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RF STABILITY TEST OF RFQ CAVITY WITH PROTOTYPE LOW-LEVEL RADIO FREQUENCY IN RAON

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Abstract

RAON is a heavy ion accelerator of the Institute for Basic Sciences (IBS) in Korea. The prototype Low-Level Radio Frequency (LLRF) operated at 81.25 MHz has been designed and fabricated for a prototype Radio Frequency Quadrupole (RFQ) cavity in RAON. Stabilities of ±1 % in amplitude and ±1 degree in phase are required for specifications of the RFQ system. The prototype LLRF controls the RF amplitude and phase in the cavity by PID feedback loop. The prototype LLRF has been tested with one RFQ cavity and stabilities have been measured. In this paper, we present the design and results of stability test.

INTRODUCTION

Prototype LLRF for RFQ cavity is designed to maintain the stability of amplitude and phase of RF power in the cavity at 81.25 MHz frequency within ±1 % and ±1 degree through PID feedback control. Table 1 shows parameter of 81.25 MHz LLRF. The prototype LLRF has one reference clock, two RF input channels and one output channel. The reference clock input channel operates with a reference signal of -15 to 0 dBm and the sampling frequency is generated by using a clock signal down-converted to 4/5 times. The operating frequency range is 81.25 ±1 MHz. The RFQ pick-up signal is put into the RF input channel and feedback control is performed. The RF power from the output channel is used as the input drive power for the SSPA (solid state power amplifier). The LLRF controller based on EPICS OPI (operator interface) communicates with the LLRF module via ethernet. It is responsible for controlling the RF field of the RFQ cavity, interlocking, monitoring and data archiving. Feedback on-off is applied independently to amplitude and phase. User can set the target values of amplitude and phase and the PID coefficients. The RF output power limiter is equipped for SSPA protection. The LLRF module consists of RF module and FPGA board as shown in Fig. 1.

Table 1: Parameter of 81.25 MHz LLRF

Parameter	Value
Frequency Range	81.25 ± 1 MHz
Amplitude Stability	< ± 1 %
Phase Stability	< ± 1 degree
Operating Mode	CW, Pulse
RF Input	Ref. : -15 ~ 0 dBm Ch 1, 2 : -40 ~ 0 dBm
RF Output	-40 ~ 0 dBm
I/O Impedance	50 ohm

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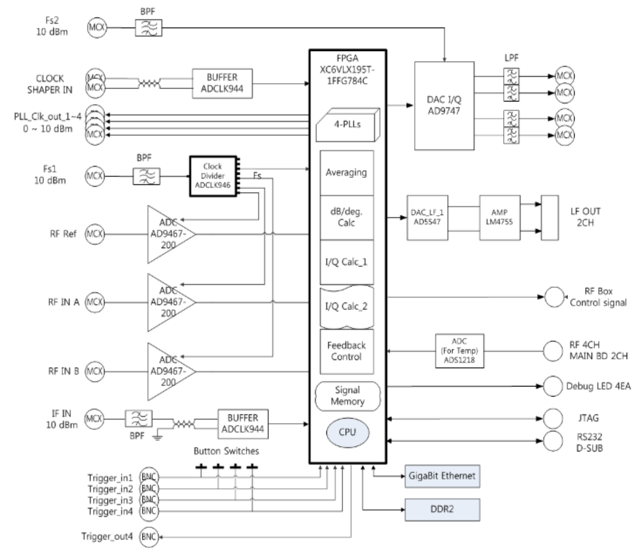

Figure 1: Block diagram of 81.25 MHz LLRF module.

STABILITY TEST

We set up the test bench with 81.25 MHz LLRF, 15 kW SSPA and RFQ cavity as shown in Fig. 2. The block diagram of the test bench for stability test is shown in Fig. 3.

