Low Level RF Workshop 2022

POHANG ACCELERATOR LABORATORY

Preliminary design study of LLRF system for Korea-4GSR

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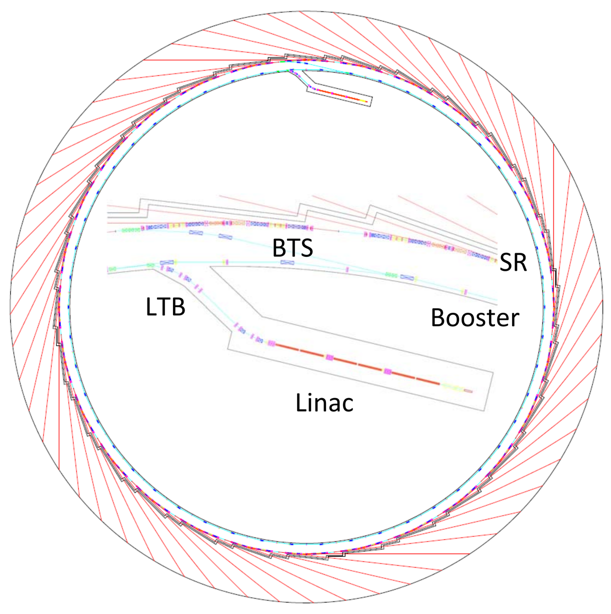
Abstract

The Korean 4th Generation Storage Ring (4GSR) project is being under construction with the plan of commissioning at the end of 2027. The beam energy of this facility is 4 GeV, and a 500 MHz EU HOM-damped normal cavity will be adopted to generate the ultra-low emittance beam of 58 pm rad with the beam current of 400 mA. This paper covers the design considerations of the low level RF (LLRF) system for digital feedback control of the 4GSR RF system and the preliminary design for its implementation. In addition, the configuration of the RF system and peripheral control devices related to the LLRF system will be presented.

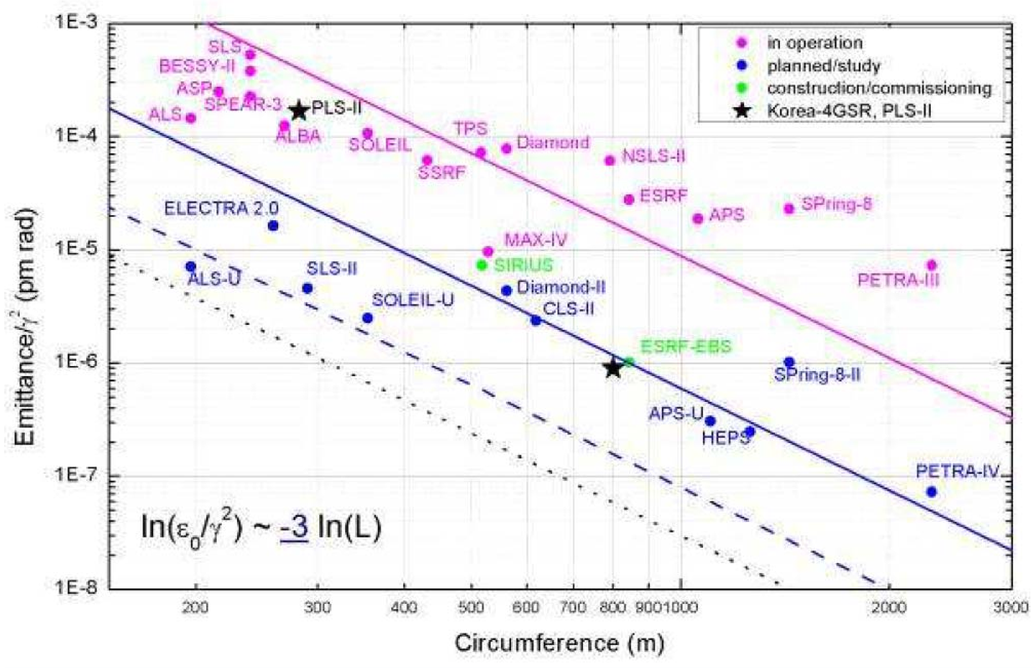
1 INTRODUCTION

Overview of Korean 4th generation storage ring project

- 4GSR aims to reduce the emittance by more than 100 times compared to 3GSR by further increasing the number of dipole magnets installed in one storage ring to 5 to 9, while 3GSR operates two dipole magnets or three dipole magnets in one storage ring cell.



