Development of New LLRF System

~ KEKB LLRF Team ~

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Talk Outline

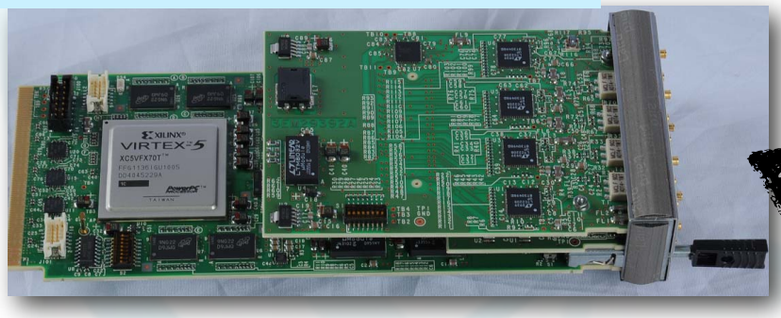
1. Overview the Digital LLRF System
2. Performance Evaluation of the prototype
   a) FB Control
   b) Temperature Dependency
   c) Auto Tuner Control
3. RF Reference Distribution
4. Summary

Features of New LLRF System

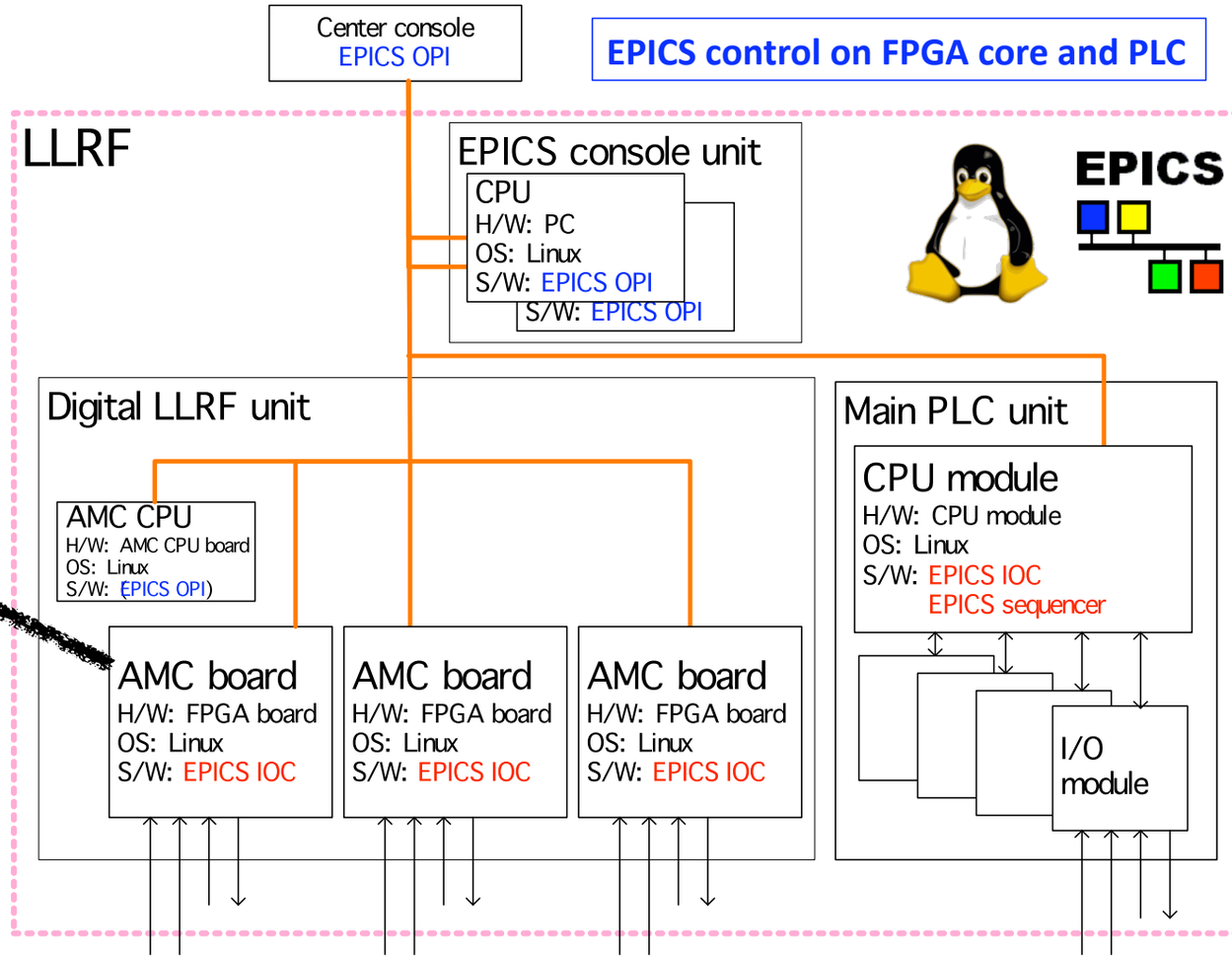
Preset analog systems will be replaced by new digital ones step-by-step.

- It consists of µTCA-based FPGA boards & PLC (EPICS-Sequencer).
- EPICS-IOC on Linux-OS is embedded in each of them. They can be operated remotely via EPICS-Channel Access.
- Hardware is common for both of ARES & SC Cavity. (Also both softwares are much the same.)
- EPICS record names will be consistence with the present systems.
- Klystrons (LLRF) : Cavity unit = 1 : 1 (SuperKEKB)

uTCA-platform FPGA Boards



with CPU (PPC) running Linux-OS for EPICS-IOC.



Prototype of New LLRF System for the SuperKEKB

A prototype of new digital LLRF system (α-version) was produced in last year. And the performance was evaluated.

PLC：EPICS Sequencer (F3RP61)

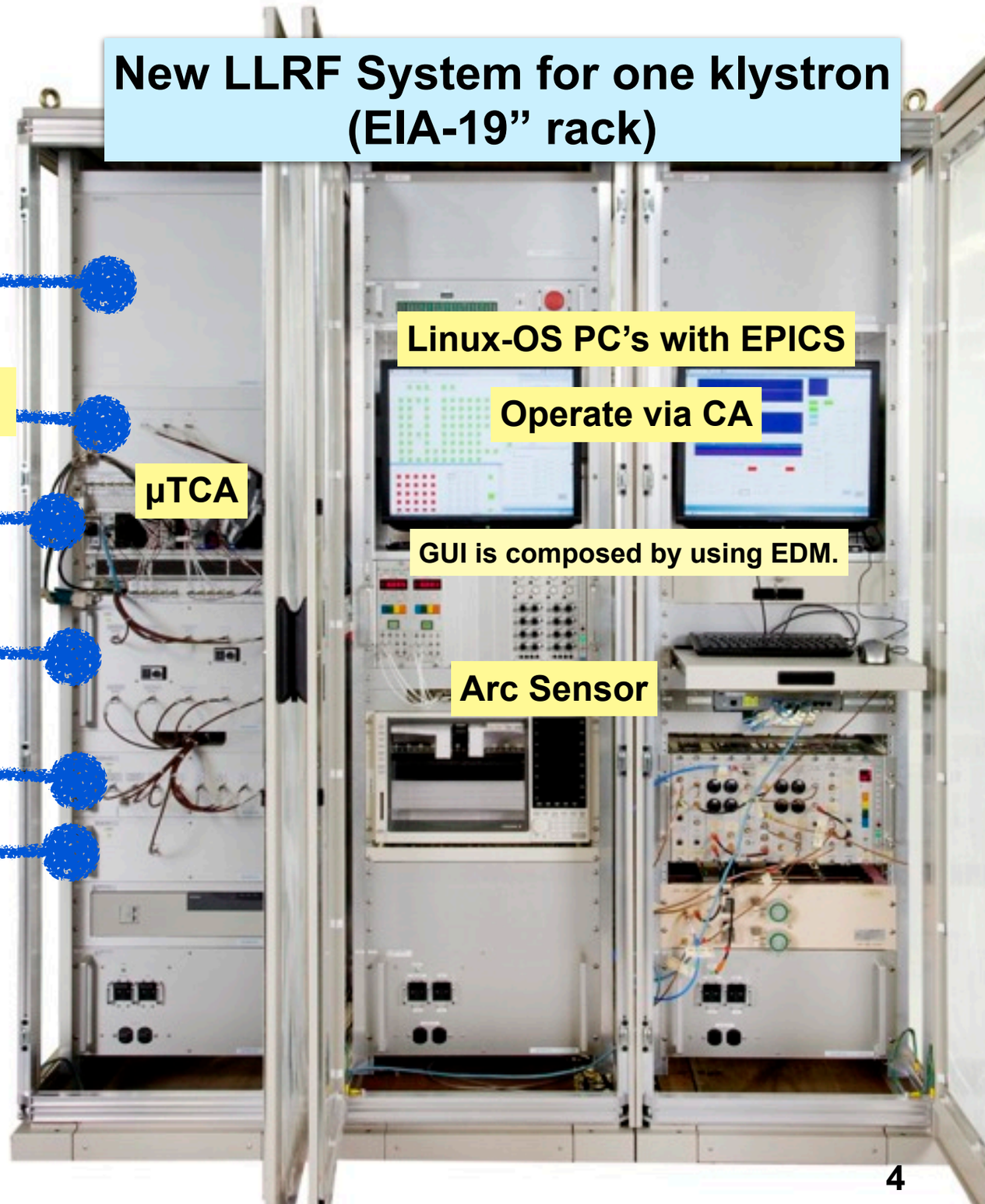
RF-Output Unit (IQ-Modulator & RF-SW)

μTCA-based Digital FB unit

Down Converter Unit (IF out)

RF Interlock Unit

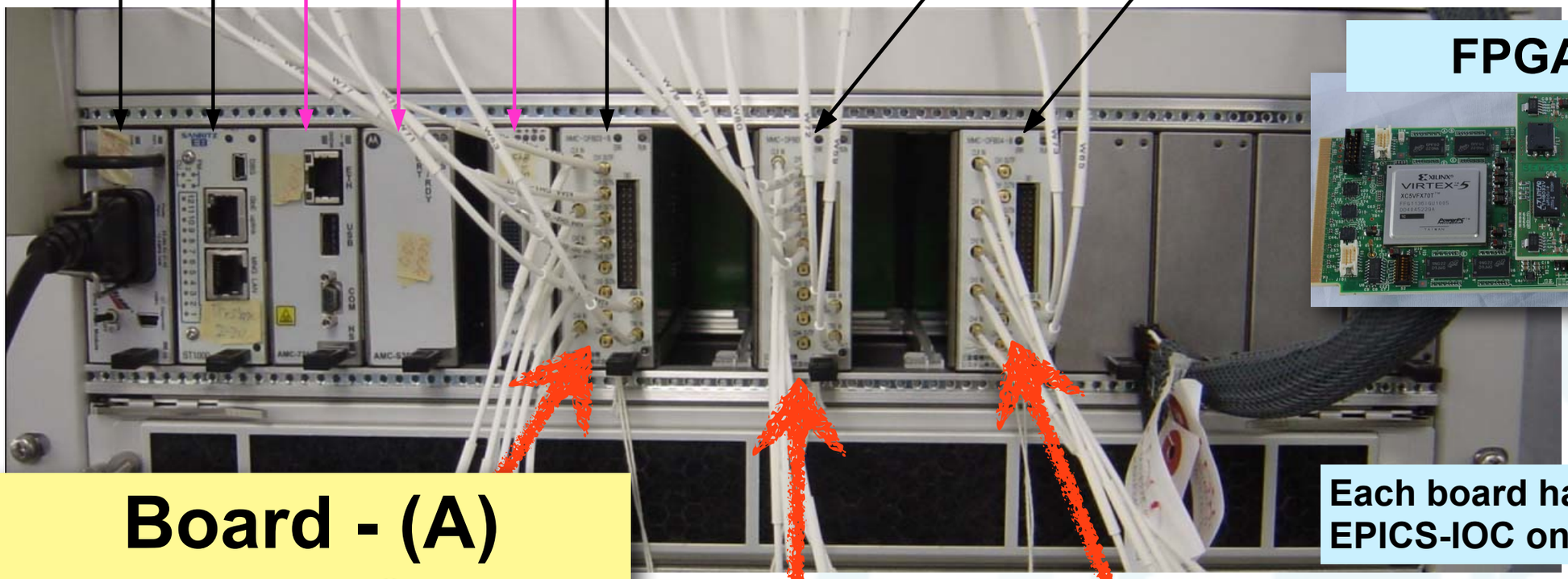
Distribution Unit
(LO & CLK generation and distribution)



uTCA-platform Digital Control Unit

common with the STF.

