



Digital LLRF feedback control system for the J-PARC linac

Shin MICHIZONO

KEK, High Energy Accelerator Research Organization (JAPAN)

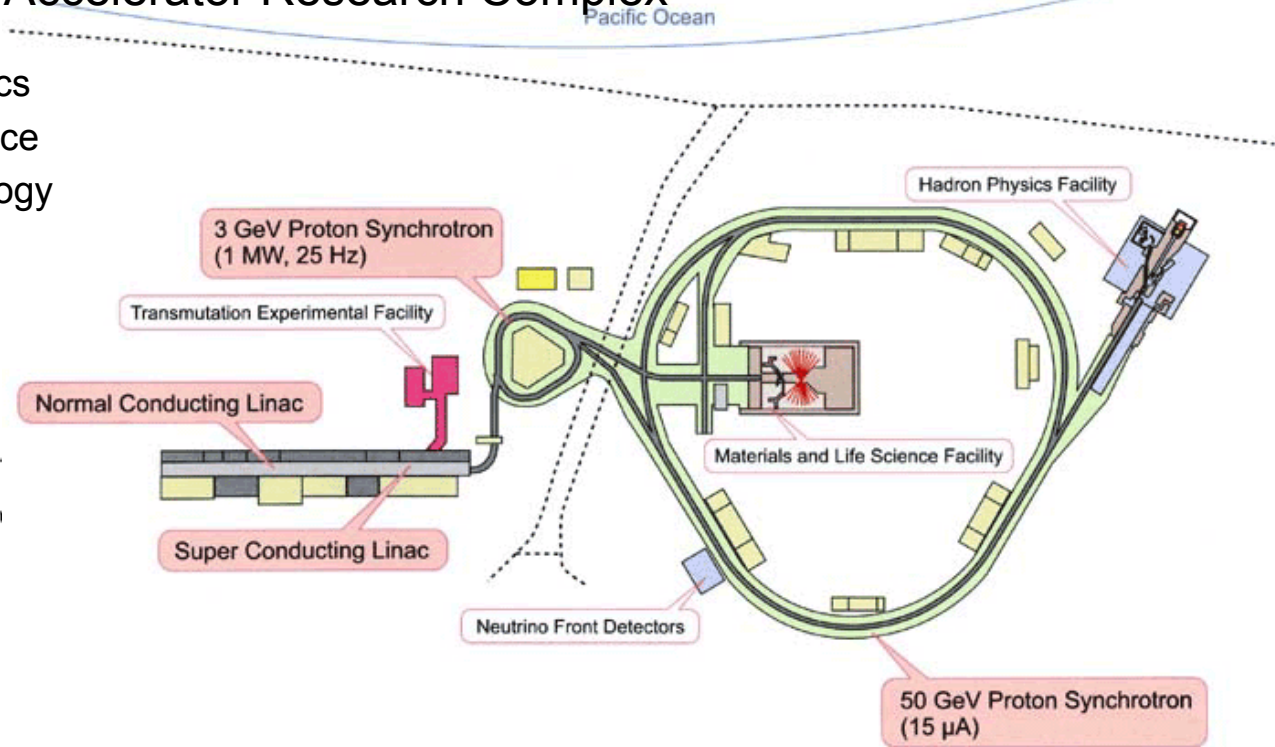
- J-PARC linac
- LLRF system
- FPGA based Digital FB system
- Performance
 - During rf pulse
 - Tuner control
 - Running
 - Beam compensation

What's J-PARC?

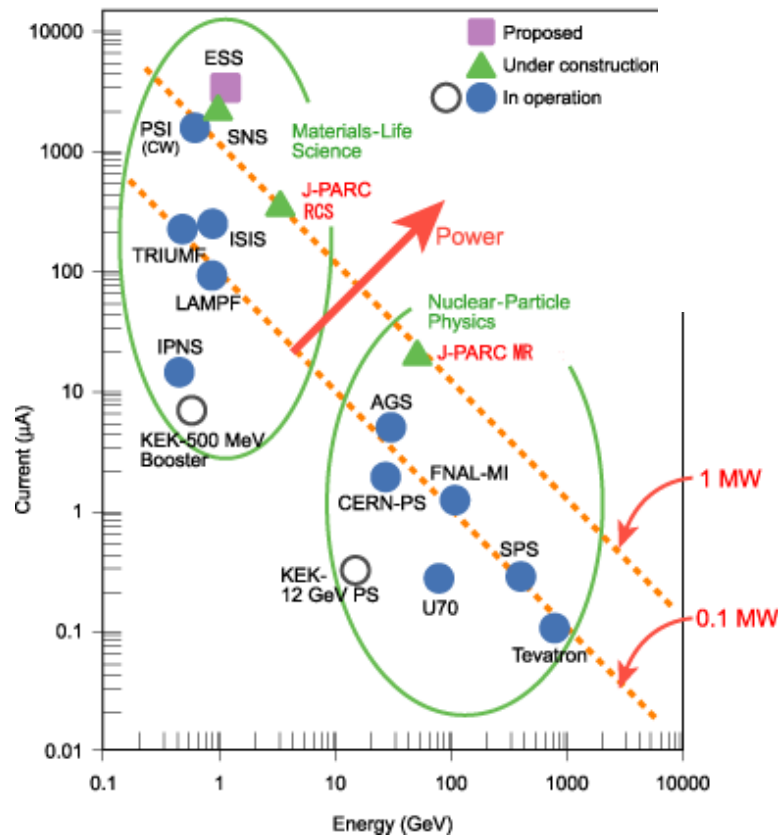


J-PARC: Japan Proton Accelerator Research Complex

- ◇ frontier science in particle physics
- ◇ nuclear physics, materials science
- ◇ life science and nuclear technology



Power map of worldwide proton accelerators



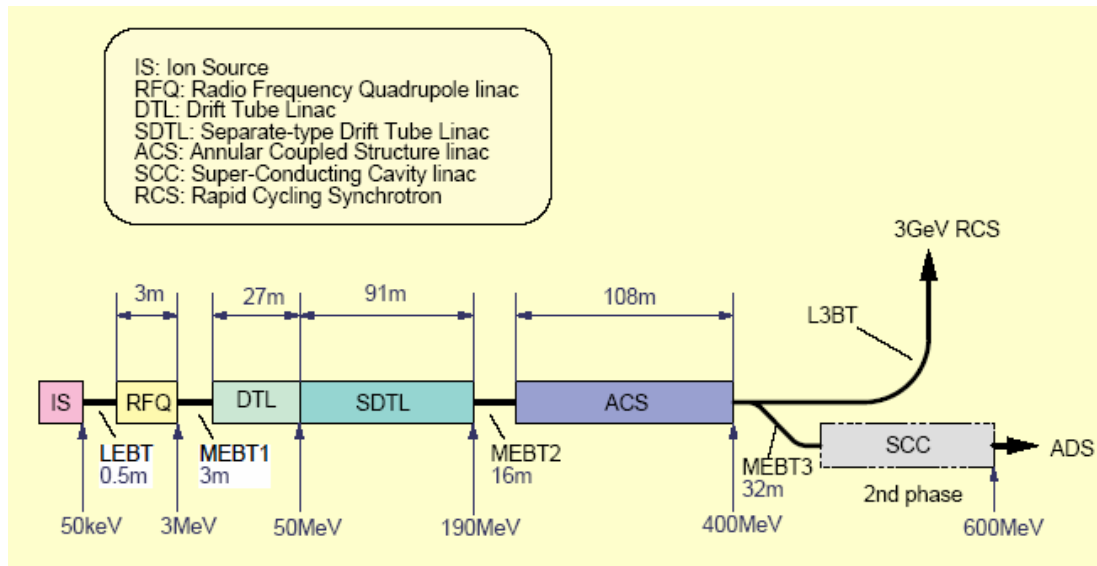
Construction Schedule

	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008
Linac		Bldg. construction	Equip. construction			Beam test		
RCS		Bldg. construction	Equip. construction			Beam test		
MR		Bldg. construction	Equip. construction			Beam test		

LLRF requirements



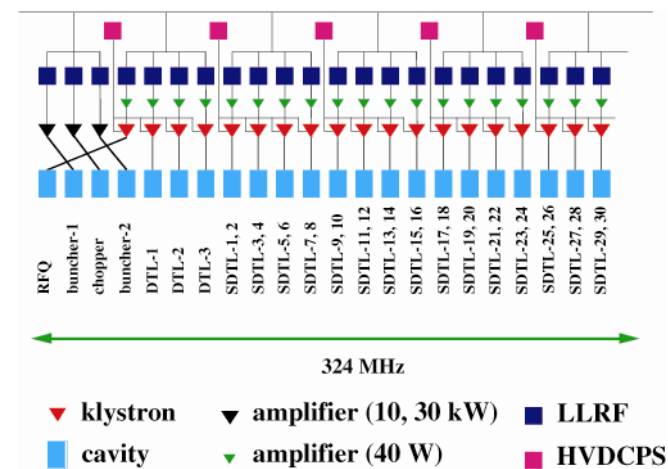
- ✧ 190 MeV normal conducting proton linac
- ✧ Operation frequency: 324 MHz
- ✧ Total 19 klystrons (max.3 MW)
- ✧ RF flat top: 650 us
- ✧ Requirements of cavity electric field stability
- ✧ $\pm 1\%$ (amplitude),
- ✧ $\pm 1\text{deg.}$ (phase)