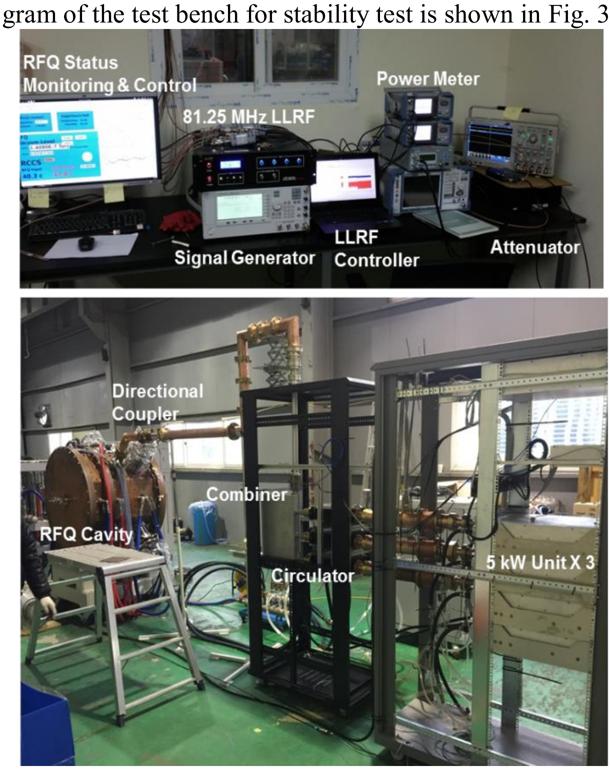

Figure 2: Test setup with 81.25 MHz LLRF,15 kW SSPA and RFQ cavity.

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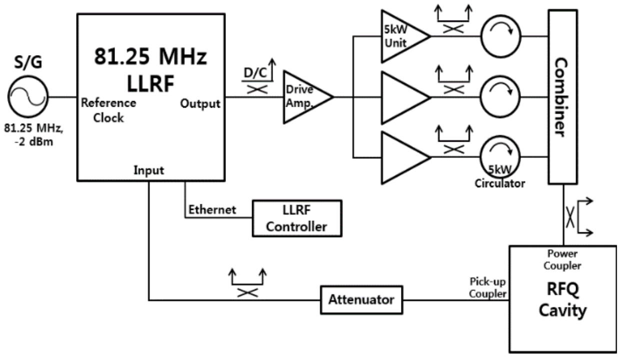

Figure 3: Block diagram of test bench for stability test

Operating frequency for RFQ system is 81.25 MHz. The reference clock signal of the prototype LLRF is –2 dBm of 81.25 MHz RF signal generated by the signal generator. The output RF power of the prototype LLRF is amplified by the SSPA and then put into the cavity from the RF power coupler. The RF field of the RFQ through the pick-up coupler is sent to prototype LLRF to constitute the amplitude and phase loop. The SSPA output power is 15 kW by combining three 5 kW amplifier units. The 3-1/8" coaxial type rigid transmission lines are designed to deliver the RF power to RFQ up to 15 kW (CW). Because handling power of 3-1/8" 50 Ohm coaxial line is approximately 50 kW at 81.25 MHz, no additional cooling is needed [1]. The Dual Directional Coupler is used to monitor the forward and reflected power. Directivity is more than 20 dB for correct power measurements because of minimizing the effects of coupling signals. The circulator is used to protect the SSPA from over-reflected RF power from RFQ. The isolation is higher than 20 dB and insertion loss is less than 0.3 dB. The RFQ adopts the RCCS (Resonance Control Cooling System), which supplies cooling water to each vane and quadrant, to control the temperature and adjust the resonance frequency. Experiment conditions are 1~2 × 10^{-7} torr, 29.4~36 ˚C of RCCS temperature, 10~45 Hz of pump speed, 1~50 % of heater level and 13~15 ˚C of SSPA cooling water temperature. To control the resonance frequency of the RFQ, the target values for RCCS temperature, pump speed, and heater level are set manually.