PM (Power Module)
AC/DC
MCH
CPU
HDD
DVI
Board - (A)
MMC-DFB02-B
Board - (B)
MMC-DFB03-B
Board - (C)
MMC-MON02-B



FPGA Board

16-bit ADC x 4ch,
16-bit DAC x 2ch

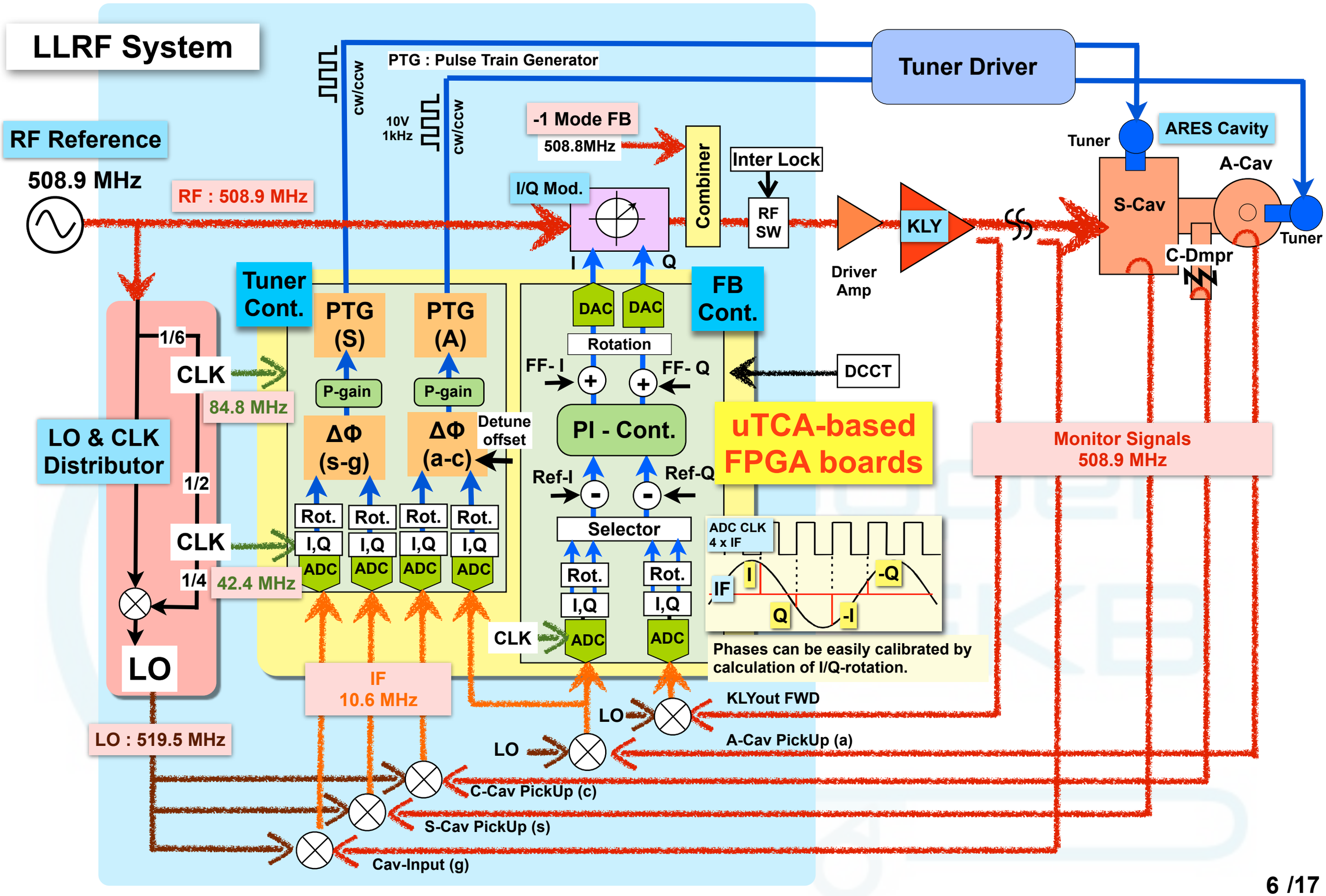
Each board has a CPU (PPC), and the EPICS-IOC on Linux-OS is embedded.

Board - (A)
Digital FB Control

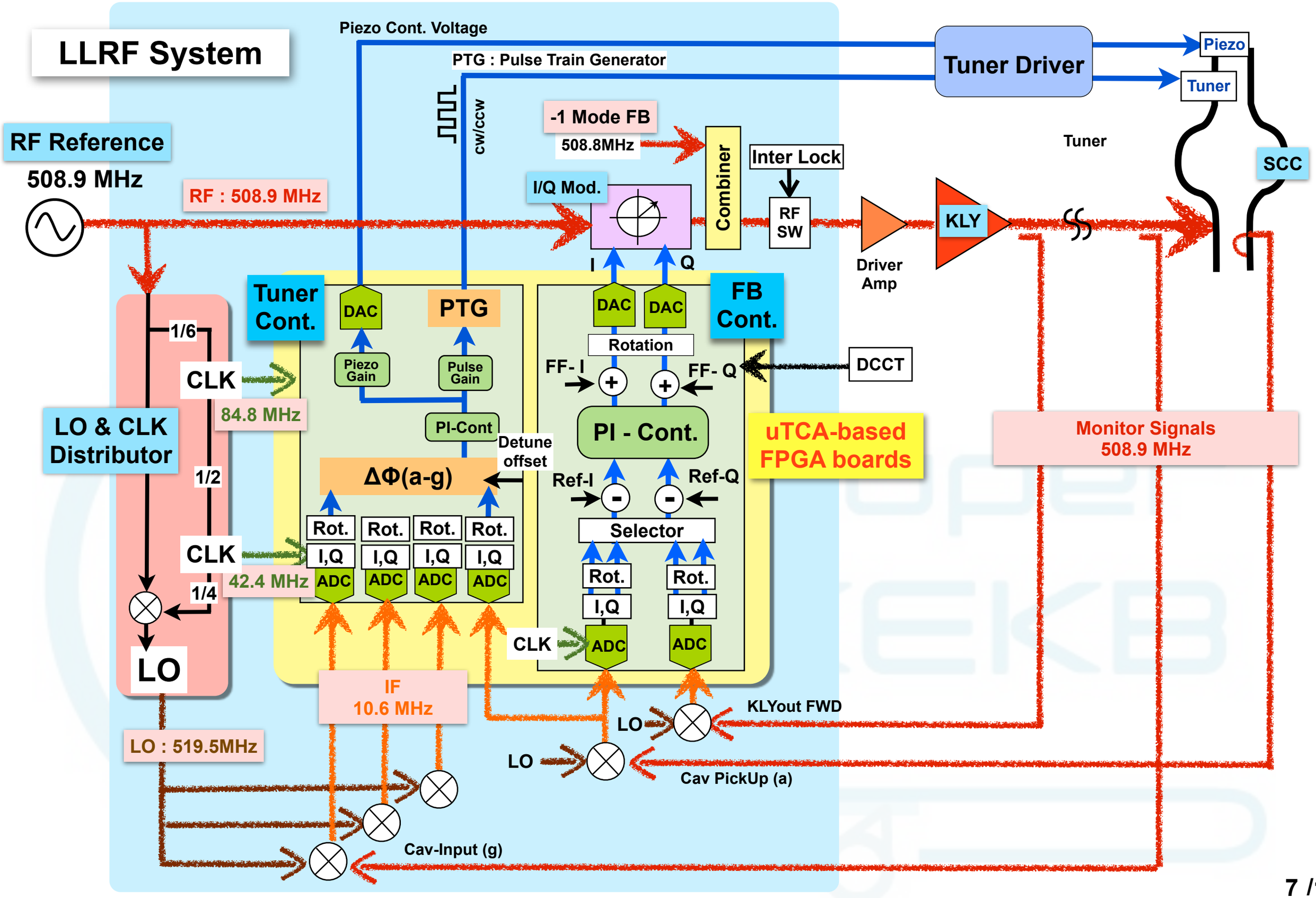
Board - (B)
Tuner Control

Board - (C)
I/L Control
& VSWR Monitor

Block Diagram of FB&Tuner Cont. (ARES)