Total 19 klystrons drive cavities



Klystron gallery





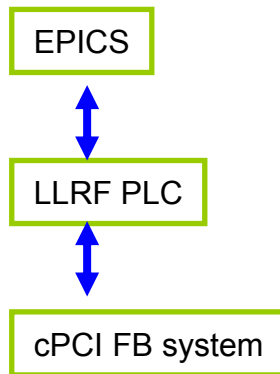
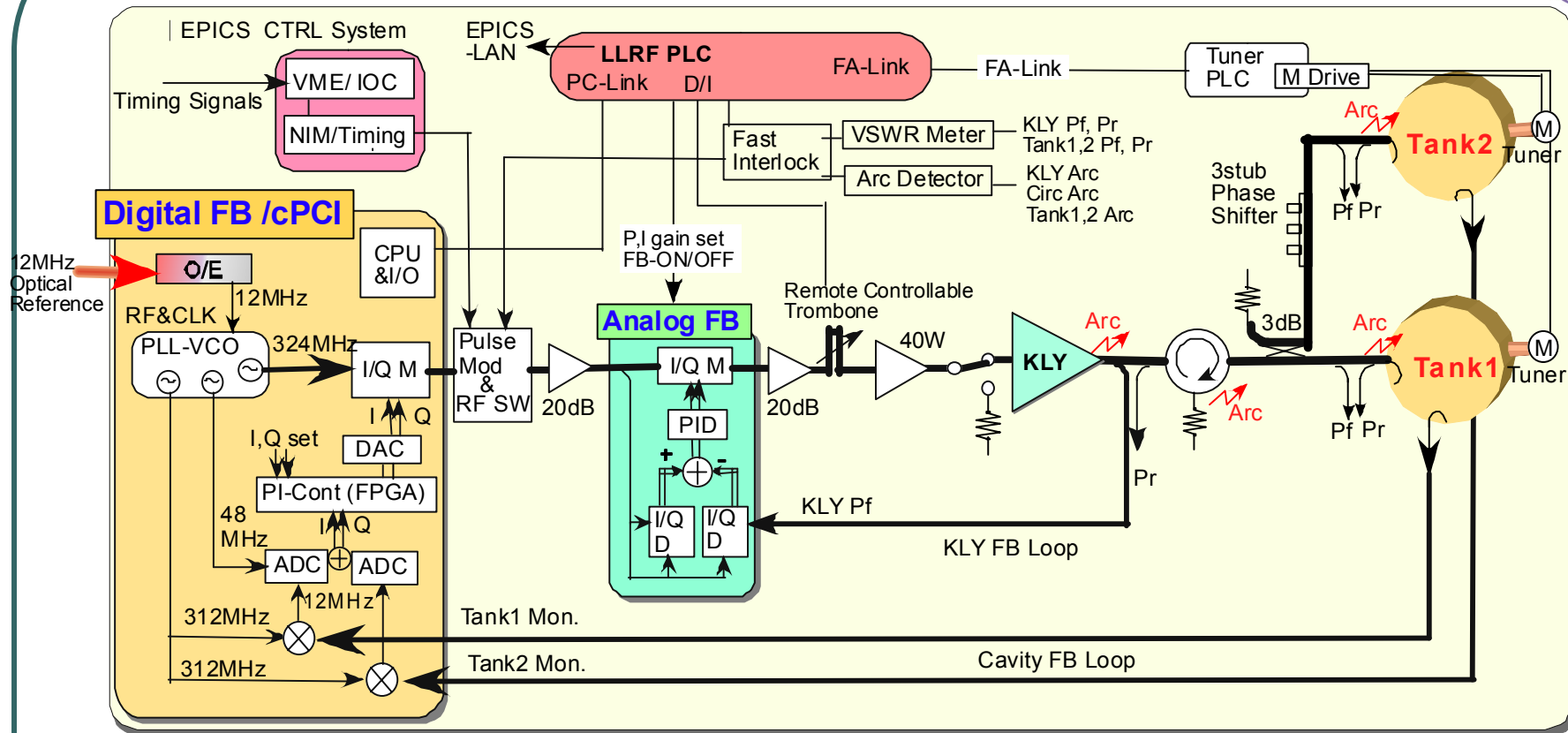
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J-PARC LLRF system



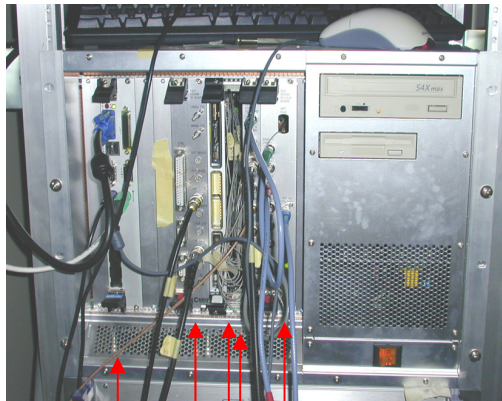
cPCI digital FB system

- generates LLRF signal (12 MHz, 48 MHz, 312 MHz and 324 MHz)
- delivers I/Q modulated rf signals to 2 cavities
- receives rf signals from cavities and down-converts to IF

Fast hardwire interlock is connected to Pulse Modulator (outside cPCI).

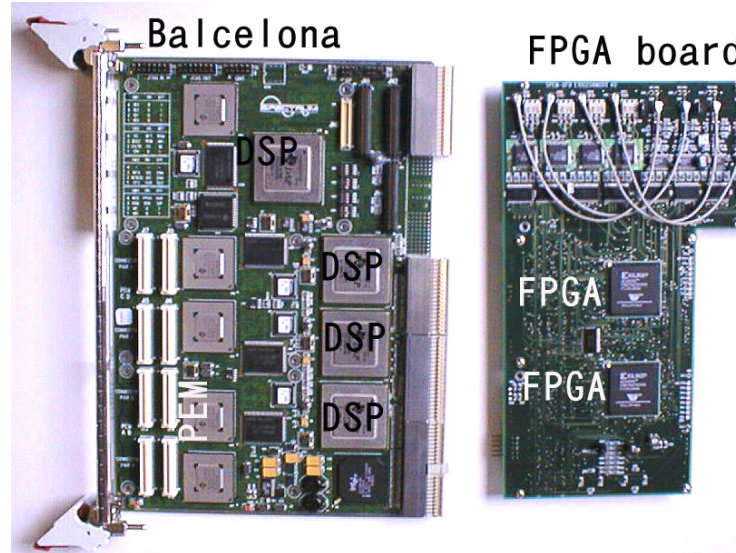
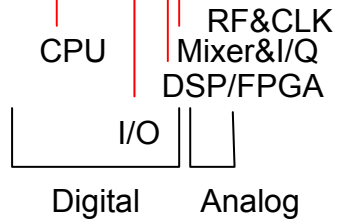
Analog fast FB will be used for klystron FB loop.
Cavity-tuners are controlled from cPCI by way of PLC.

cPCI digital FB system

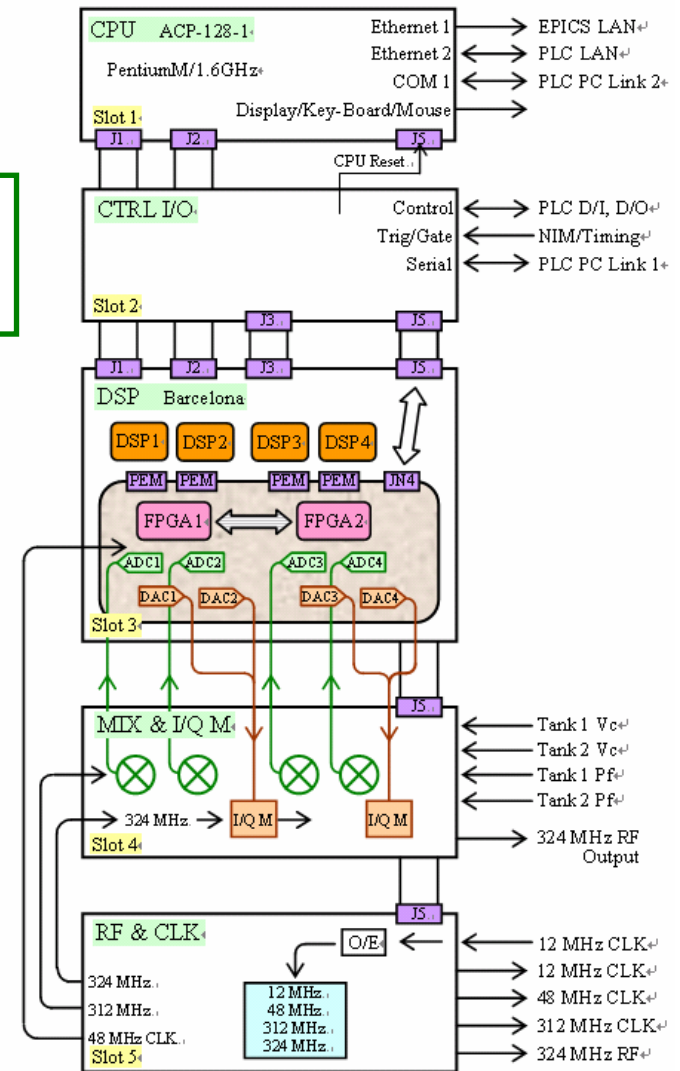


cPCI is adopted for the crate.