Total Number of Beam Line: 52



Primary parameters of 4GSR

Parameter	Values	Unit
Beam energy	4	GeV
Beam average current	400	mA
Straight sections - No.	28	-
Straight sections - length	6.5	m
Ring circumference	798.8	m
Emittance (flat beam)	58	pm rad
Emittance (round beam)	38	pm rad
Energy spread	1.20E-03	-
Bunch length (ps) (without H.C)	10.68	ps
Bunch length (ps) (with H.C)	53.4	ps
Lifetime (flat beam)	4.54	h
Lifetime (round beam)	8.81	h
Beam pipe (in achrom.) @ straight section	D : 24(H) * 20(V)	mm2

2 Overview of 4GSR RF system for main ring

Primary specifications of RF system

Parameters, related to RF system

Parameter	Values	Unit
Beam current	400	mA
Revolution frequency	0.37528	MHz
Harmonic number	1332	-
RF frequency	499.8773	MHz
Electron enery loss /turn by bending magnet	1010.01	keV
Electron enery loss /turn by IDs	790.00	keV
Electron enery loss /turn by Others	50.00	keV
Total beam energy loss /turn	1850.01	keV

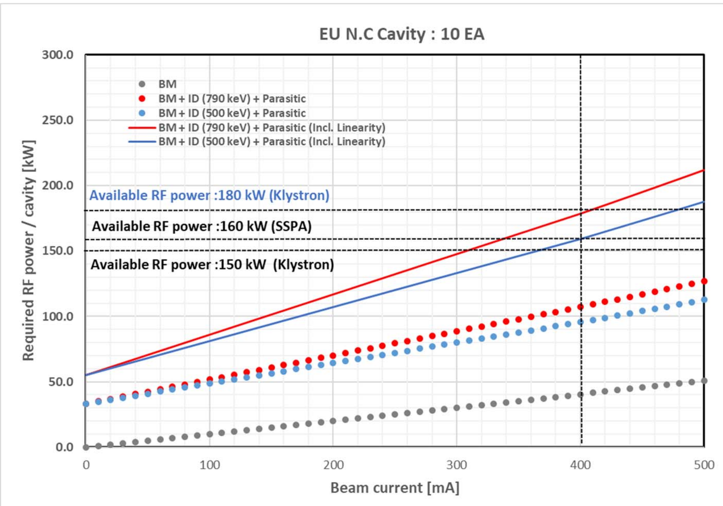
Normal conducting cavity (EU HOM damped cavity case)

Parameter	Values	Unit
Resonant frequency	499.82	MHz
Shunt Impedance	3.4	MΩ
Quality factor	>29000	Q0
Coupling beta (variable)	1 ~ 8	-
Max. power coupler	120	kW
Operating temperature	30	°C

RF parameters

Parameter	Values	Unit
Total accelerating voltage	3.5	MV
Number of cavity	10	-
Coupling beta	~5.5	-
Required accelerating voltage per cavity	0.35	MV/unit
Wall loss power per cavity	18.01	kW/unit
Beam loading power per cavity	74.00	kW/unit
Power loss at HOM absorber	5.00	kW/unit
Required power to coupler per cavity	97.02	kW/unit
Transmission line loss per cavity	10.00	kW/unit
Output power of HPRF	107.02	kW/unit
Rated power of HPRF	178.36	kW/unit
Total AC power for RF source (klystron case)	4458.97	kW
Total AC power for RF source (SSPA case)	3963.53	kW

- A total of 10 Normal conducting cavities are used to achieve the desired beam current and energy.
- Considering the initial installation cost and mean time between failure (MTBF), the type of cavity was selected as a normal conducting cavity.
- In the case of the normal conducting cavity, since the HOM characteristic of the RF cavity itself is not as good as that of the super conducting cavity, it is necessary to improve the beam stability by using an additional feedback system such as LFS for 400 mA high current operation.