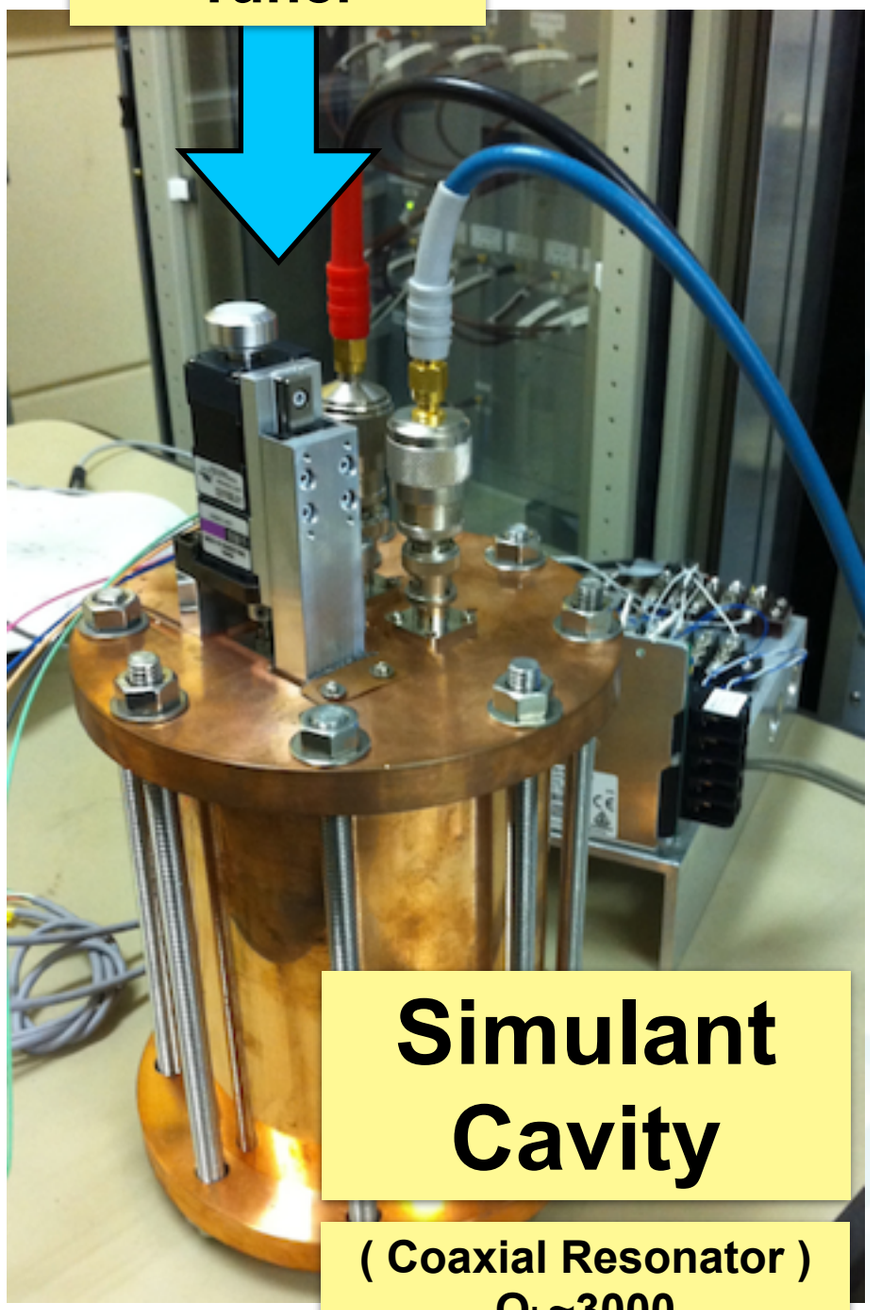


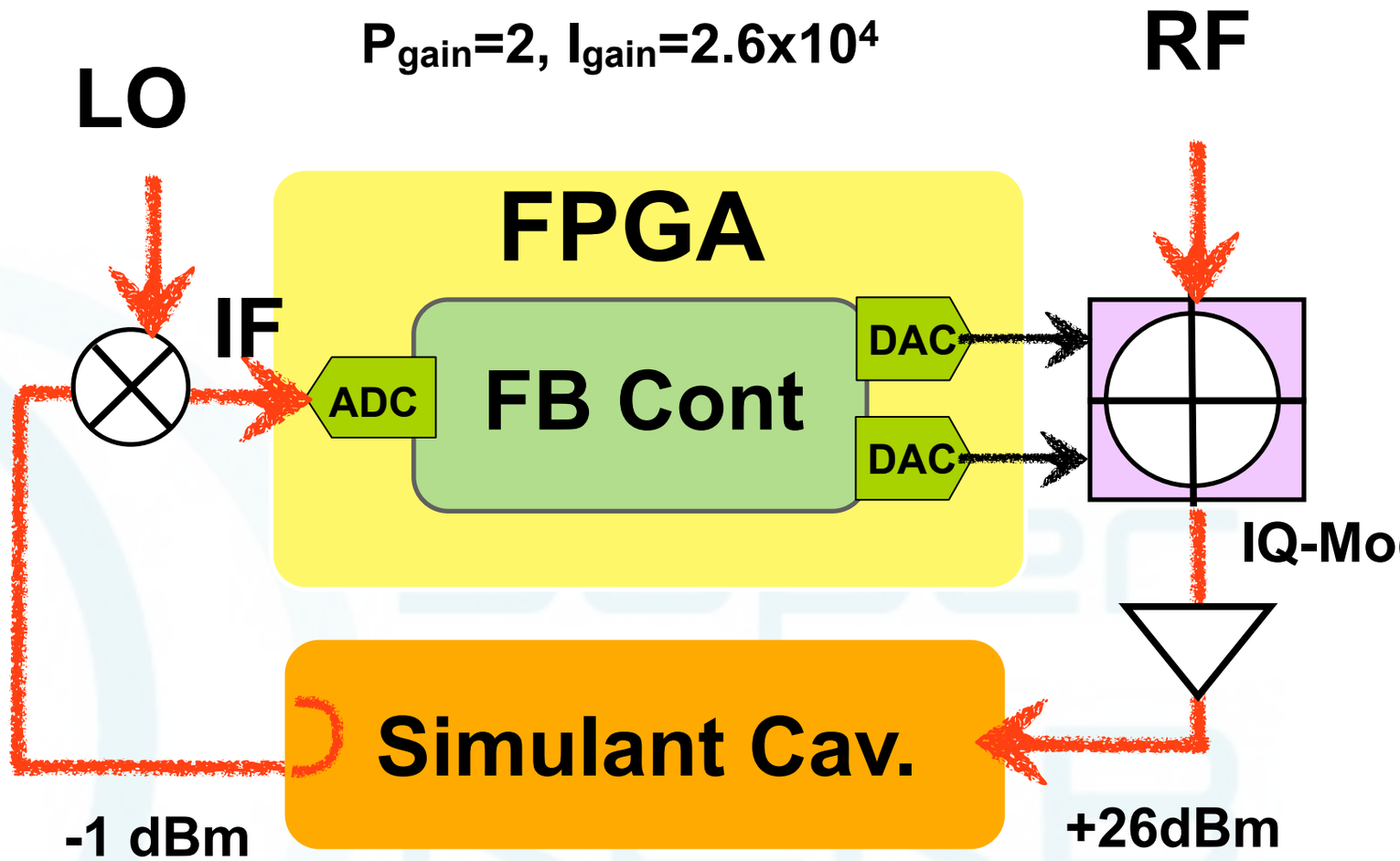
Block Diagram of FB&Tuner Cont. (SC)



Evaluation of FB Control

FB control performance was evaluated by using a simulant cavity





This evaluation condition is more adverse than the real operation for the stability.

ARES Cavity: Q_L~20000 (β~5)

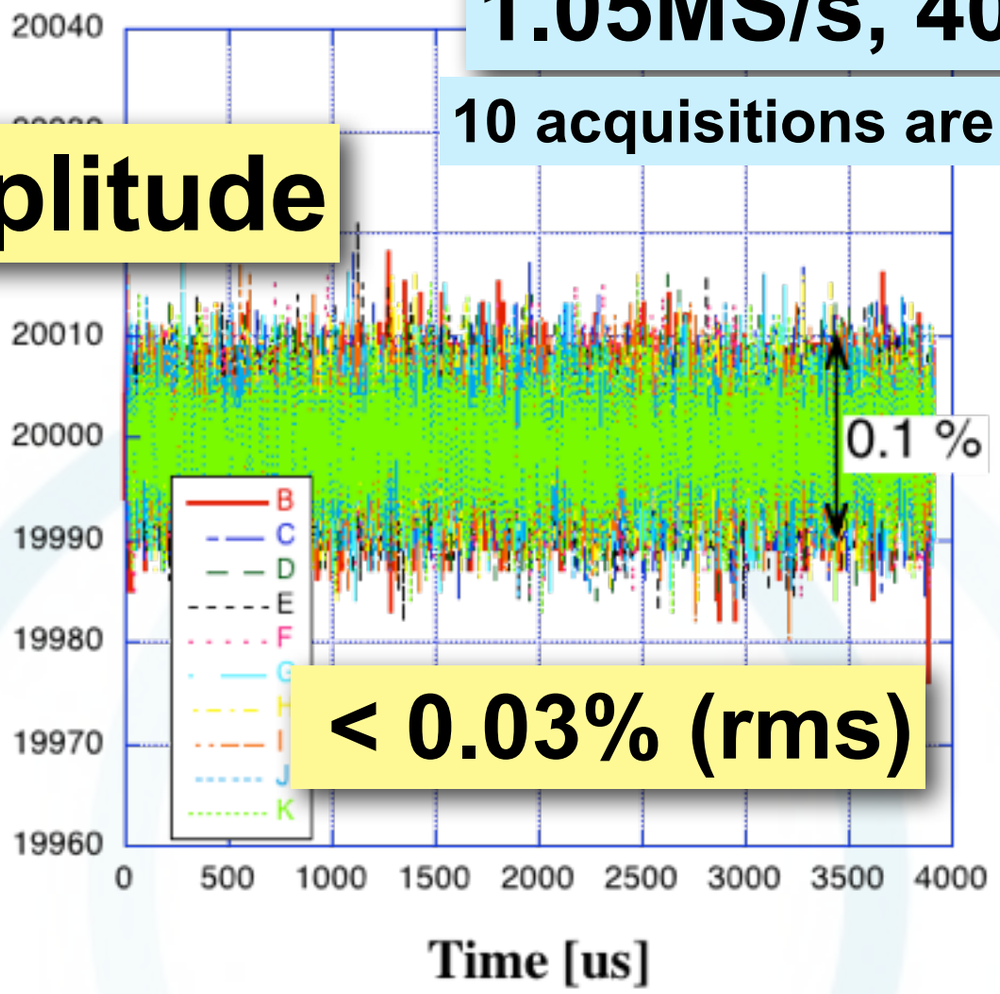
FB Control Result

(Monitored Data by FPGA acting FB cont.)

1.05MS/s, 4096 points (~ 4-ms duration)

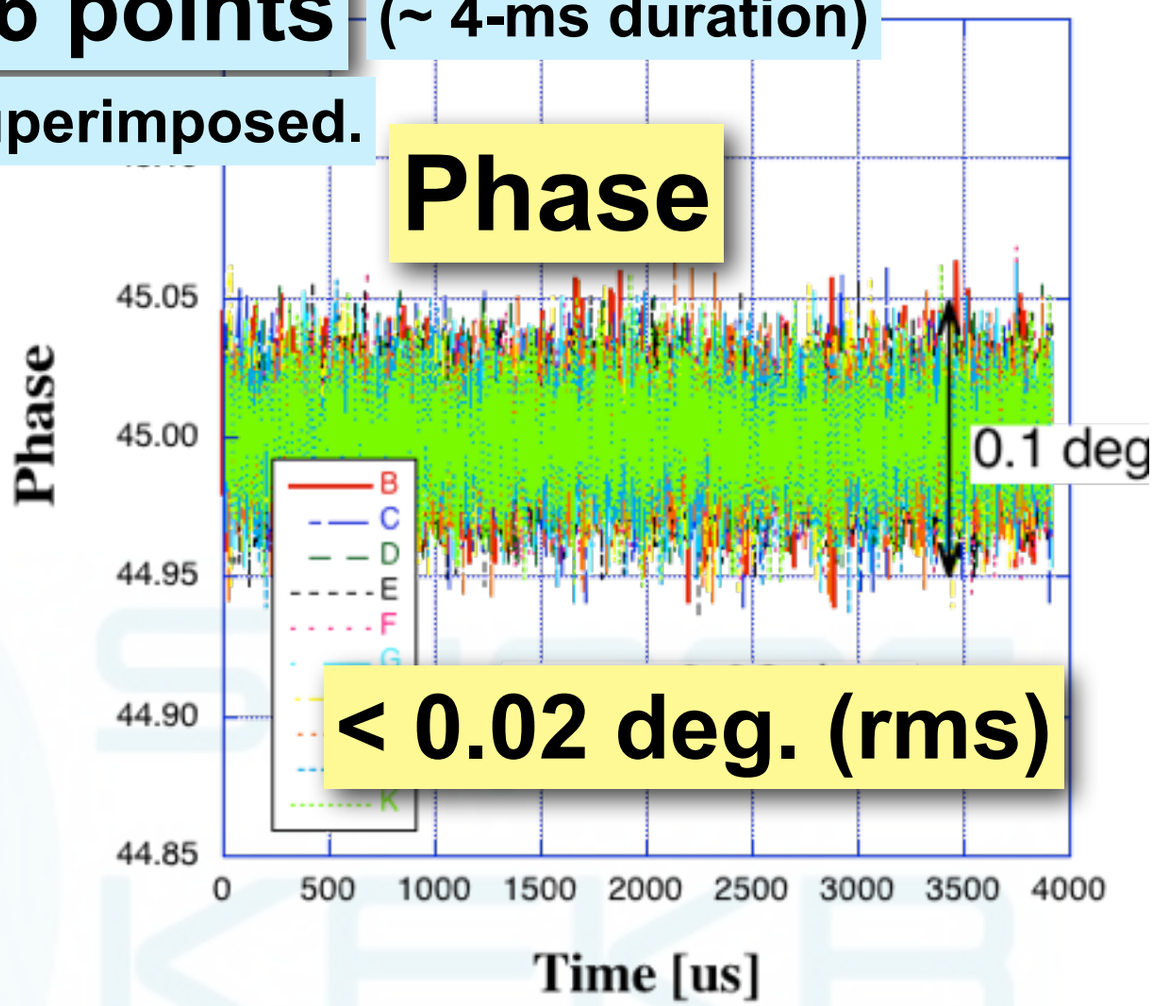
10 acquisitions are superimposed.

Amplitude



< 0.03% (rms)

Phase



< 0.02 deg. (rms)

Very good stability was obtained.

The amplitude and phase stabilities are 0.03% and 0.02 deg., respectively.

The FB control performance satisfy the requirements very well in short term stability.