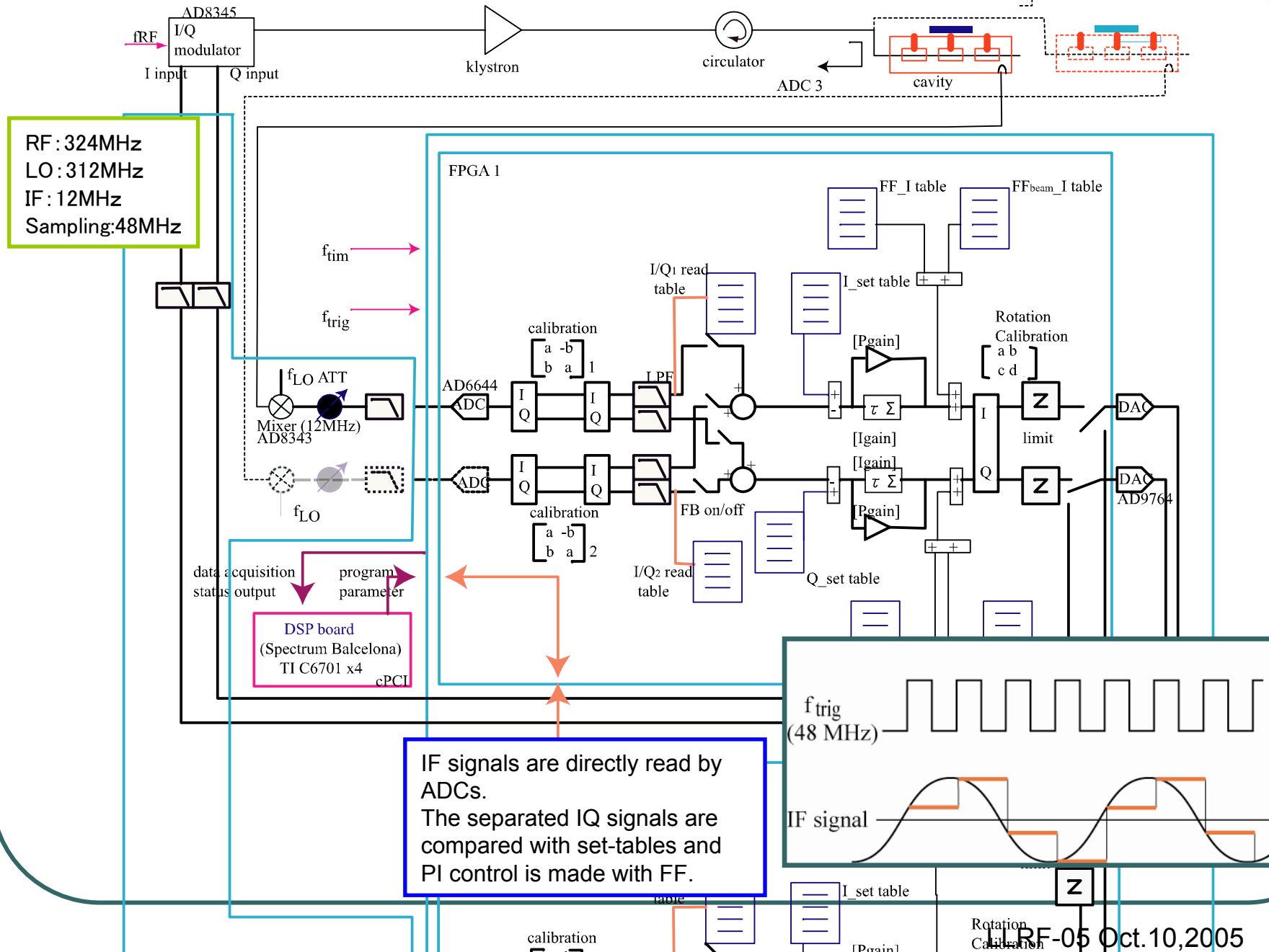
FPGA based digital FB system
FPGA: Mezzanine card of the commercial DSP board



- **2-FPGAs (2x VirtexII 2000) are installed with 4x14bit-ADCs and 4x14bit-DACs at 48 MHz sampling**
- DSP board enables to calculate complex diagnostics such as cavity control.
- FPGAs are used only for fast feedback.



FB algorithm





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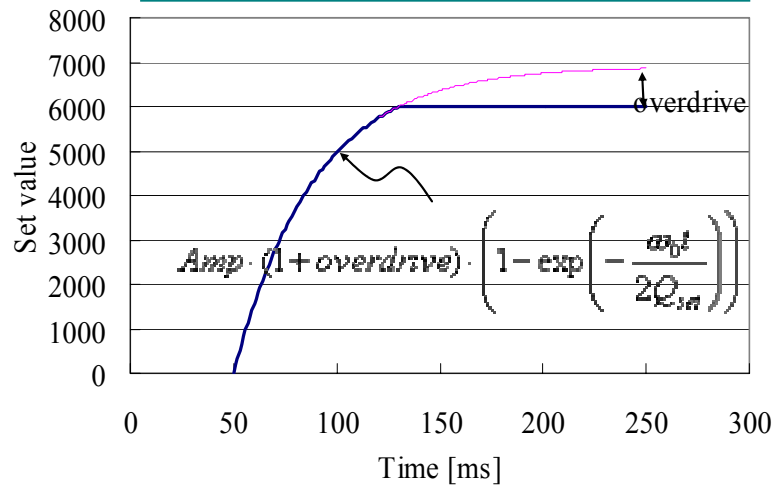
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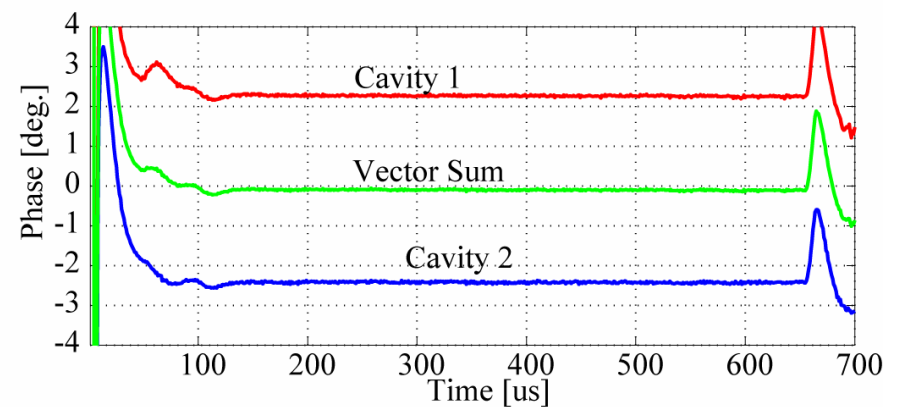
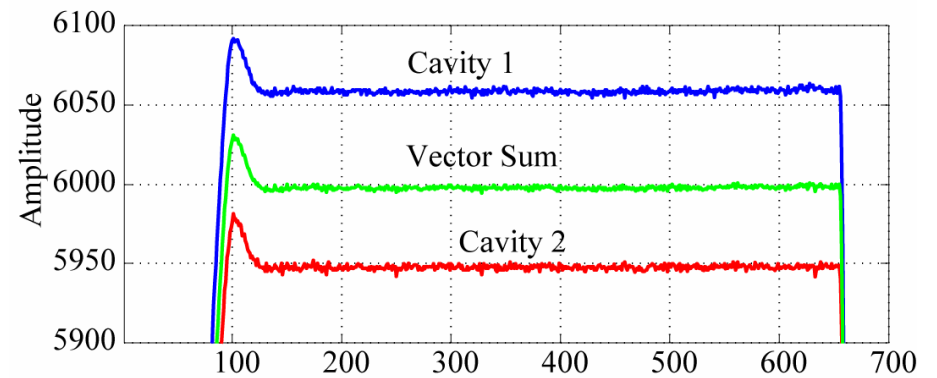
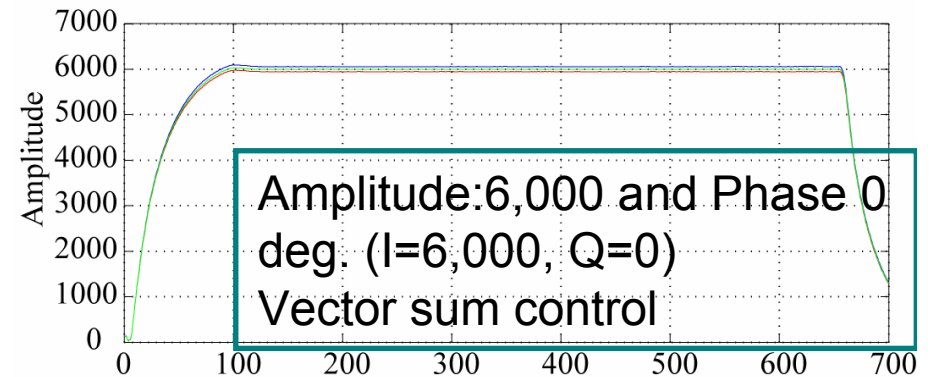
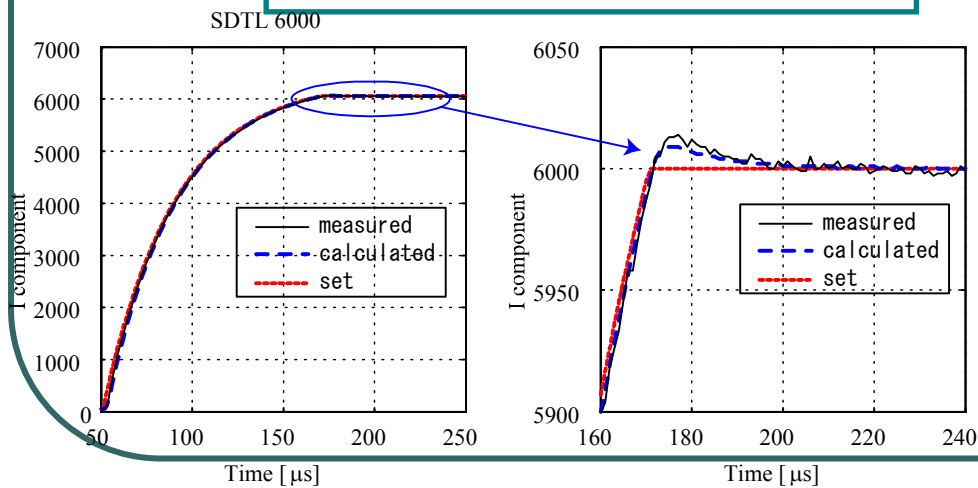
Vector Sum Control