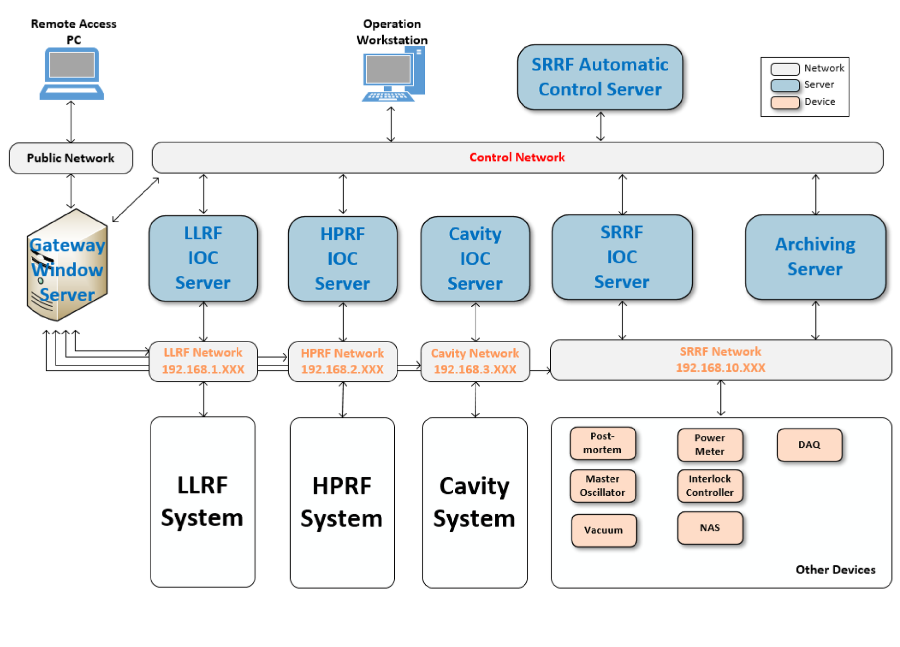
High power RF source

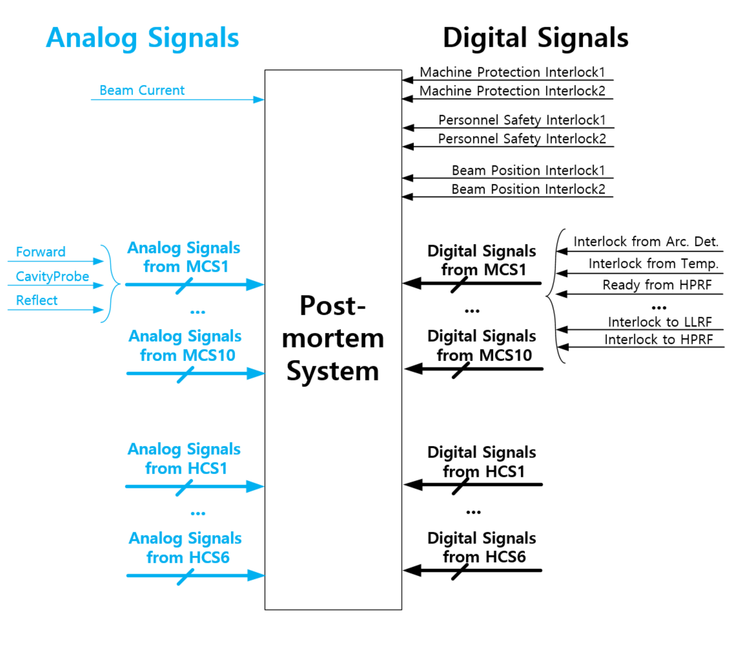
- Considering the use of SSPA as high power RF source

Comparison	Klystron	SSPA(Solid State Power Amplifier)
Advantage	▪ Less space ▪ Long lifetime(>50,000hrs) ▪ Many references	▪ Lower price (Abt. 95% of Klystron) ▪ Higher operability (Operation with faults) ▪ Easy maintenance by modularity ▪ Lower phase noise(Abt. -68dBc) ▪ Easier to upgrade in future ▪ No additional shielding for High Voltage and X-ray required
Dis-advantage	▪ High price (increasing annually) ▪ Whole replacement is required at Fault ▪ Declining Industries ▪ High Voltage Protection required ▪ X-ray Shielding required ▪ PWM Ripple(Abt. -50dBc)	▪ More space is required ▪ Less references