Long Term Stability or Temperature Dependency

for acc. gradient

Required Stability

+/- 1% in Amplitude
+/- 1 deg. in Phase

Our target value of the stability

for LLRF System

+/- 0.3% in Amplitude
+/- 0.3 deg. in Phase

(pk-pk)

Ambient Temperature Change : about +/- 2 deg.C

Acceptable Temp. Coefficient

0.1%/deg.C in Amplitude
0.1 deg./deg.C in Phase

Measured Result

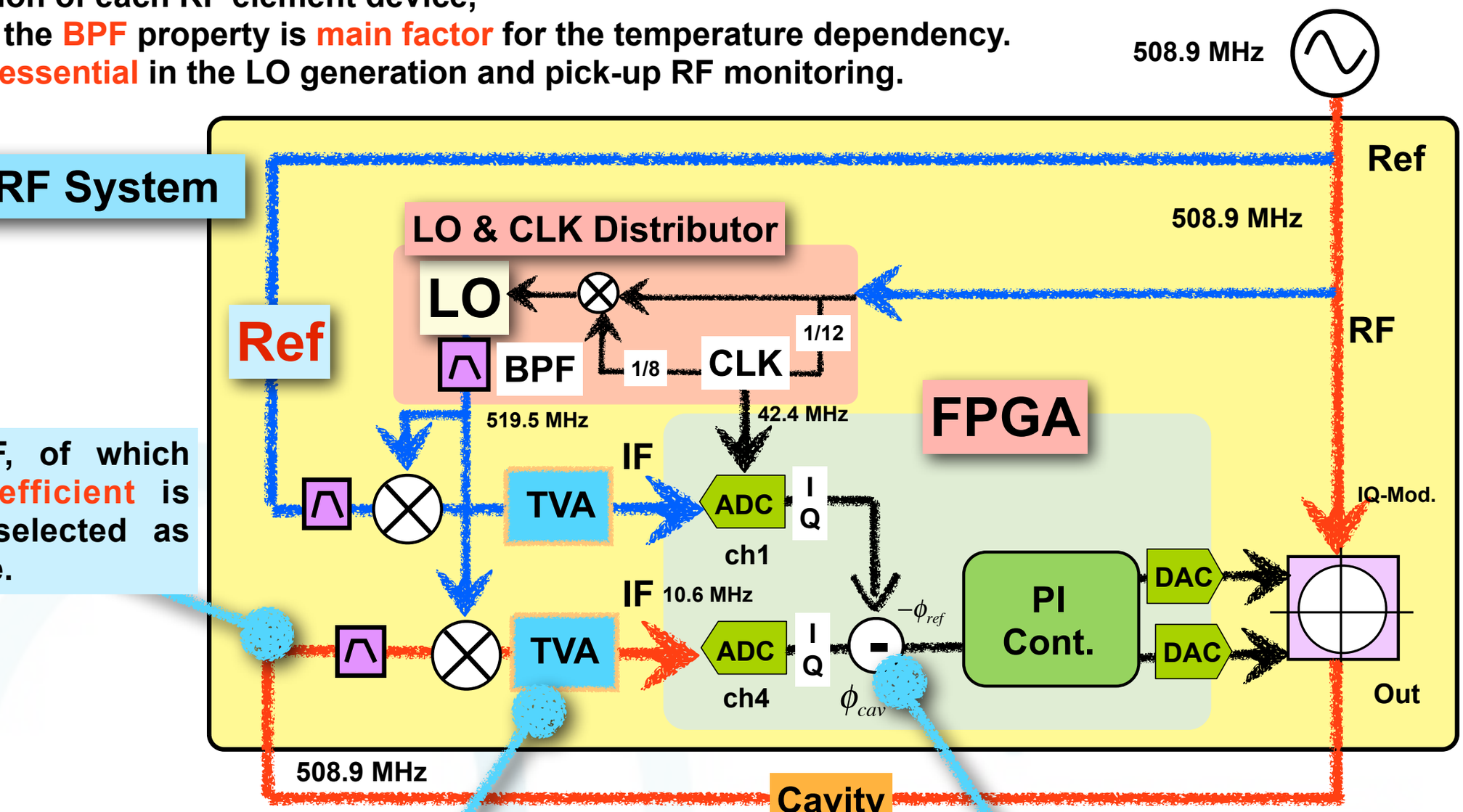
LLRF system total

Amplitude: 0.5 % / deg.C
Phase: 0.25 deg. / deg.C

Requirements are not satisfied.

Countermeasure for Temperature Dependency

From the evaluation of each RF element device,
It was found that the BPF property is main factor for the temperature dependency.
However, BPF is essential in the LO generation and pick-up RF monitoring.



Appropriate BPF, of which temperature coefficient is lower, will be selected as much as possible.

"Thermal Variable Attenuators (TVA)" will be inserted here to compensate amplitude change.

For the phase stability, Directly reference signal is monitored together on FPGA, and the FB-control will be calibrated with the reference.

Amplitude

0.09 % / deg.C

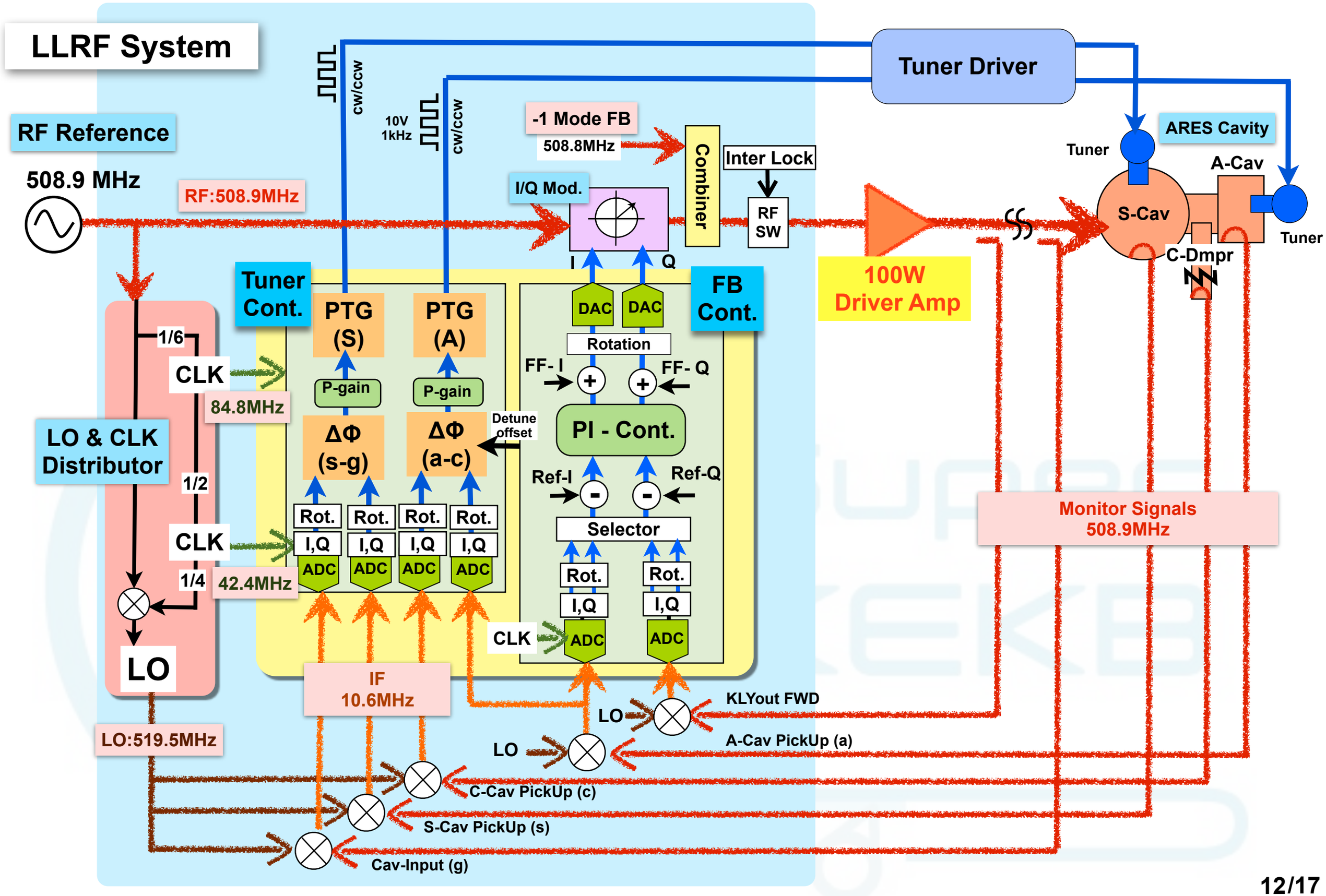
Expected Value

Phase

0.04 deg. / deg.C

Improvement will be verified in next test model.

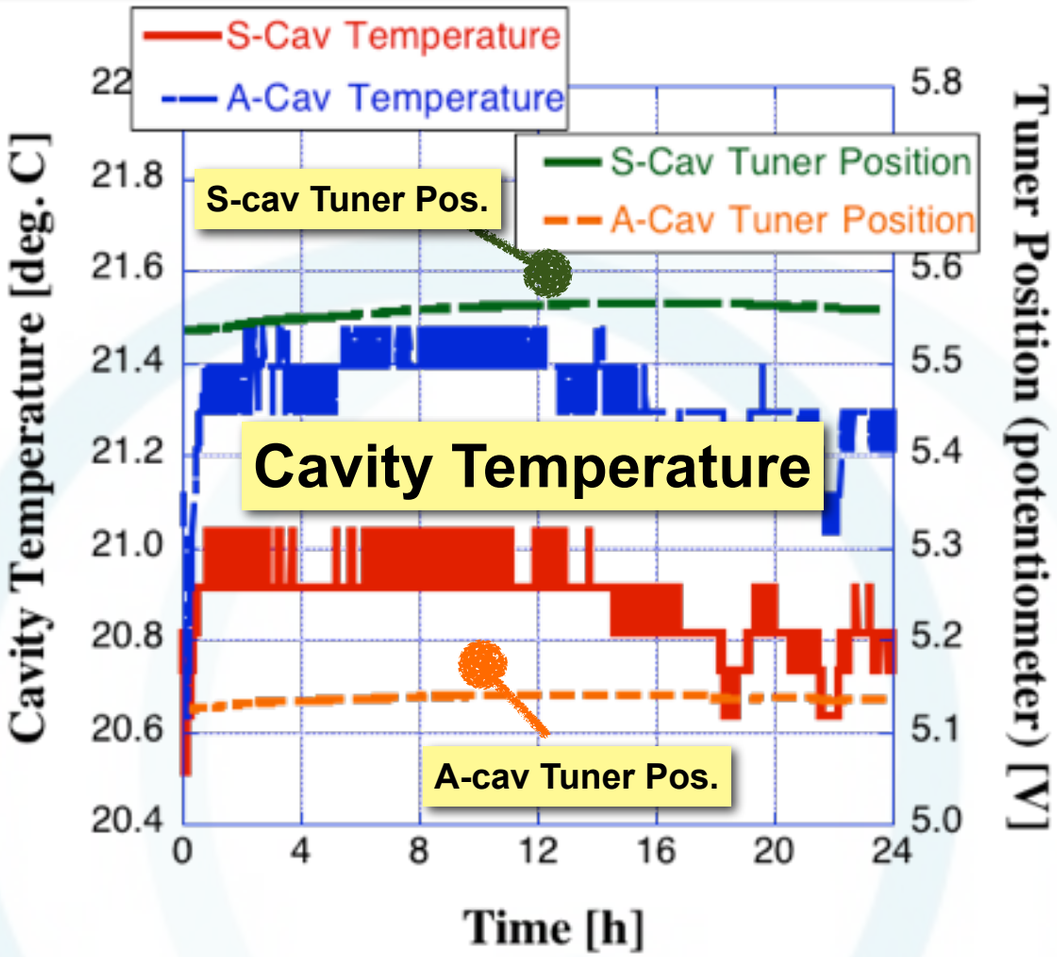
ARES 100W Drive Test for FB & Tuner Control



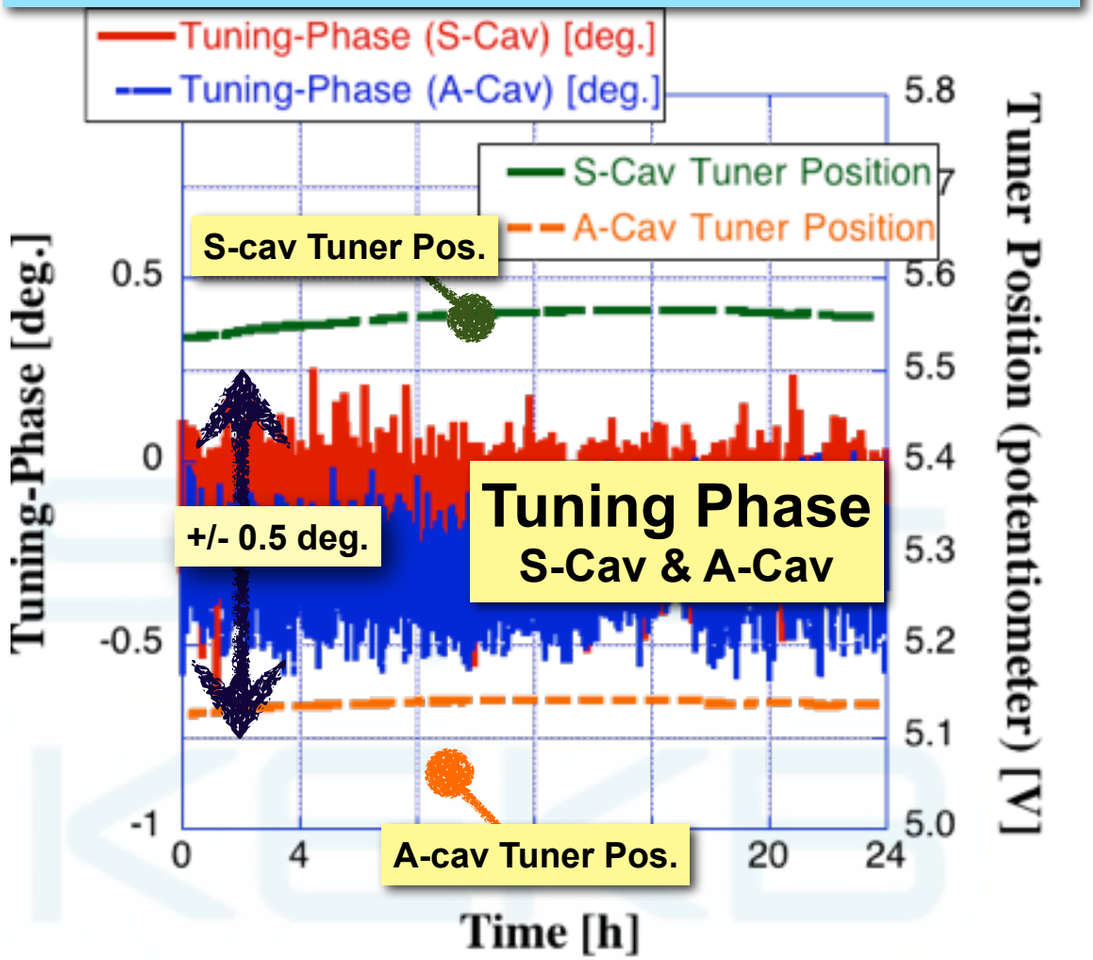
Running Test of ARES Auto Tuning by 100W Driving (not High Power)