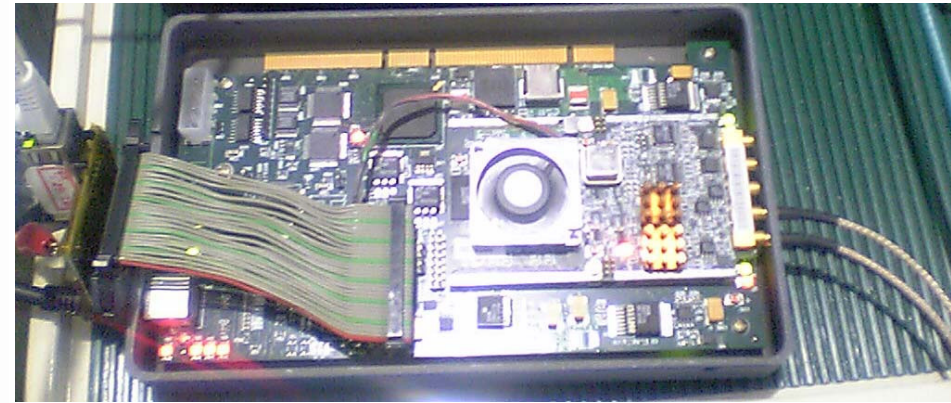
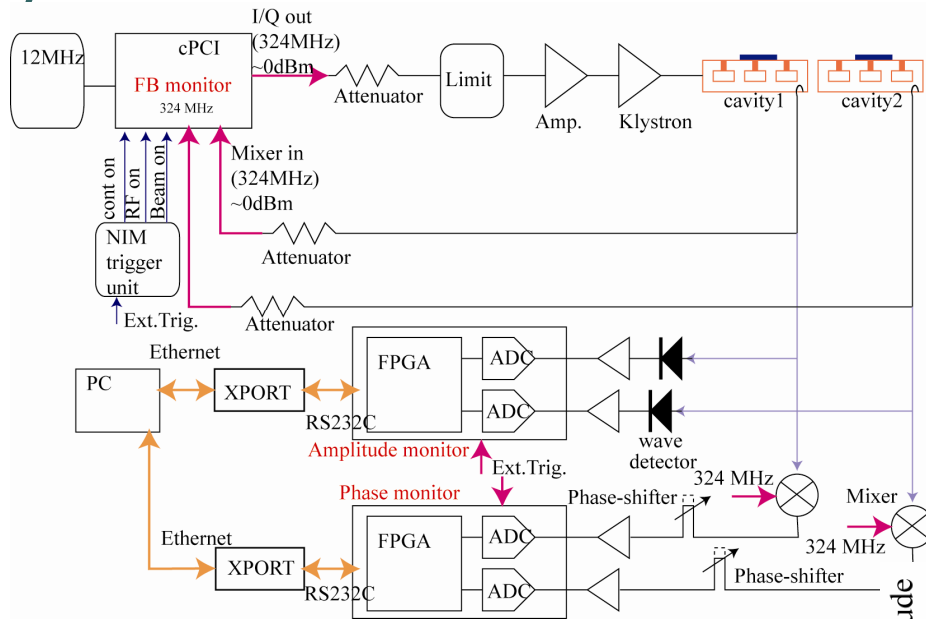
Set table is exponential function



Agrees well with simulation

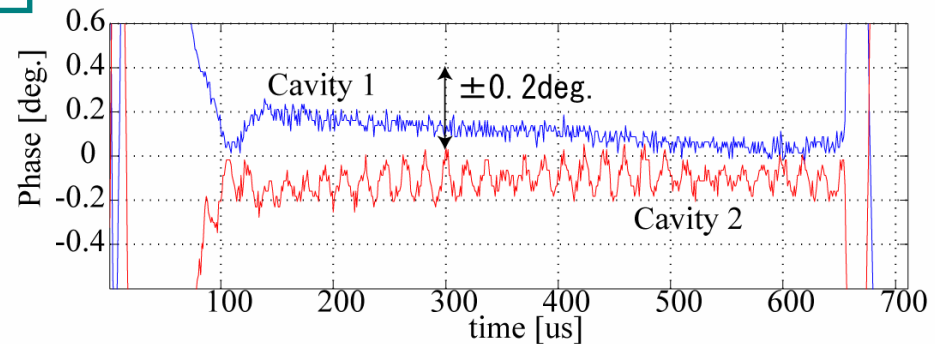
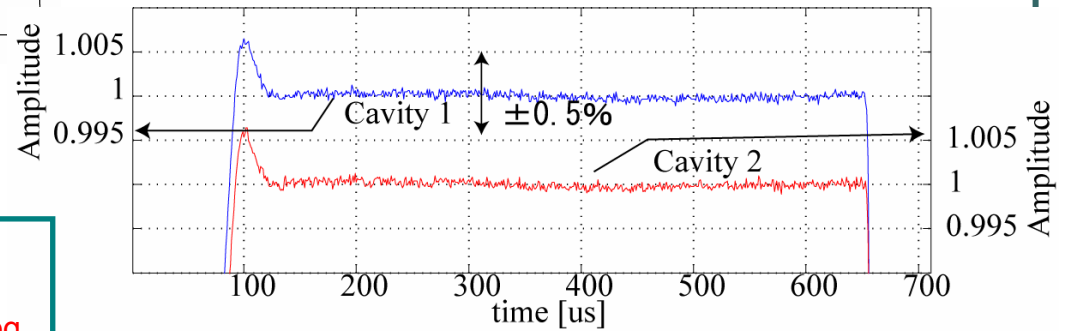