4 Networks and Post-mortem system

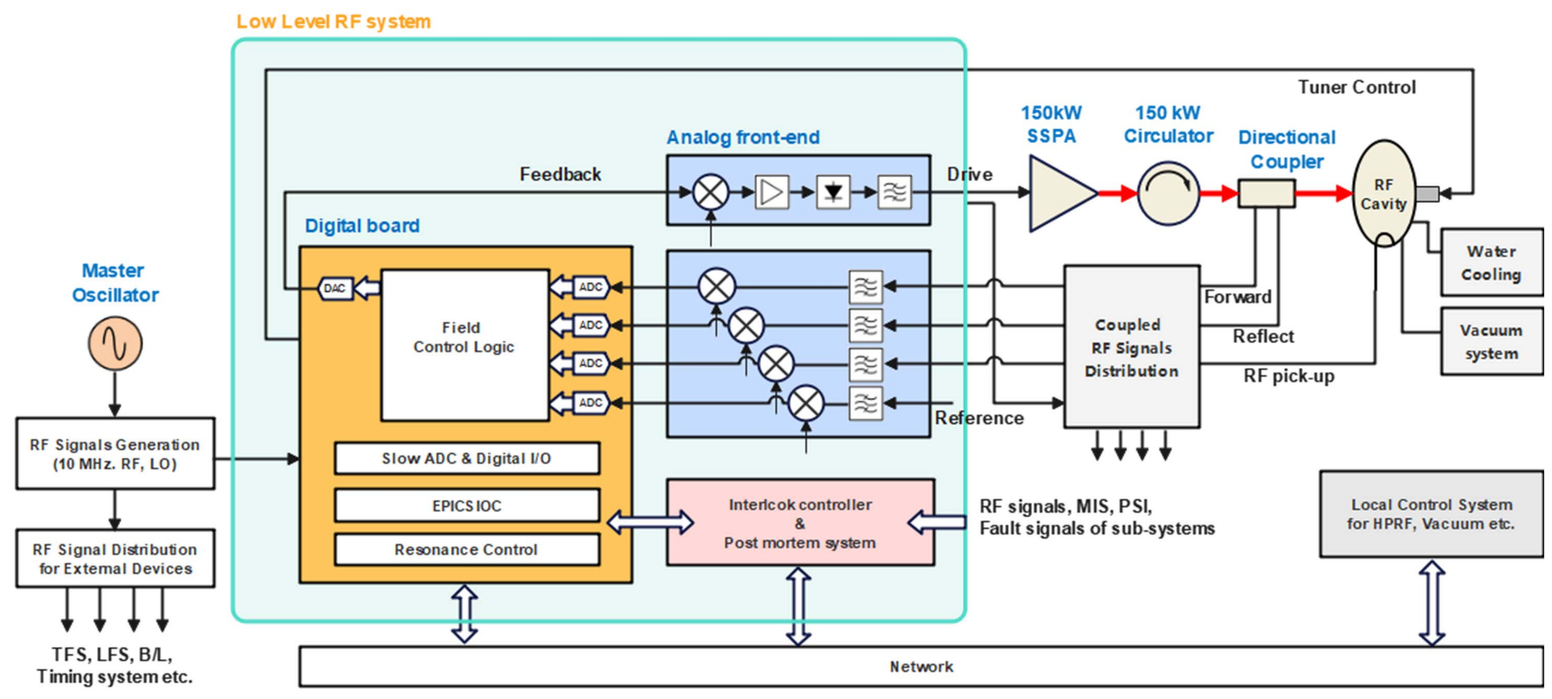
- Each sub-system composing the Cavity, LLRF, and HPRF systems is operated by the EPICS-based integrated control system.
- Through the post-mortem system, it is possible to analyze the correlation between the fault signals measured from each device, MIS, PSI, and to analyze the cause of the beam dump.