Trend graph for 2 days

Cavity Temperature



Tuning Phase (Cavity Transmission Phase)

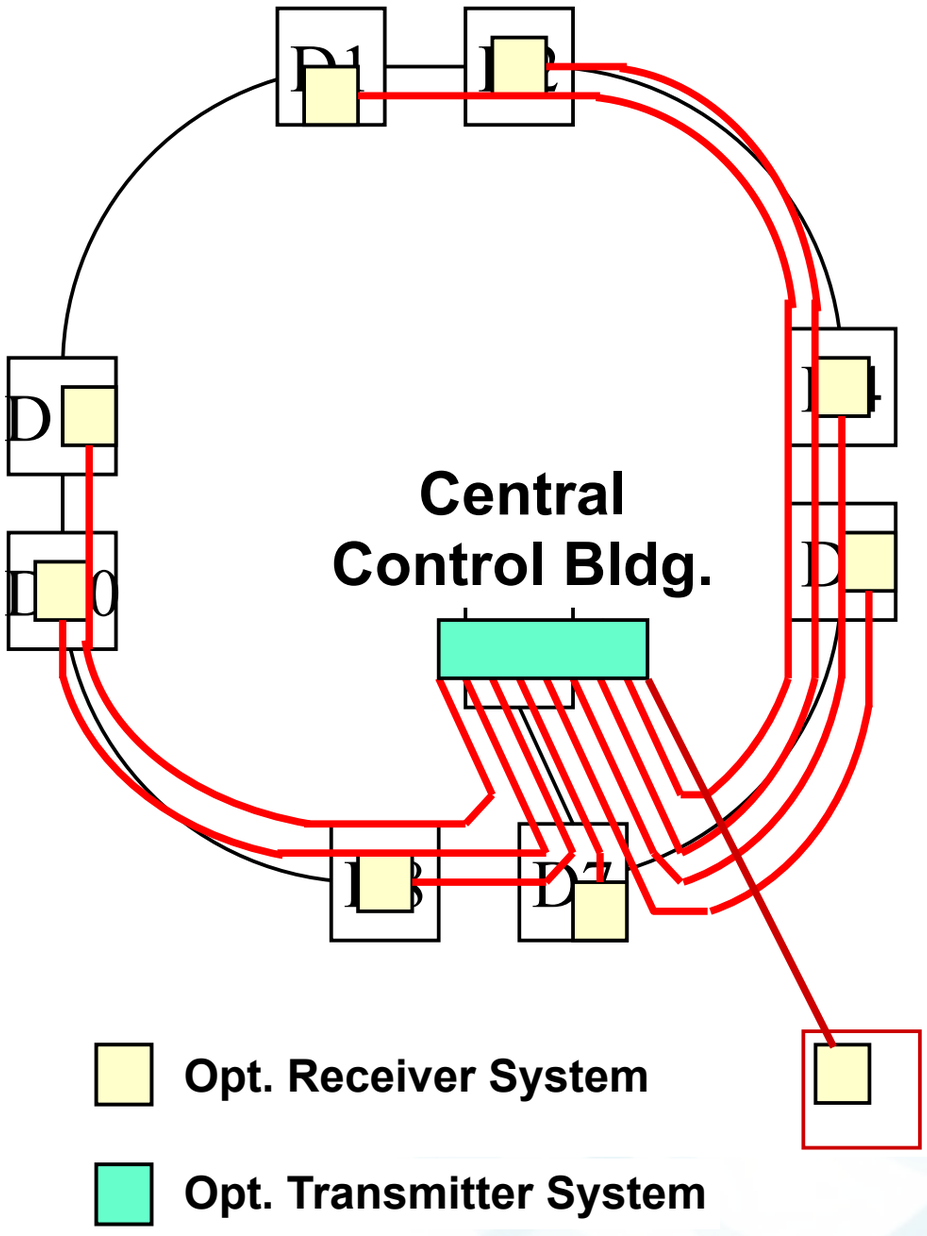


Cavity temperature change is small. (It is maybe due to ambient temperature.) Also tuner moved slightly to keep tuning. This tuner position change corresponds to about 15 degrees of the storage cavity.

Auto tuner controller of FPGA board worked successfully.

RF Reference Distribution

The details are under consideration now.

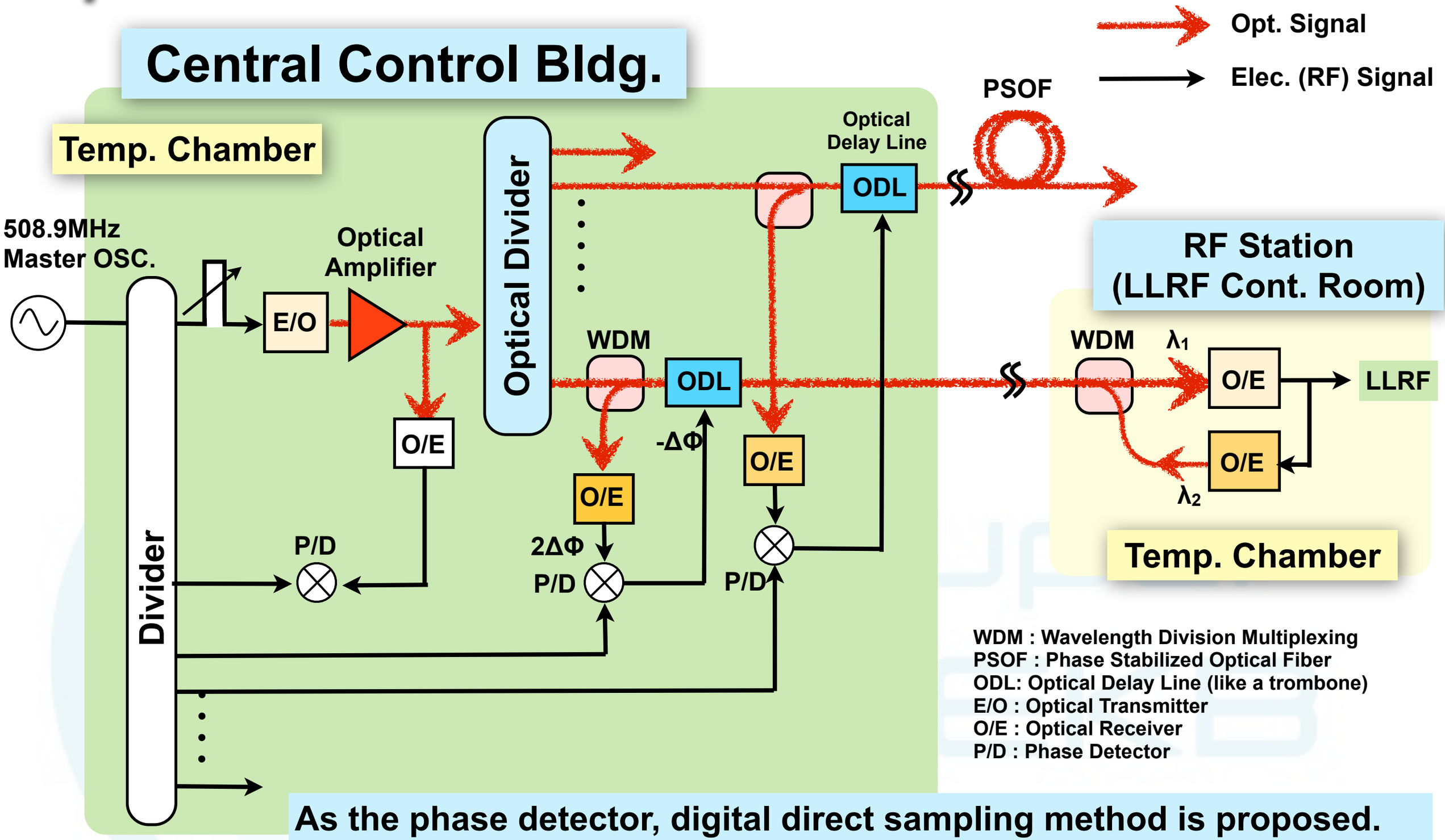


Design Concept

- Optical Distribution （Master OSC. -> E/O -> O/E）
- Phase Stabilized Optical Fiber (PSOF) will be used.
- The PSOF cables will be transferred in the acc. tunnel. (Temperature stability : +/- 1 deg.C)
- Distributed by means of “Star” configuration.
- Phase FB control will be implemented to compensate temperature drift of the cable if necessary.

Present reference system is maintained for the backup.

Optical Reference Transmitter & Receiver



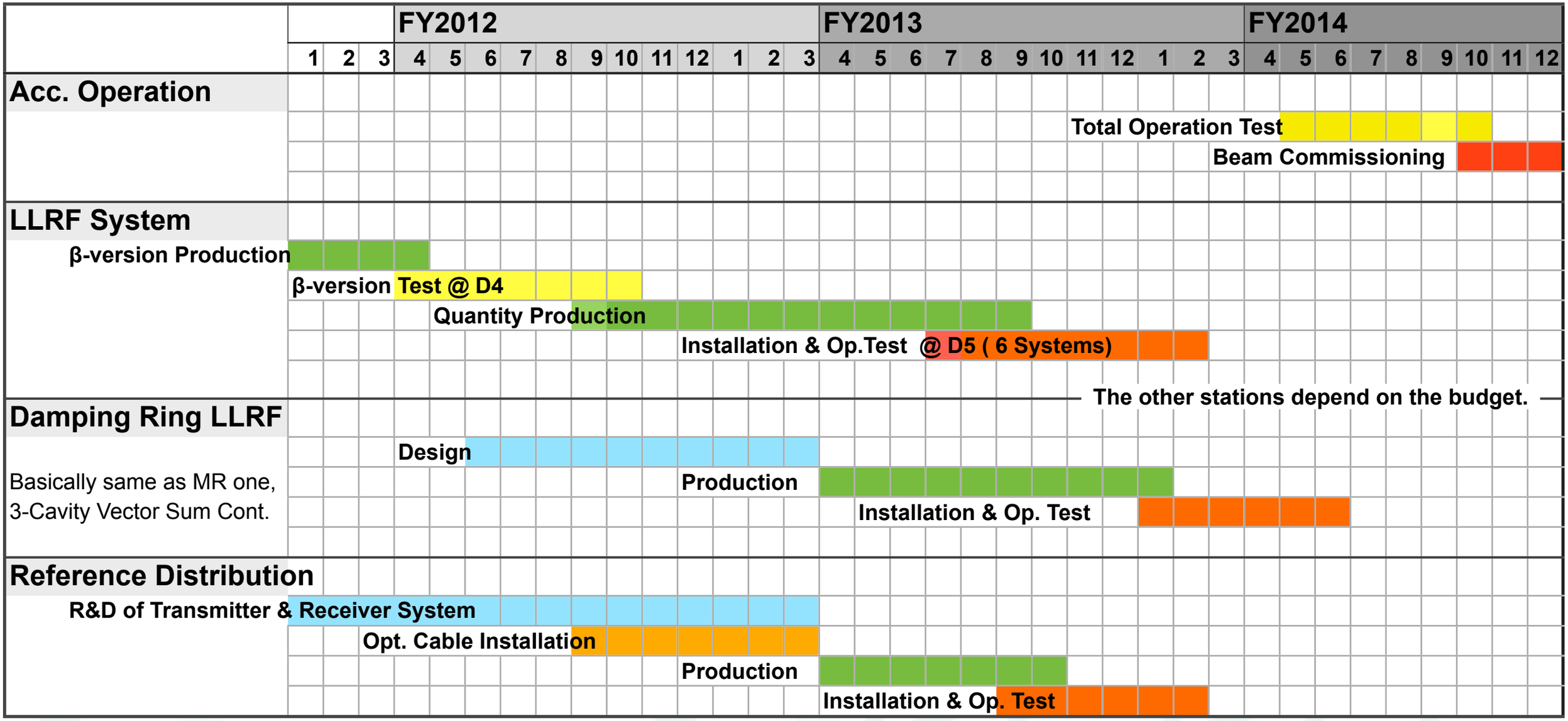
WDM : Wavelength Division Multiplexing
PSOF : Phase Stabilized Optical Fiber
ODL: Optical Delay Line (like a trombone)
E/O : Optical Transmitter
O/E : Optical Receiver
P/D : Phase Detector

As the phase detector, digital direct sampling method is proposed.