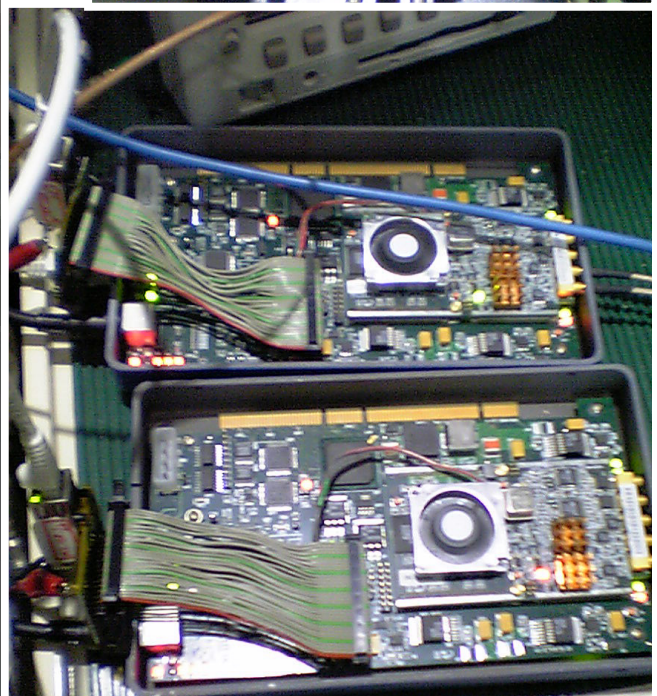
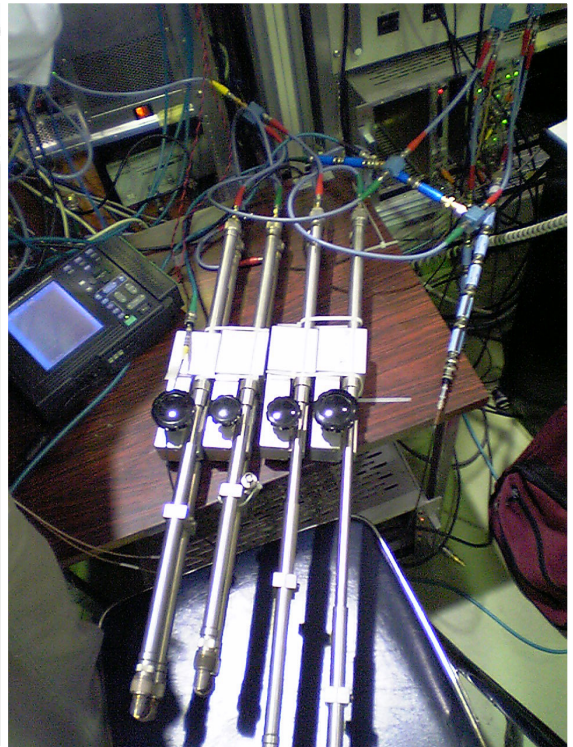
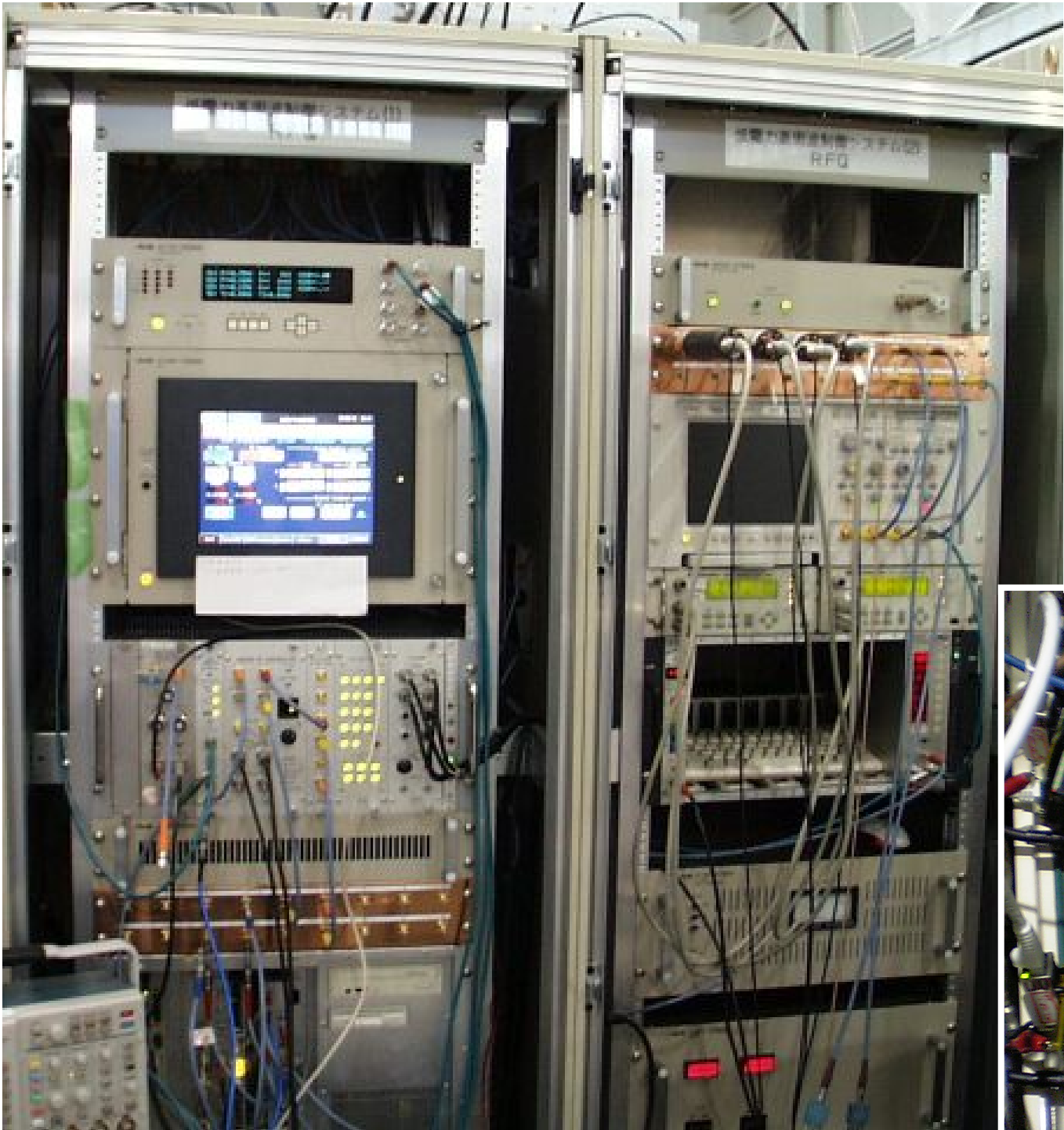
External monitor



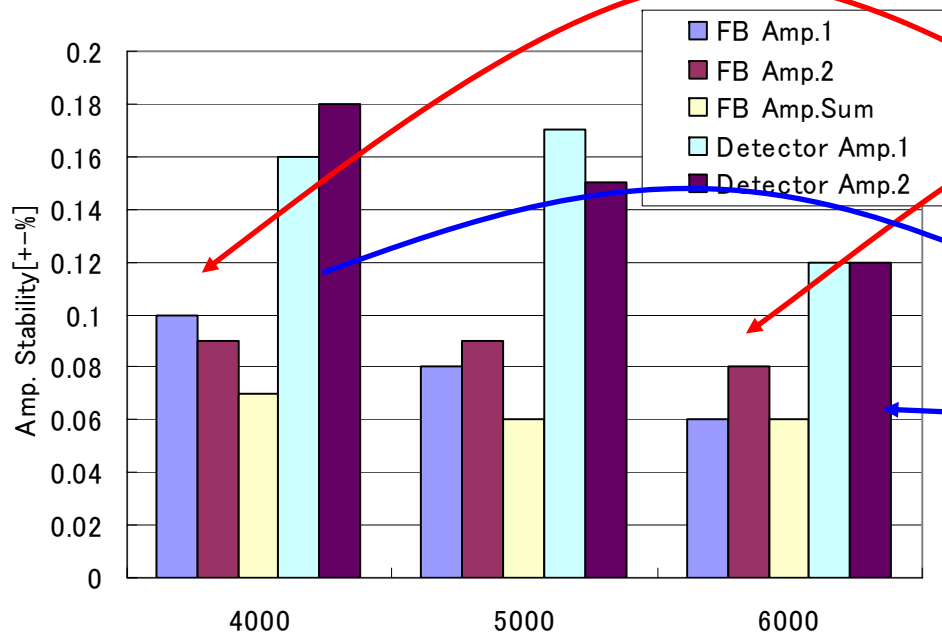
Xtreme DSP board by Xilinx (commercial FPGA board with 66 MHz ADCs)

External monitors are assembled with commercial fast FPGA board.
The amplitude and phase stability is $\pm 0.15\%$, $\pm 0.15\text{deg}$.