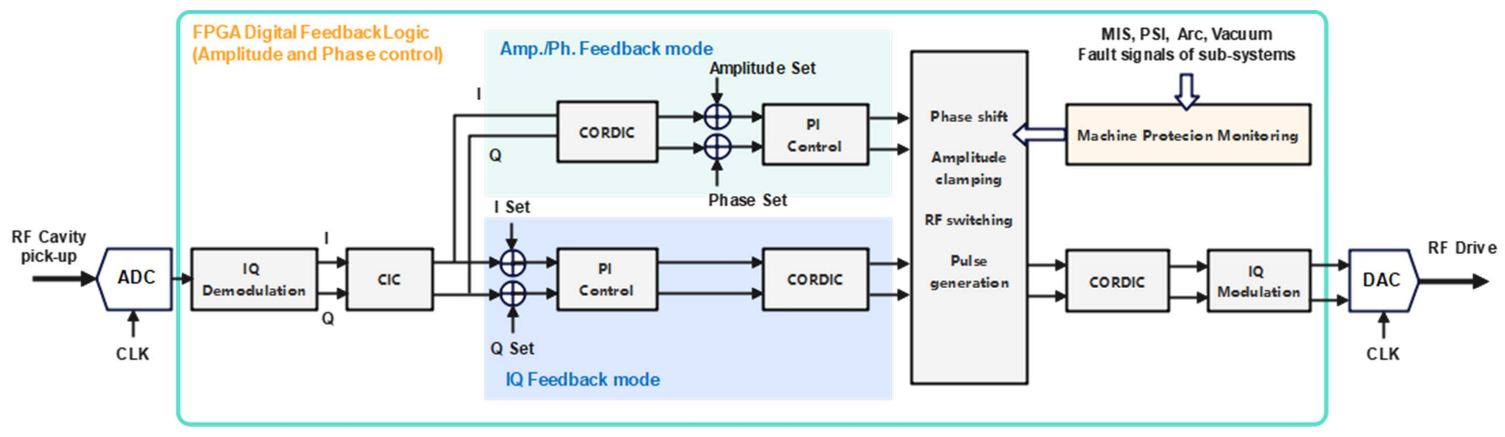
3 Preliminary design of LLRF system

- It aims to stabilize the amplitude and phase of the accelerating electric field within 0.1% and 0.1 degree respectively.
- Field control and resonance control by matching one LLRF system for each high power amp.
- Control the IF frequency through frequency converting



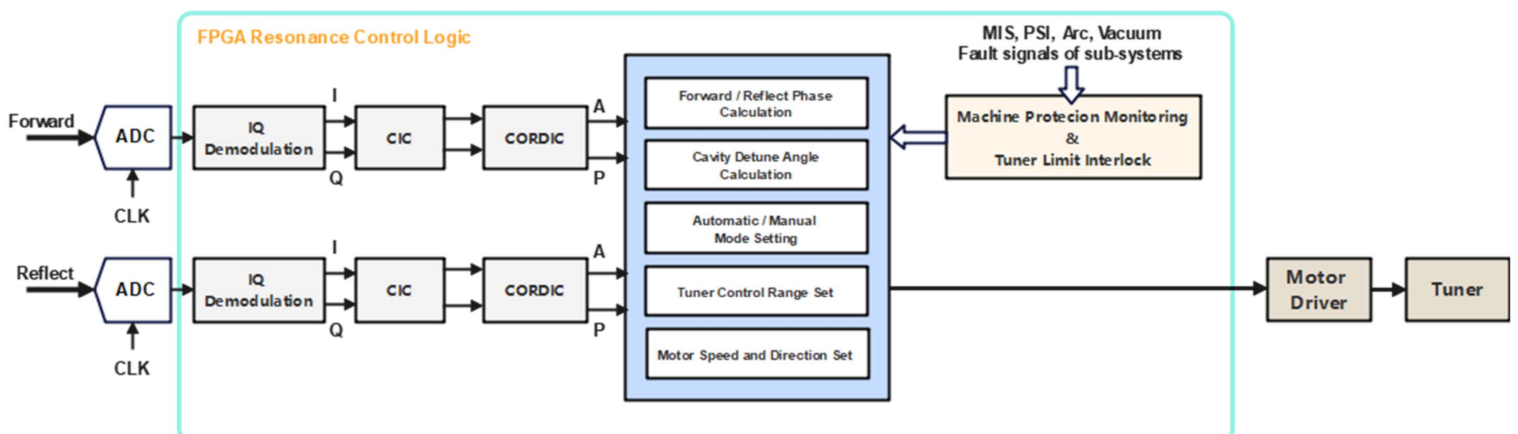
Configuration of RF system and LLRF system

- The control mode of LLRF is divided into Pulse/CW mode, and in the case of CW mode, it is composed of Tone, SEL, and GDR (IQ control / AP control).
- Using Xilinx Zynq FPGA to install Linux OS on ARM core inside FPGA and develop EPICS IOC.
- Both IQ sampling and Non-IQ sampling schemes are being considered, and will be selected after testing at the prototype development.



Digital feedback control scheme for field control

- The detune angle is calculated by calculating the phase difference between the forward and reflected signals, and when the detune angle becomes larger than the set control range, the tuner operates so that it can resonate within the tolerance range.



Digital feedback control scheme for resonance control

5 Future plan

- One RF station will be installed at the PAL site until October 2023 for basic performance verification and testing of the normal conducting cavity and SSPA to be applied to Korean-4GSR.
- In the case of the LLRF system for the cavity performance test at the test facility, commercial products will be applied, and it will be used as a reference for development of the LLRF prototype and final product.