Temperature of the transceiver system should be stabilized.

Validity of these method and components will be studied and the specification will be fixed next fiscal year.

Schedule of Production and Installation



- β-version (final test model) is under production now and will be evaluated at D4 from April this year.
- 6 new systems (actual operation model) will be produced and installed in D5 station in FY2013. Additional production & installation for the other station will rely on the budget.
- DR-LLRF system also will be designed next fiscal year and will be produced in FY2013.
- For the reference distribution, the design detail will be studied and fixed next fiscal year, and the installation will be in FY2013. Optical cables will be installed next year.

Summary

- Prototype of the digital LLRF system for the SuperKEKB was developed, and Its performance was evaluated.
- Very good stability of is obtained in FB control. (0.03% in amp. & 0.02 deg. in phase)
- But, temperature dependency is not negligible. Some countermeasures should be studied.
- Auto Tuner Control given by the FPGA works successfully. (Piezo tuner control is not yet tested.)
- Optical RF reference distribution system is under consideration. The detail specification will be fixed next fiscal year.

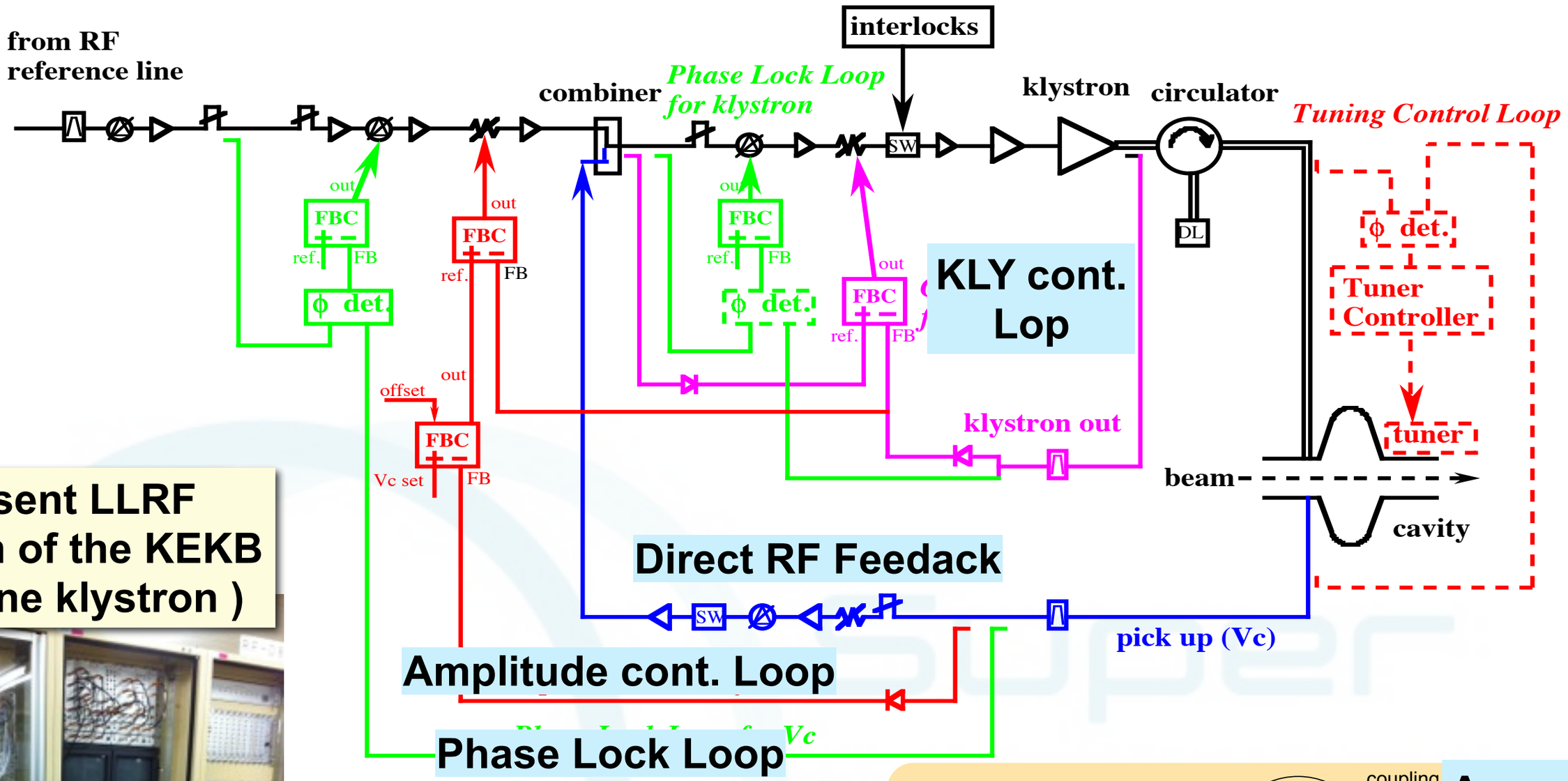
Next model for the quantity production (β version) is in the process of fabrication now.

Thank you for your attention !

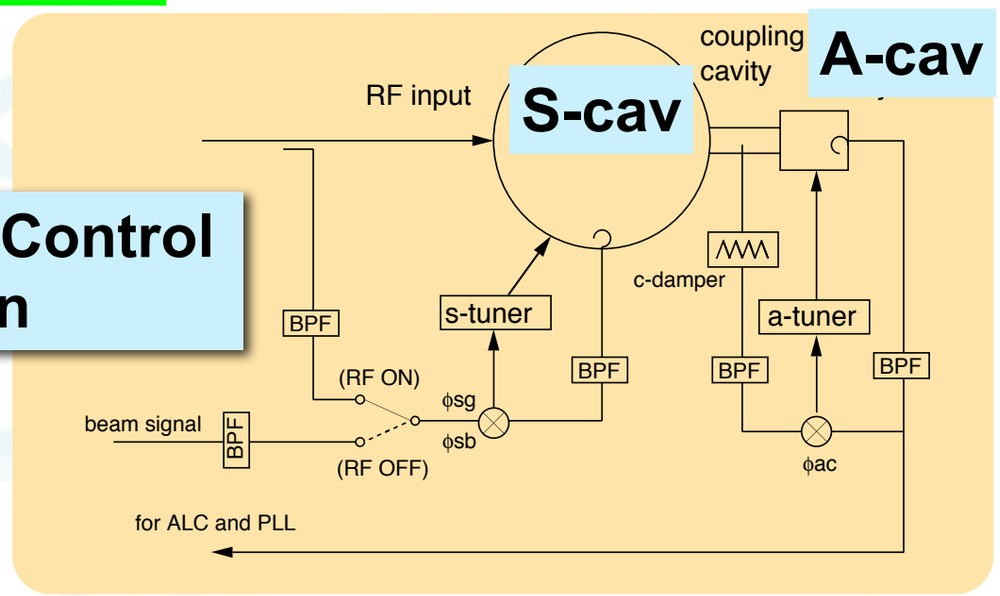
Followed by Backup Slides

KEKB-LLRF System (Present)

Present LLRF System of the KEKB (for one klystron)

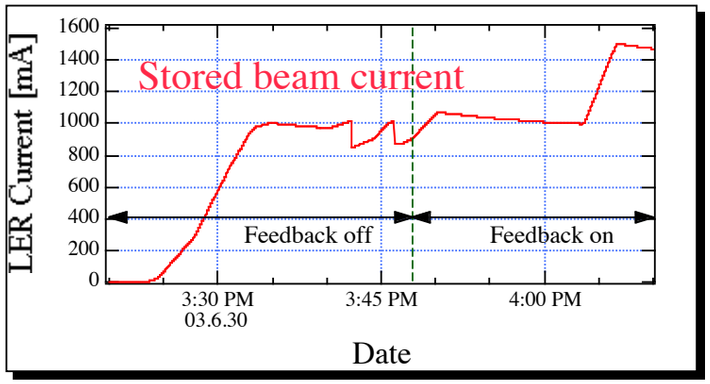


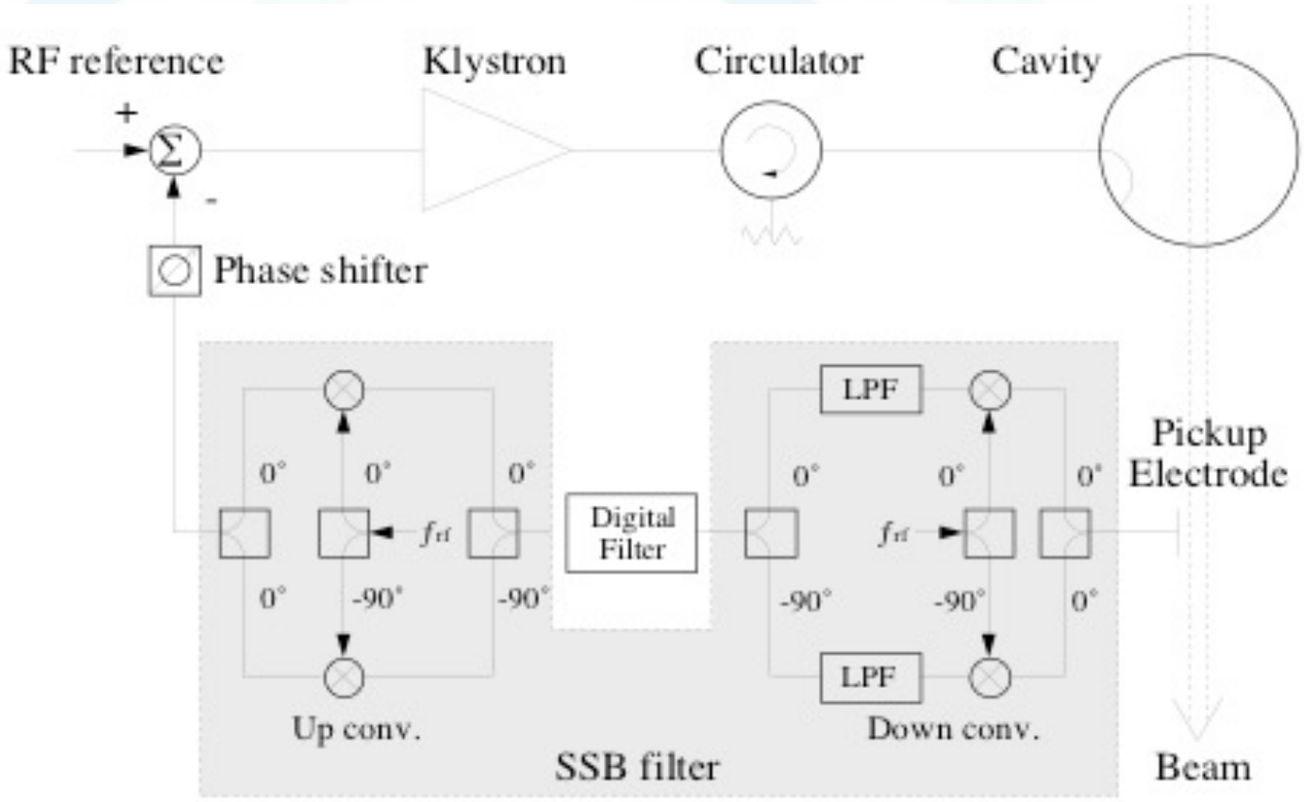
ARES Tuner Control Configuration



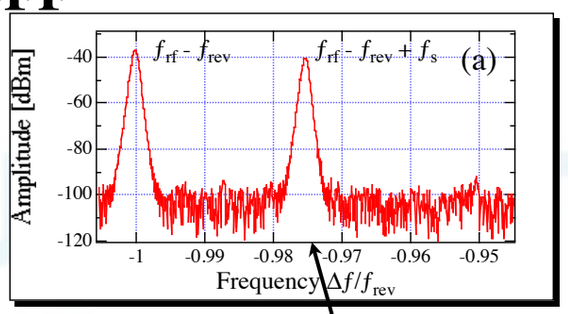
The -1 mode feedback

- Beam current was limited due to the -1 mode instability at 1 A in LER and 1.2 A in HER, much lower current than expected.
- The -1 mode digital feedback selectively reduces impedance at the driving frequency.
- After the -1 mode feedback was installed, the beam current could be successfully increased.