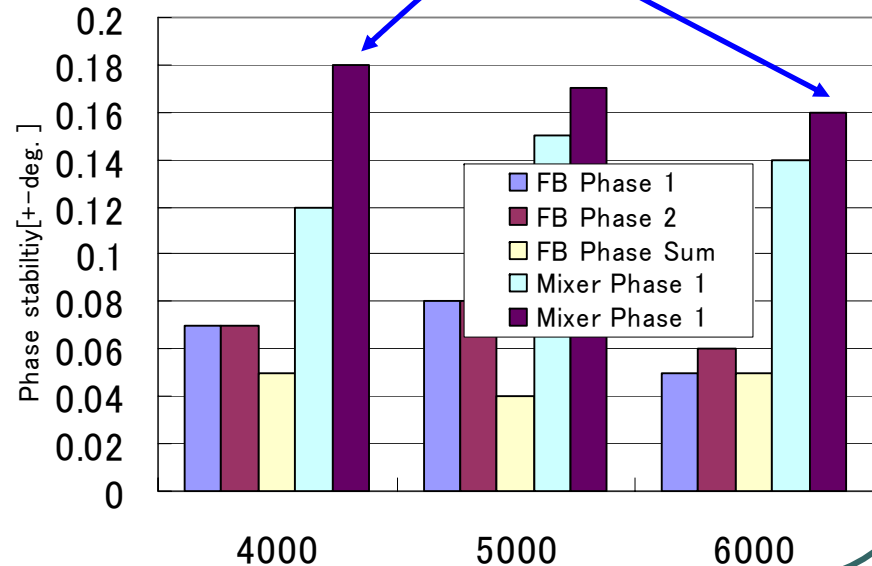
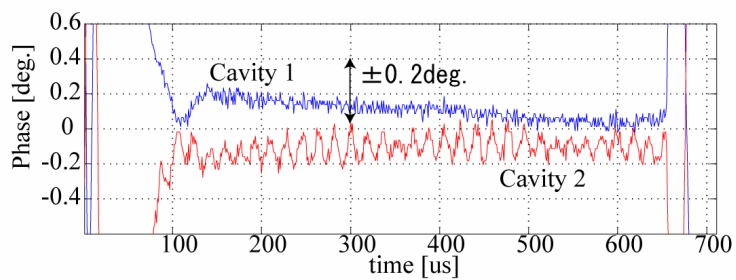
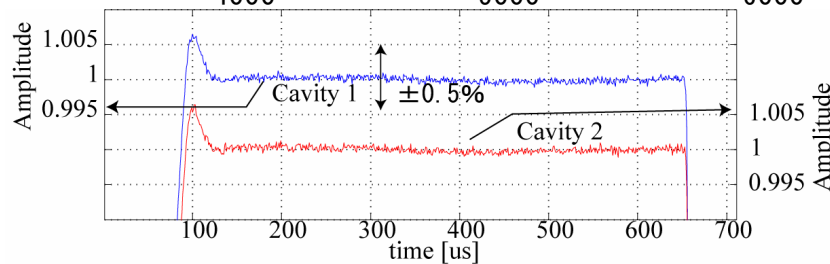
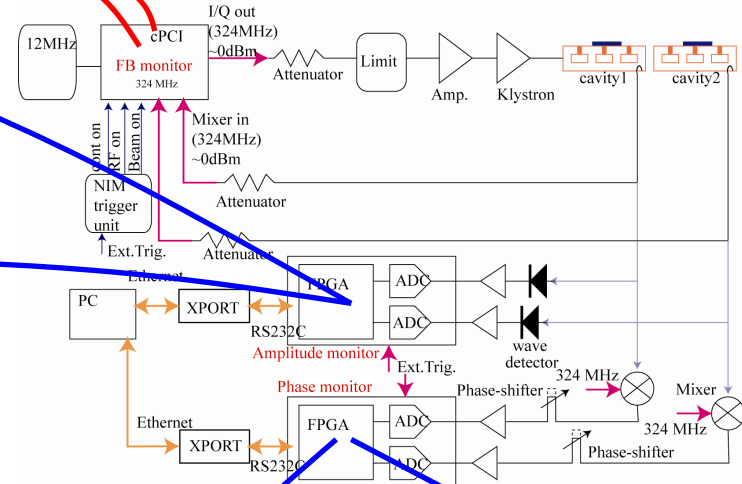




FB stability



Set value: 6,000 → 5,000 → 4,000
 With same FB parameters.
 FB works well with the amplitude variation of >20%.





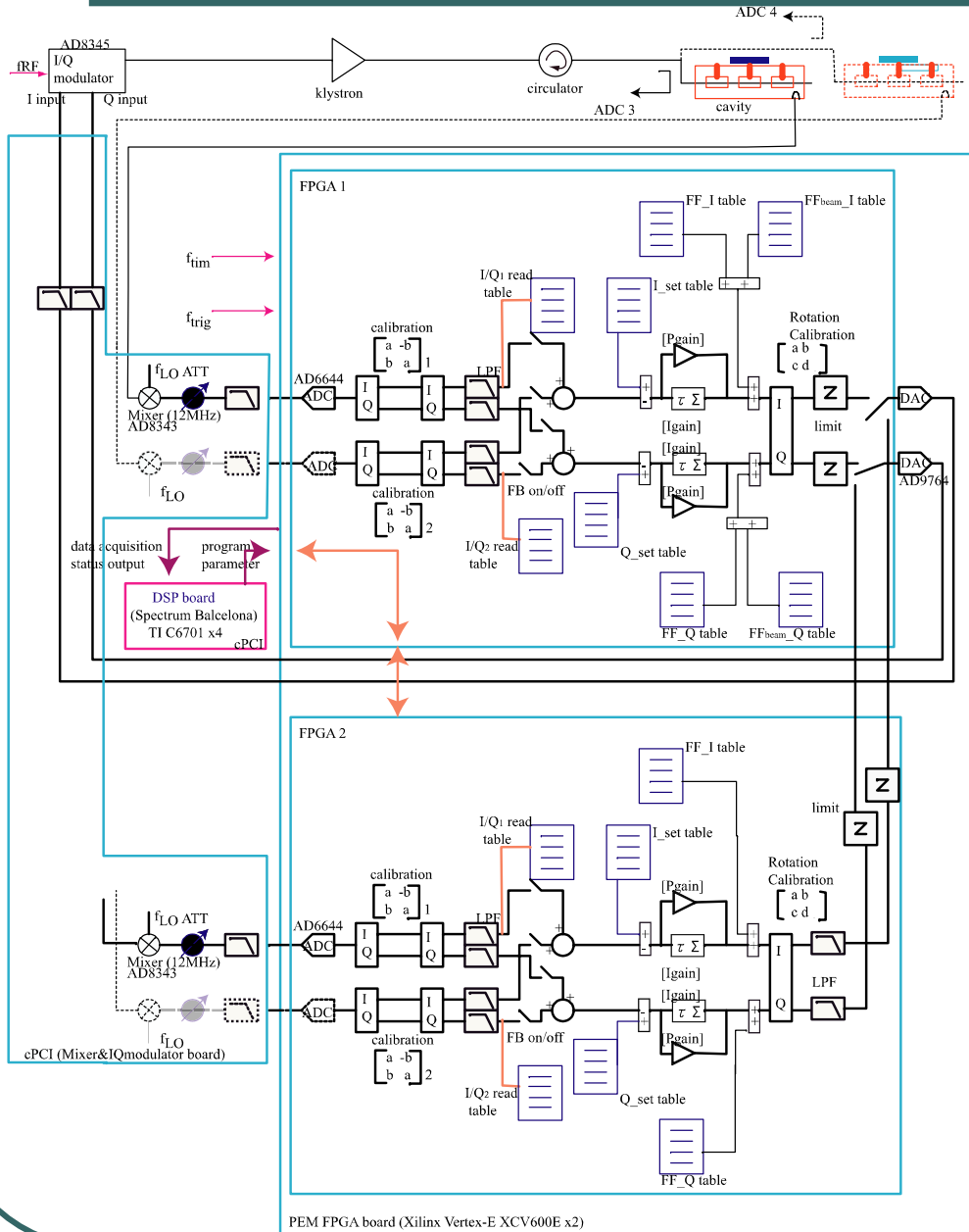
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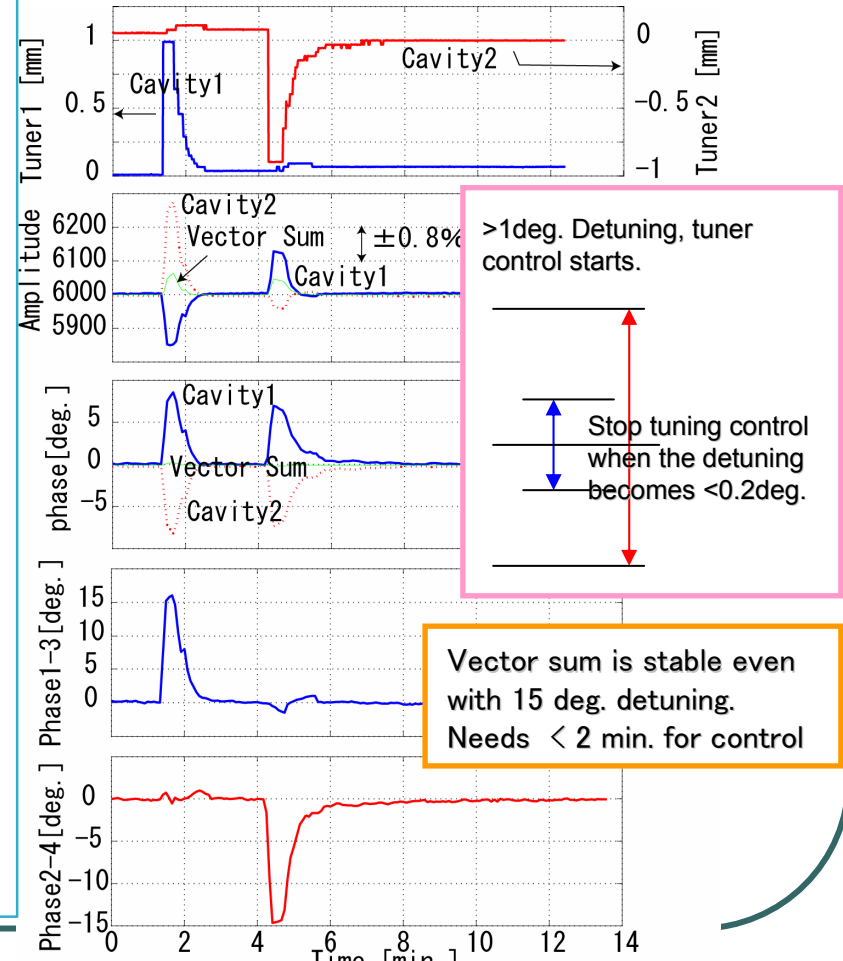
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Tuner control



A klystron drives 2 cavities.
 ADC_1,2:cavity field monitors
 ADC_3,4:cavity input monitors
 Detuning is calculated from the difference between input and cavity by DSP.
 -> Tuner control is carried out by DSP.