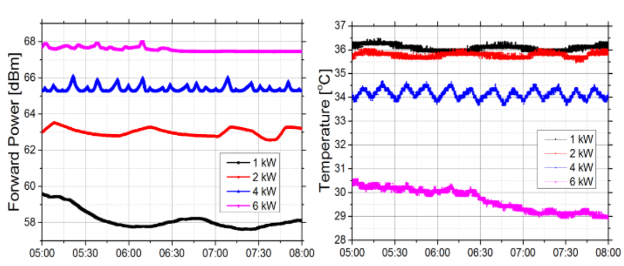

Figure 4: Forward power and temperature of RCCS during the stability test.

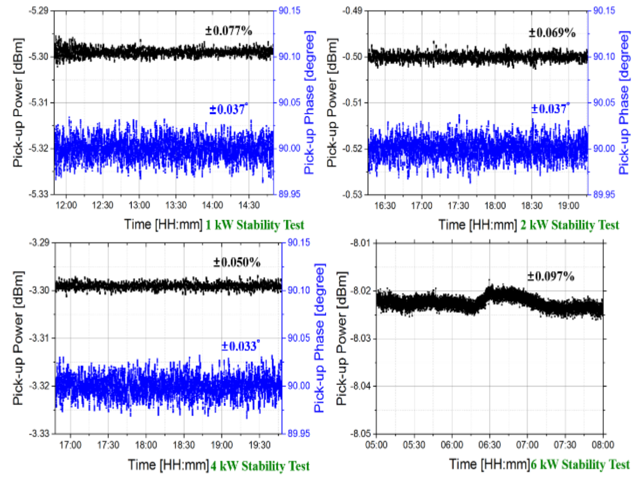

Figure 5: RF amplitude and phase stability.

Figure 4 shows the forward power and temperature of RCCS during the stability test. Figure 5 shows the RF amplitude and phase stability for each test and the measurement time is 3 hours.

We control the RCCS temperature and pump speed to avoid over-reflected power of the interlock during the experiments. Each attenuator used in the stability test is 40, 40, 46 and 53 dB. The fluctuation of forward power is respectively 2.00, 0.96, 0.85 and 0.56 dB and 335, 446, 724 and 769 W based on power of watt. The period of RCCS temperature is getting shorter as the power is higher and can not know at the 6 kW stability test. The reflected power changes according to the temperature change of RCCS. Stabilities of ±1 % in amplitude and ±1 degree in phase are required for specifications of the RFQ system. The amplitude stability is less than ±0.097 % and the phase stability is less than ±0.037 degree, so the measurement values satisfied specifications during the stability tests. In the 6 kW stability experiment, the phase stability was satisfied but the data was not stored. Stability may vary depending on the PID coefficient. Table 2 shows the experimental conditions and results for each stability test.

Table 2: Experimental Conditions and Results for Each Stability Test

Parameter	1 kW	2 kW	4 kW	6 kW
Amplitude Stability [%]	±0.077	±0.069	±0.050	±0.097
Phase Stability [degree]	±0.037	±0.037	±0.033	-
Forward Power Fluctuation [dB]	2.00	0.96	0.85	0.56
RCCS Temperature [˚C]	36	36	34.5 ~ 35.0	29.4 ~ 31.0
Pump Speed [Hz]	10~15	26~30	25~30	37~45
Heater Level [%]	50	50	50	1
Attenuator [dB]	40	40	46	53

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Figure 6 shows the correlation between pick-up power and temperature of prototype LLRF module. The pick-up power values measured by the power meter was different from the LLRF module at the beginning of the experiment, while the actual power is the same as the temperature trend of the LLRF module. Therefore, all subsequent experiments are conducted by using the temperature control rack with a temperature setting of 22 degrees. This problem disappeared after using the temperature control rack.