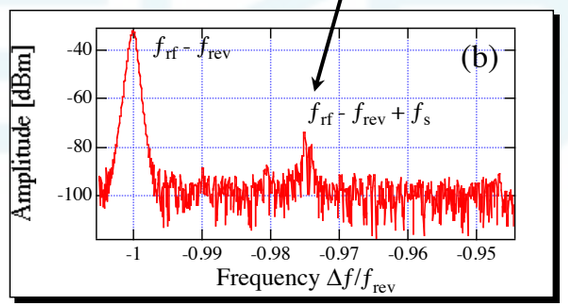


FB OFF

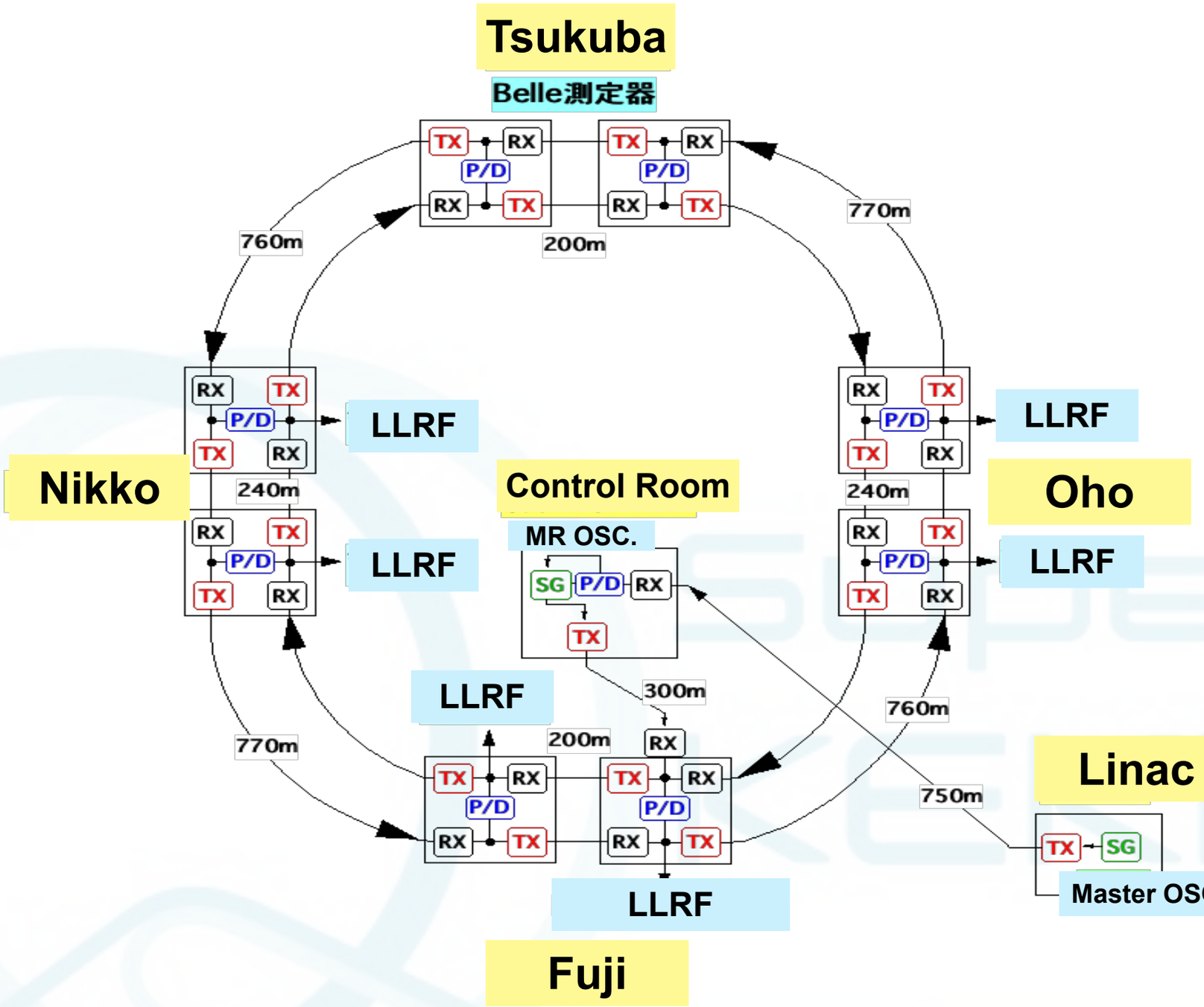


-1 mode sideband

FB ON



KEB RF Reference System

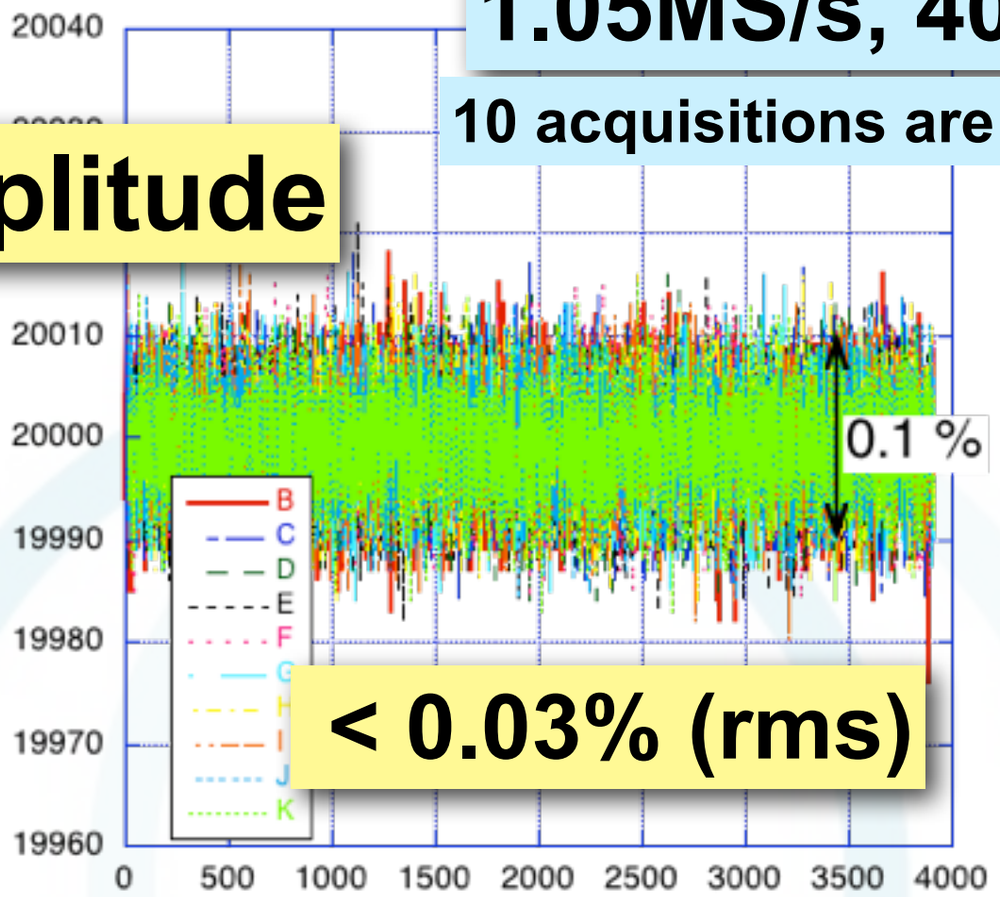


DFT of the waveform

1.05MS/s, 4096 points (~ 4-ms duration)

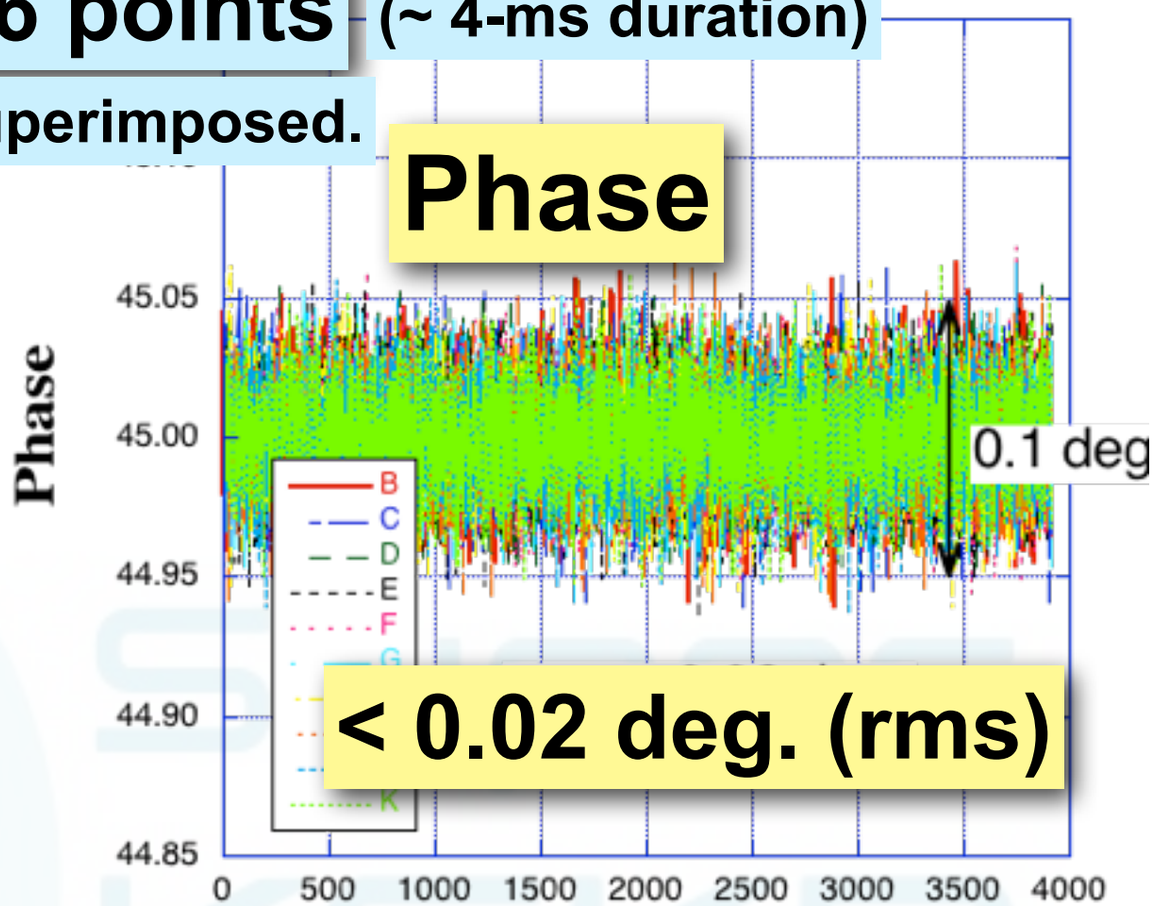
10 acquisitions are superimposed.