PEM FPGA board (Xilinx Vertex-E XCV600E x2)



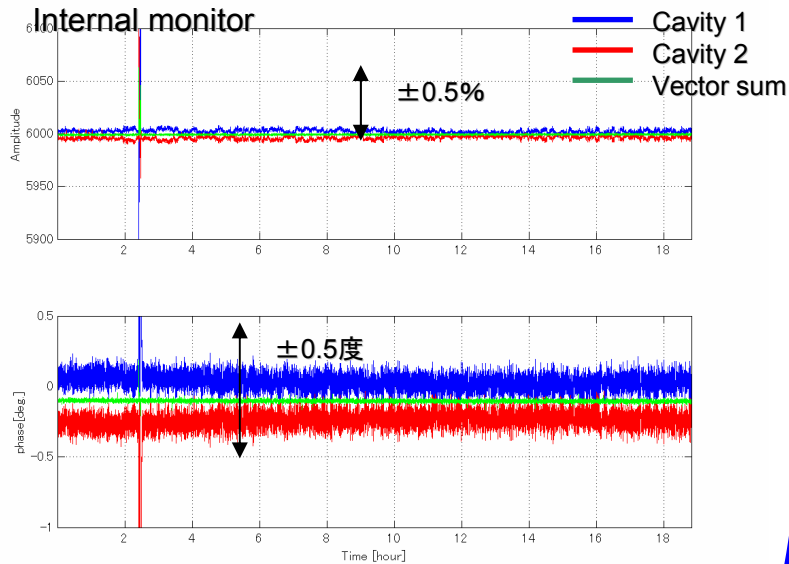
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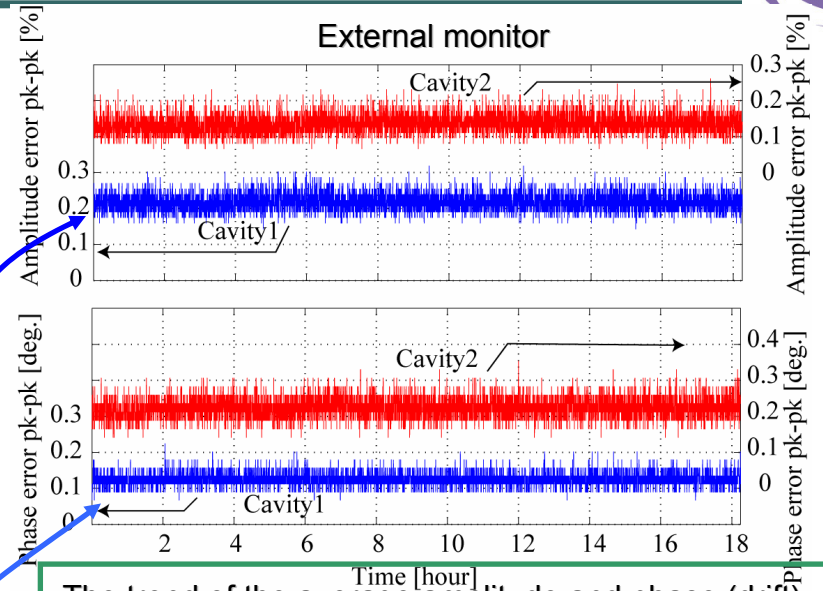
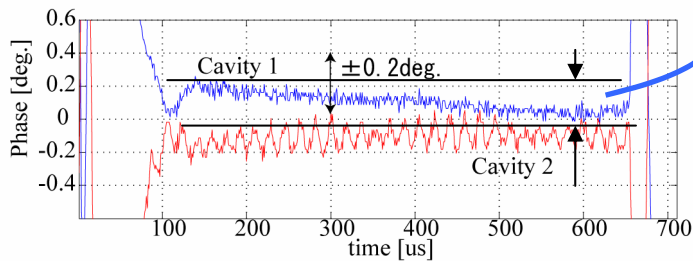
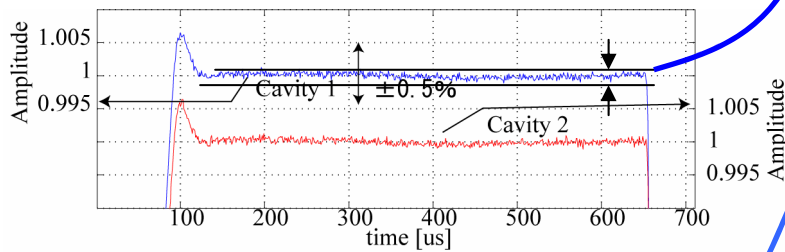
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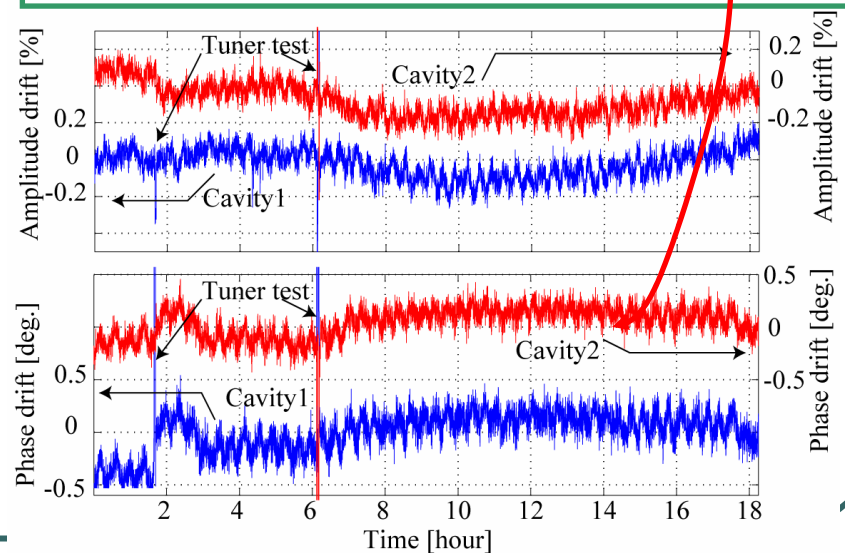
Running data of J-PARC LLRF



Quite stable



The trend of the average amplitude and phase (drift)
 The small drifts (<.2%, .2 deg.) are caused by the temperature dependence of the rf circuits.
 These will disappear at the new version.