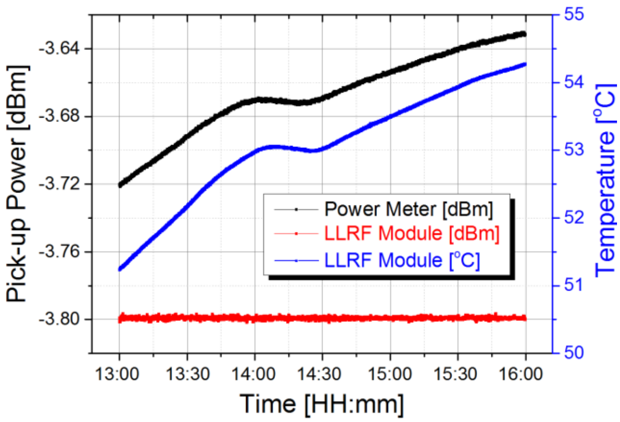

Figure 6: Correlation between pick-up power and temperature of LLRF module.

RF CONDITIONING

We set up the 2ea × 40 kW SSPAs and coaxial type rigid transmission lines from SSPA to RFQ cavity for RF conditioning as shown in Fig. 7. In order to synthesize 20 kW power, 4ea × 5 kW final amplifiers are combined with 4-way Gysel method [2, 3]. Two 20 kW racks are synthesized by using the hybrid combiner, and the two RFQ couplers are supplied with up to 40 kW power respectively.

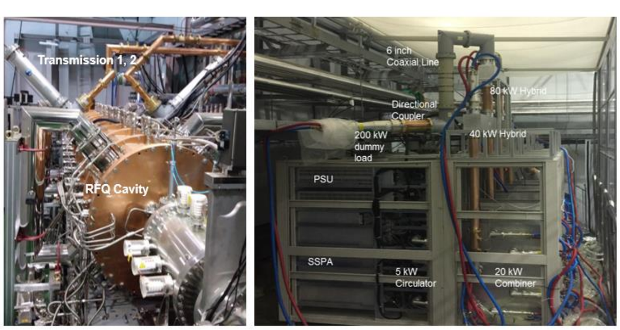

Figure 7: RFQ cavity, transmission lines and SSPAs for RFQ RF conditioning.

After approximately 6 weeks of scan conditioning for RFQ cavity, its multipacting region has been improved. The applied power is up to 40 kW in pulsed and CW mode.

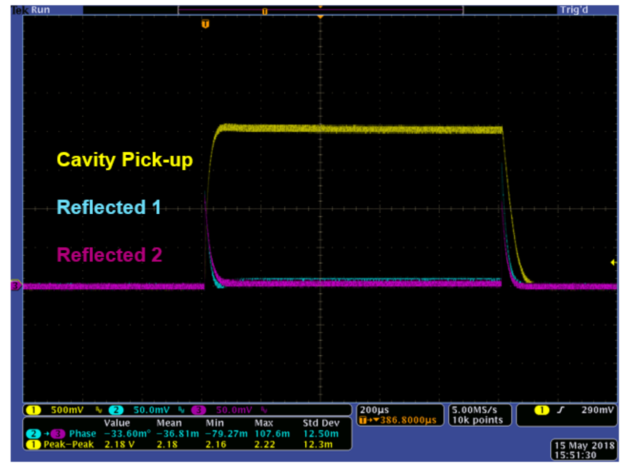

Figure 8: Measured RFQ field and reflected power in pulsed mode.

Figure 8 shows the measured RFQ field and reflected power in pulsed mode. The conditions of pulse operation are 30 kW, 1 ms, 20 Hz by combining two power couplers. The reflected waveform shows almost critical coupling and the vacuum level is also maintained steadily with no significant change.

CONCLUSION

A prototype LLRF is developed and successfully tested for RFQ cavity and showed promising results, for the RAON specifications. The amplitude stability is less than ±0.097 % and the phase stability is less than ±0.037 degree, so the measurement values satisfies with specifications during the stability tests. RFQ RF conditioning is performed up to 40 kW through two couplers to improve the multipacting and maintain the vacuum level.

In the future, RF Conditioning for RFQ cavity will be performed more than 40 kW of RF power and stability test will be conducted for beam acceleration. We will improve the reliability of LLRF and optimize the PID coefficients.

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