Amplitude



< 0.03% (rms)

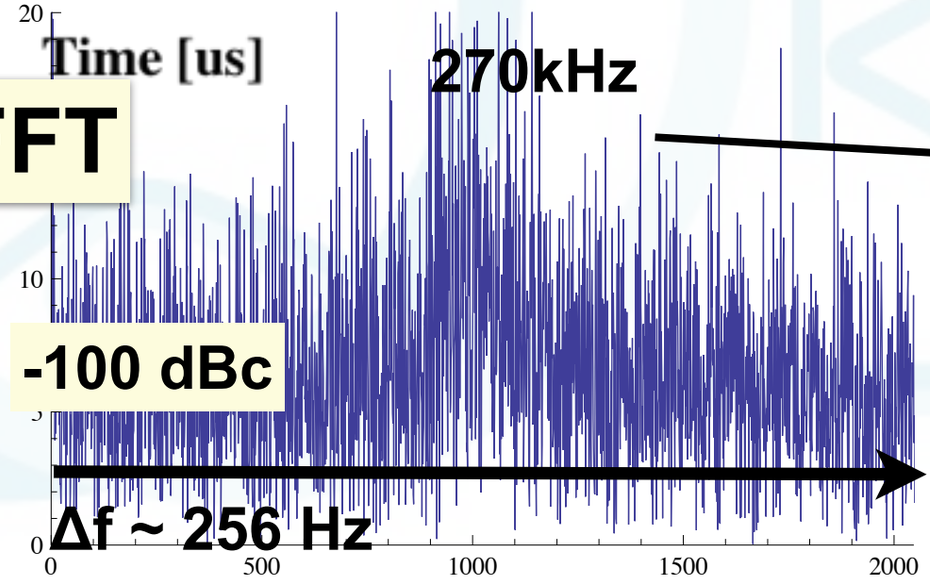
Phase



< 0.02 deg. (rms)

Time [us]

FFT



270kHz

-100 dBc

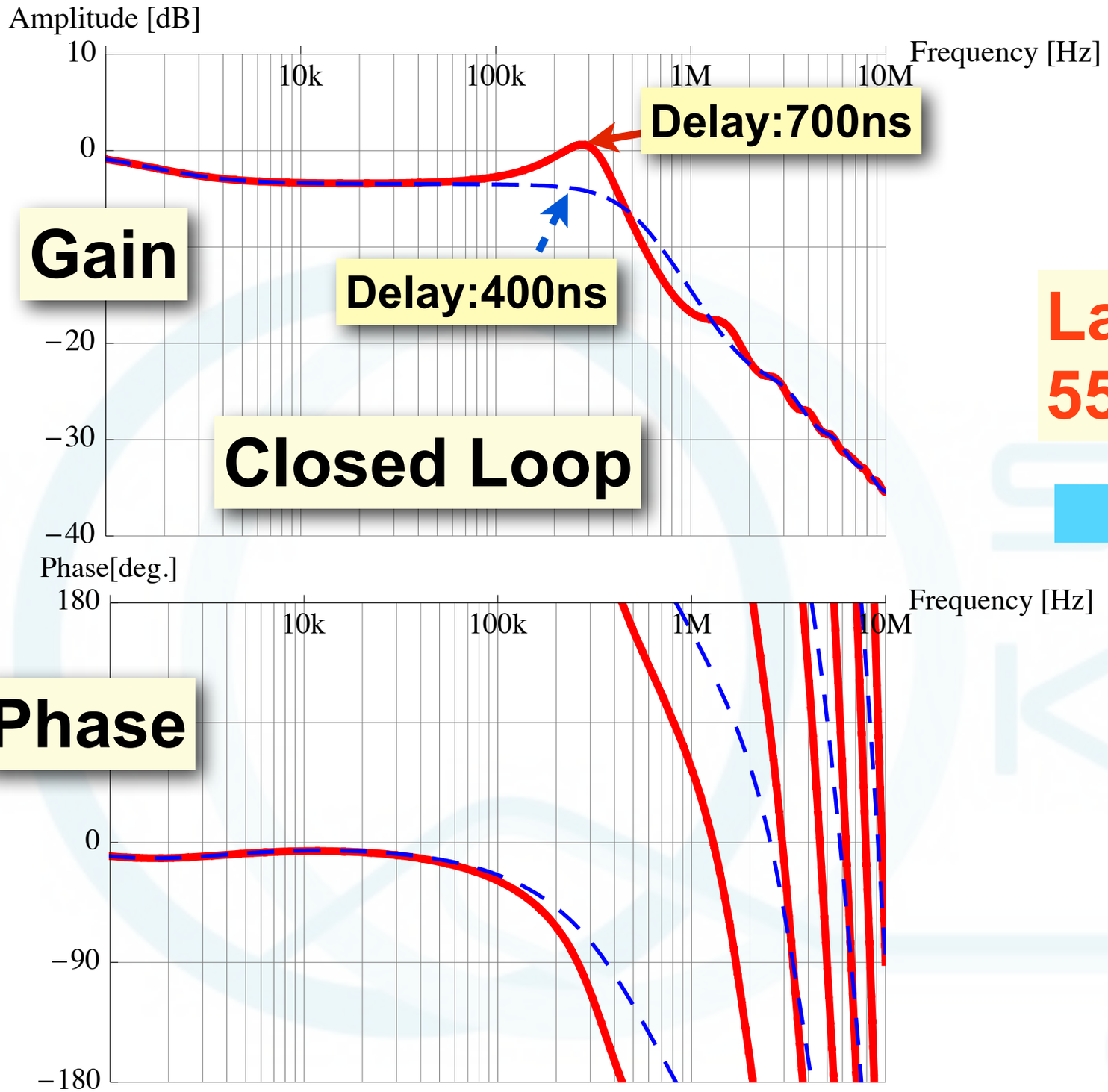
524kHz

Δf ~ 256 Hz

Due to the latency of the FPGA and DAC, which makes 650ns-loop delay.
No problem for the ARES Cavity (Q_L~20000).

Bode Plot for the Simulant Cavity
(Q_L~3000)

P_{gain}=2, I_{gain}=2.6x10^4



Q_L=3000

Δω = 0

Loop Delay = 700ns

Latency in the FPGA :
55 clock

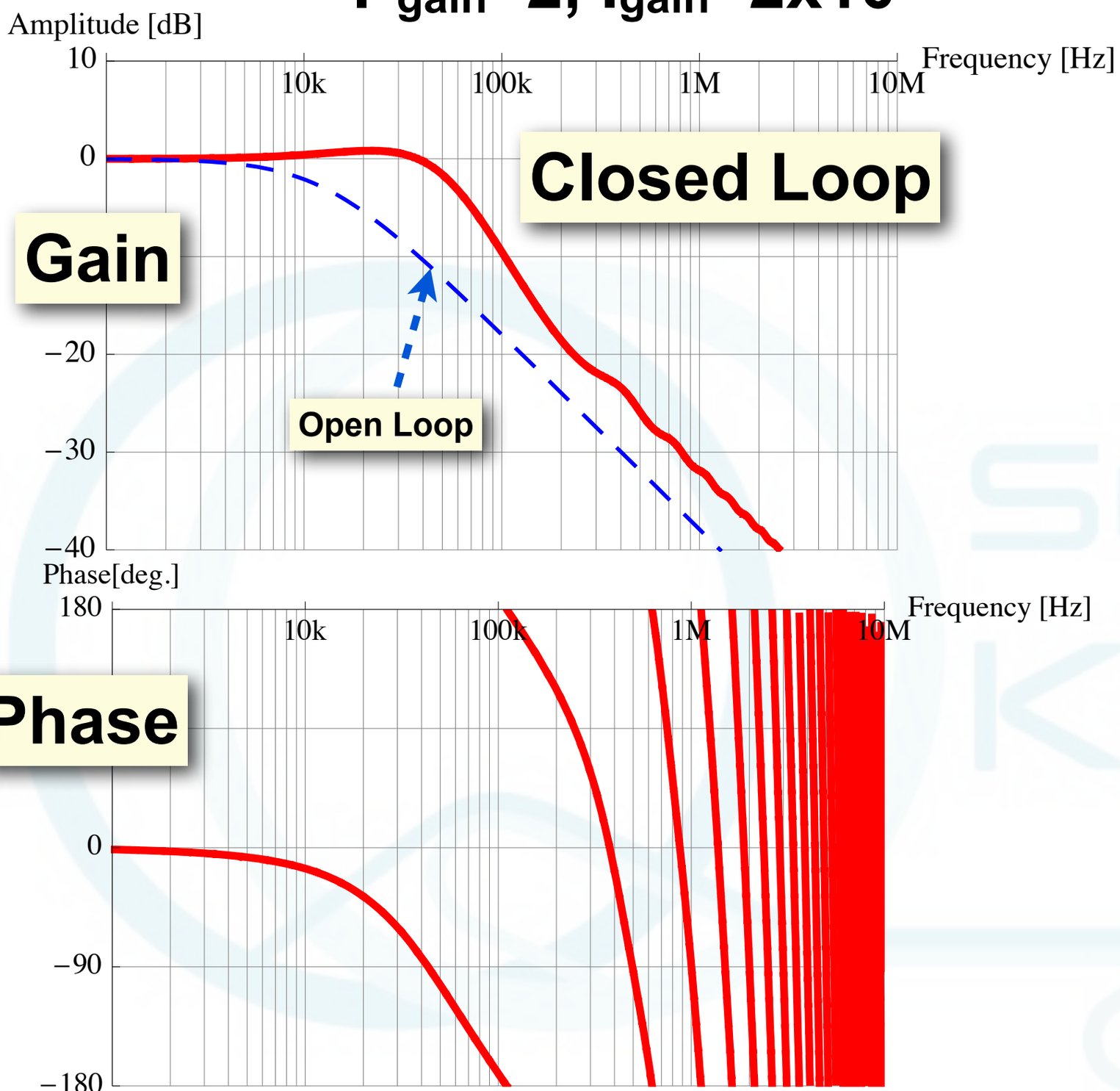
Loop Delay :
~650ns

Gain Mergin :
~13dB

P_{max} ~2.2

Bode Plot for the ARES
(Q_L~20000)

P_{gain}=2, I_{gain}=2x10^5



Q_L=20000

Δω = 0

(Q_0=120000, Coupling=5)

Loop Delay = 3us

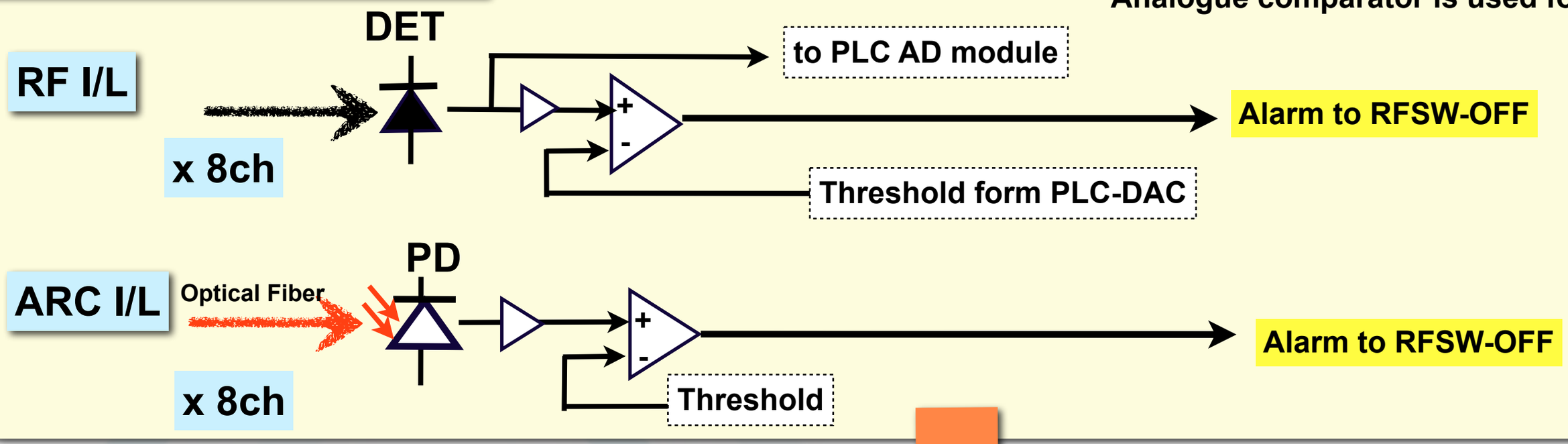
Gain Mergin : ~18dB

P_{max} ~4

RF & ARC Inter Lock

α version

Analogue comparator is used for I/L



β version

Detector output is sampled by ADC at 42-MHz Clock on FPGA.

Sampled waveform can be read as EPICS record.