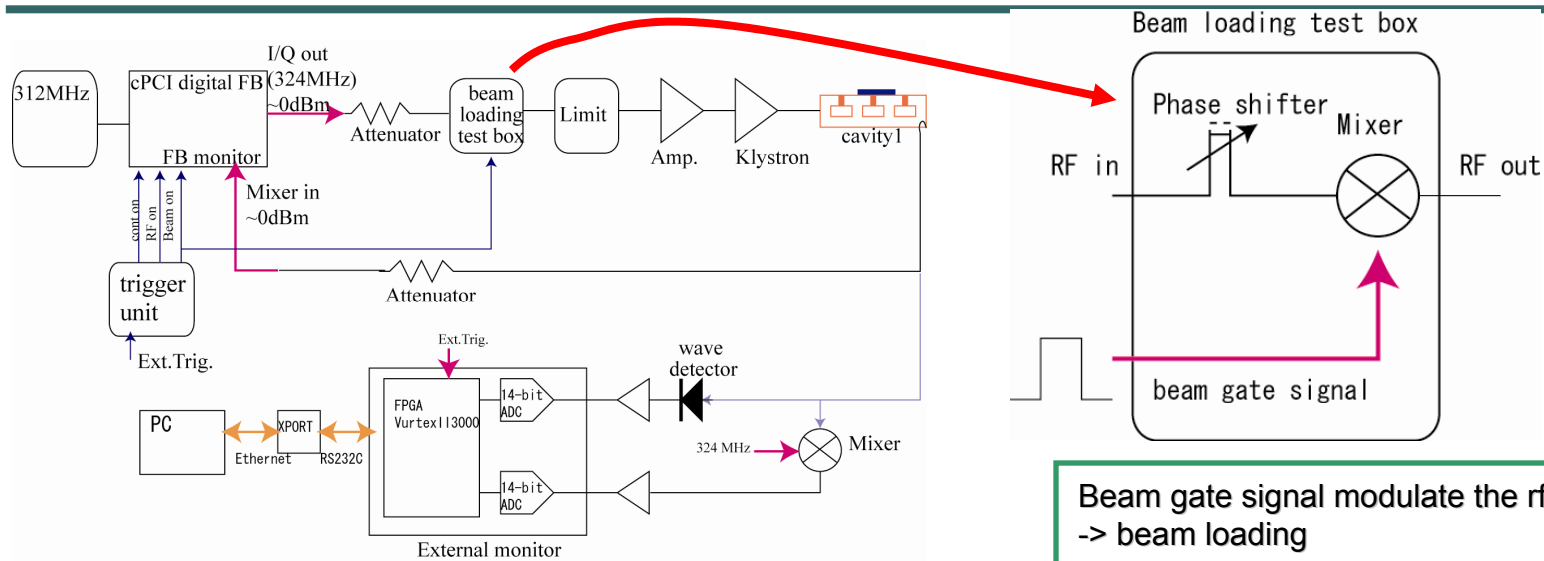
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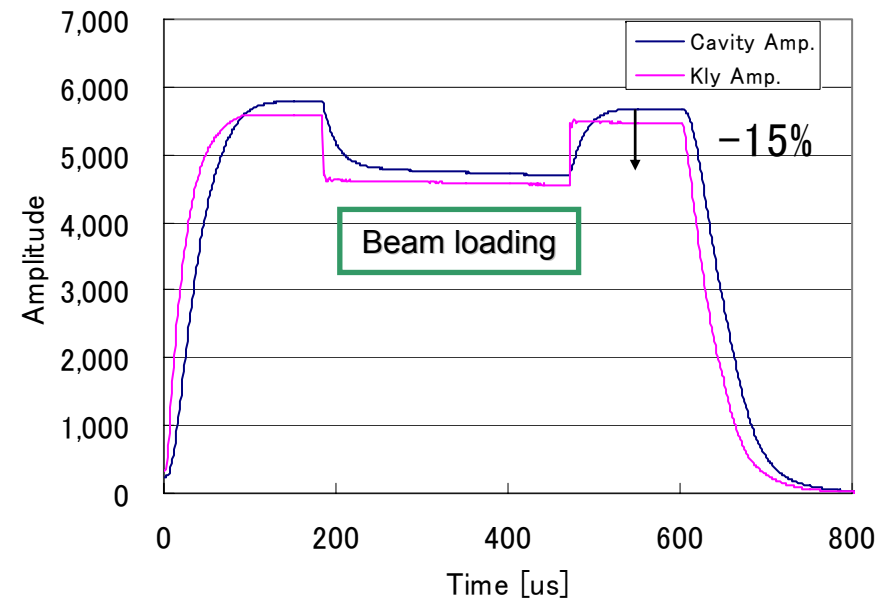
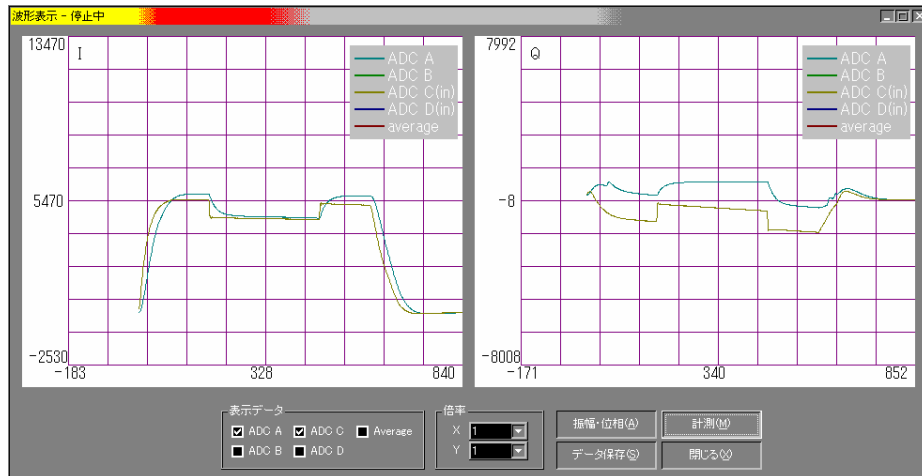
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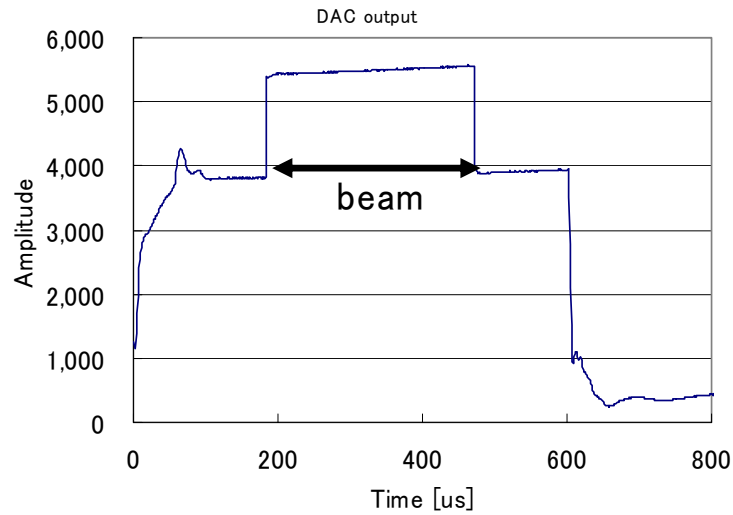
Beam loading test



Beam loading observed at FB monitor



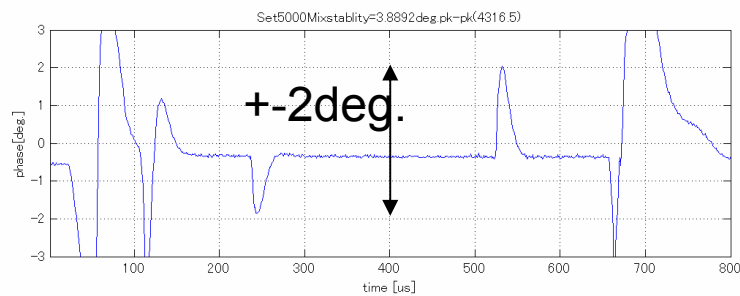
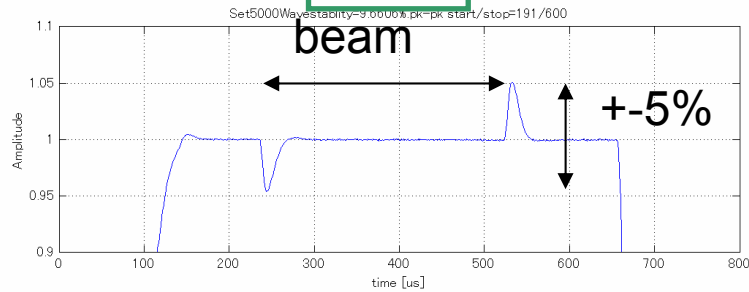
Beam loading test (cont.)



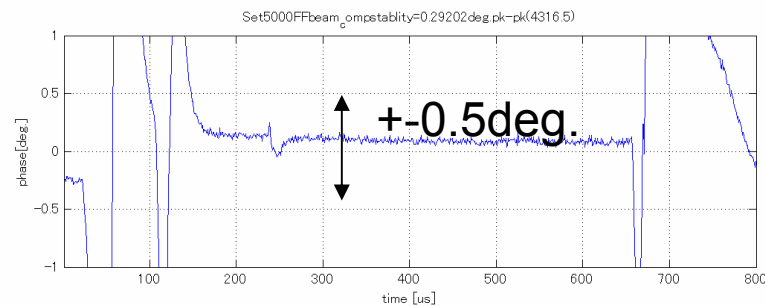
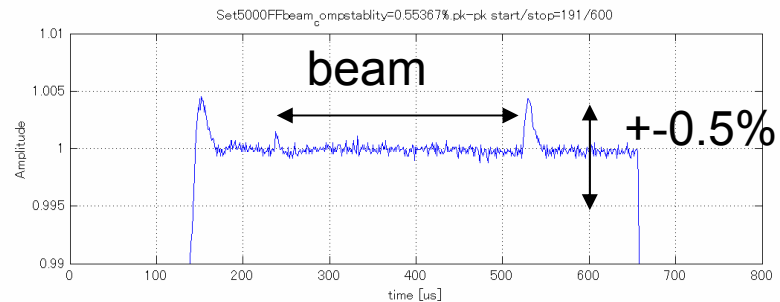
	FB monitor		Ext. monitor	
	Amplitude [%pk-pk]	Phase [deg,pk-pk]	Amplitude [%pk-pk]	Phase [deg,pk-pk]
FB only	8.6	3.5	9.7	3.9
FB+FF_beam	0.4	0.15	0.55	0.29

Beam can be compensated with FF within $\pm 0.3\%$, ± 0.15 deg.

Only FB



FB+ beam compensation FF



Summary



- Stability of **<+-0.15%, +-0.15deg.** is obtained during rf pulse with a SDTL test module.
- Tuner control works well even from 15 deg. detuning position.
- Eighteen hours running show good stability.
- Beam loading test box enables to test the beam loading effects and the stability is **~+-0.3%, +-0.15deg.** during beam pulse.
- **Linac commissioning will start from June 2006.**