LLRF will be installed at additional RF stations and DR.
  - The existing stations can be operated with old systems, and may be replaced with new ones step-by-step depending on budget.

Block diagram of upgrade LLRF for SuperKEKB

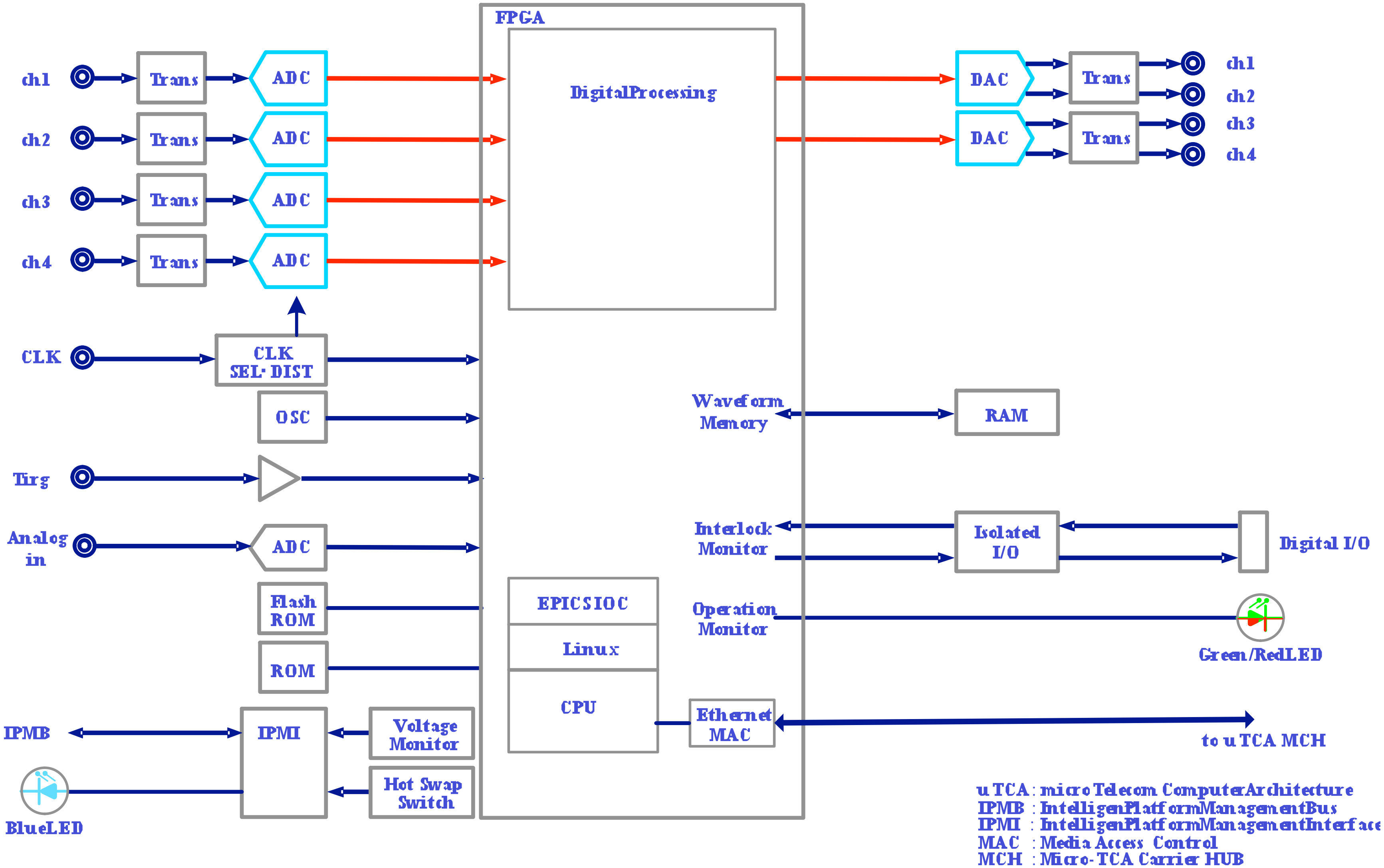



Main PLC unit
LLRF output unit
Digital LLRF unit
RF converter unit
RF discri. unit
RF distribution unit
Power Supply unit
Tuner PLC unit
EPICS console 1
Pen Recorder
Vacuum control unit
Power Supply unit
Tuner ARC unit
EPICS console 2
Vacuum pump Power Supply
Vacuum Gauge controller
Power Supply unit



Center console
EPICS OPI
EPICS control on FPGA core and PLC
LLRF
EPICS console unit
CPU
H/W: PC
OS: Linux
S/W: EPICS OPI
S/W: EPICS OPI
EPICS
Digital LLRF unit
AMC CPU
H/W: AMC CPU board
OS: Linux
S/W: (EPICS OPI)
AMC board
H/W: FPGA board
OS: Linux
S/W: EPICS IOC
AMC board
H/W: FPGA board
OS: Linux
S/W: EPICS IOC
AMC board
H/W: FPGA board
OS: Linux
S/W: EPICS IOC
Main PLC unit
CPU module
H/W: CPU module
OS: Linux
S/W: EPICS IOC
EPICS sequencer
I/O
module

Block diagram of digital LLRF board



Damping Ring RF System

- HLRF and LLRF
  - One RF station will be built for the DR.
  - Klystron power of 150 kW is enough.
  - Components can be compatible with MR (less demanding).
  - The upgrade LLRF will be used.
- Cavity
  - Tight space in the tunnel.
  - No need for the energy-storage cavity.
  - A new cavity is being designed based on the ARES, but without the storage cavity.

RF cavity for DR will be given by T. Abe.

RF-related parameters for DR		
Beam energy	1.0	GeV
RF frequency	508.9	MHz
Harmonic number	230	
Bunch length	5	mm
Maximum stored current	70.8	mA
Number of bunches	4	
Energy loss per turn	0.0714	MV
Total loss factor	5	V/pC
RF voltage	0.261	MV
Beam power (radiation)	5.1	kW
Beam power (parasitic)	2.8	kW
Beam power (total)	7.9	kW
Wall loss @0.261MV	16	kW
Wall loss @0.5MV (maximum)	60	kW

Summary

- RF system is designed to match higher beam current, higher beam power and a low RF voltage for the nano-beam scheme.
- The existing RF components will be used as much as possible, with change to one-to-one system for the ARES and introducing the reversed-phase operation of SCC.
- Nine RF stations need to be added. Some of the ARES will be moved or taken out.
- Upgrading LLRF is underway. The first production will be tested in JFY2010. The new LLRF will be installed at new RF stations and DR.