DEVELOPMENT OF HIGH POWER RF AMPLIFIER SYSTEM FOR THE KBSI RFQ

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Abstract

KBSI (Korean Basic Science Institute) has developed a compact accelerator system for generation of fast neutron by lithium beam of 2.7 MeV/u. The facility consists of 28 GHz SC-ECR ion source, LEBT, RFQ and DTL. The developed RFQ accelerator provides lithium ion beam from 12 keV/u to 500 keV/u with 98.88 % of high transmission rate at 165 MHz of operation frequency. RF power system for RFQ accelerator has been developed to provide sufficient RF power into RFQ cavity, which consists of LLRF system for control, SSPA of 5 kW as IPA, tetrode tube amplifier as FPA, coaxial transmission lines and a circulator for protection from reflection power provides 100 kW at operation frequency with CW mode. In this paper, we discuss about development of RF system and performance test in detail.

INTRODUCTION

In order to generate 2.7 MeV lithium ion beam, the RFQ system provides first acceleration from low energy ion beam of 12 keV/u which is generated from ion source and transported by LEBT, to 500 keV/u as well as high captured bunching. The design parameters of the KBSI RFQ are listed in Table 1. The RFQ has been developed as length of 232.47 cm with CW mode at 165 MHz. By studying vane structure of RFQ, we obtained RF power estimation of a quadrant of RFQ cavity as shown in Fig. 1. In order to provide sufficient RF power into RFQ cavity, the total power consumption is given by

$$P_{total} = 4 \times P_{SF} \times \alpha_{3D} \times \alpha_{op} + P_{beam} \ ,$$

where α_{3D} = 1.3 is a factor that accounts for the 3D losses [1] which includes RF transmission loss and difference between SUPERFISH [2] and experience result, α_{op} is 1.1^2 as operation margin of 10 % voltage, P_{beam} is the beam power. The RF power estimation of a quadrant of RFQ cavity along the longitudinal position is obtained as shown in Fig. 1. The integrated power of an RFQ quadrant is 8.00 kW with average Q factor of 14979. The requirements of RF amplifier for the RFQ are to drive RF power of 60.59 kW with CW mode at the operation frequency of 165 MHz. The amplitude and phase stability are determined as 1 % by error study of beam dynamics such as voltage deformation.

Table 1: RFQ Design Parameters

Particle (q/A)	Li^{3+} (3/7)
Frequency	165.0 MHz
I/O beam energy	12 keV/u / 500 keV/u
Beam intensity	3mA
Duty rate	100 %
Length	232.47 cm
Beam power	10.25 kW
Cavity loss power	50.34 kW
Total power	60.59 kW

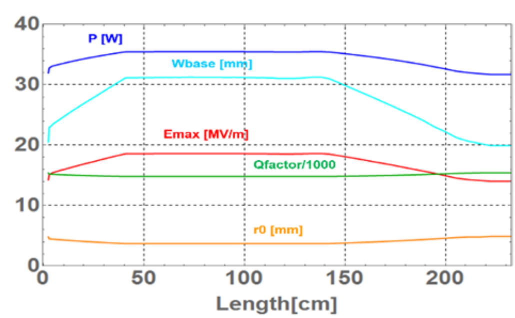

Figure 1: Power consumption in a quadrant of RFQ.

RF amplifier system consists of LLRF system for measuring and controlling RF power, IPA system of two Soild-State Amplifiers (SSPAs) of 5 kW, FPA system of tetrode tube amplifiers of 100 kW, circulator for reflect power protection, and RF transmission lines as shown in Fig. 2 [3].

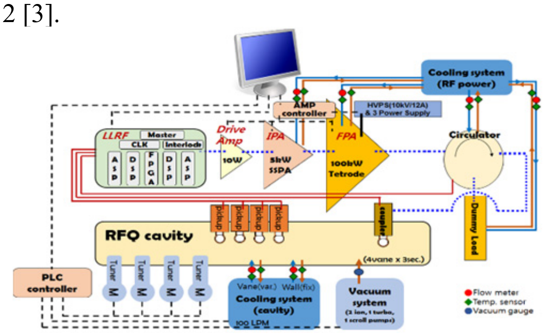

Figure 2: Diagram of RF system including the RFQ.

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LLRF SYSTEM

The objectives of LLRF system are optimization of the amplitude and phase as the requirements and automatic recovery from various faults in cavity and transmission lines. The LLRF system consists of Host PC, 9 Phase Amplitude Detection (PAD) modules, Phase Amplitude Control (PAC) module, reference module, clock module, Local distributor, FPGA board, trigger system and interlock system as shown in Fig. 3.

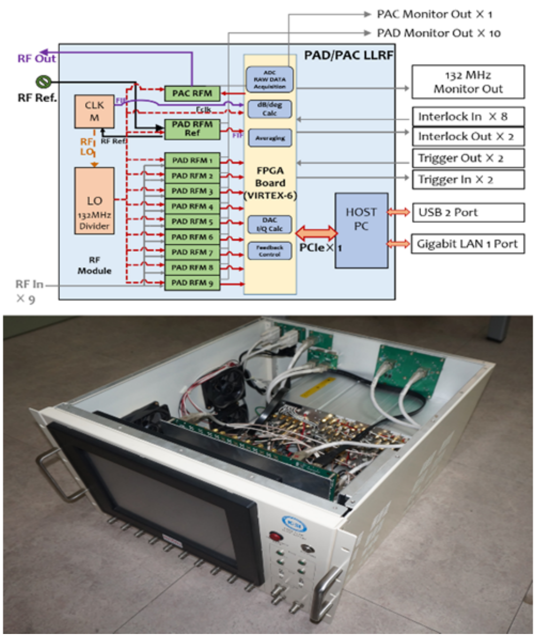

Figure 3: Block diagram and photo of LLRF system.

Linearity of RF power amplitude test was performed over dynamic range from -20 to + 11 dBm. The linearity of the PAD modules are obtained less than 0.1 % and the stability is increased when the amplitude is decreased but the amplitude stability at -11 dBm was measured less than 0.2 %. RF output is needed to control with high accuracy to drive required RF power and phase into RFQ cavity. The performance of PAC was achieved high linearity of 0.01% and stability of 0.08 % as shown in Fig. 4. Similarly, phase linearity of 0.12 % and stability of 0.015 % are achieved.

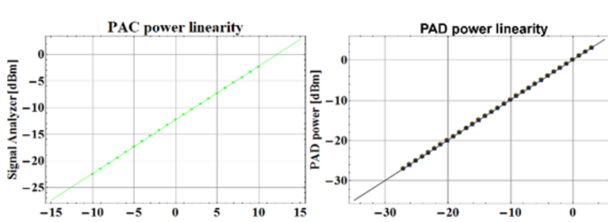

Figure 4: Result of linearity performance of LLRF system.

INTERMEDIATE AMPLIFIER SYSTEM

The objectives of Intermediate power amplifier (IPA) is to boost the LLRF output into final amplifier as an input signal to drive enough power. The IPA system is composed of two Solid-state power amplifiers (SSPAs) which is based on semiconductor of LDMOSFET. The SSPA system consists of RF modules of LDMOSFET, 8-way splitter, 2:1 combiner, cooling system, control system and 50V DC power supplies as shown in Fig. 5.

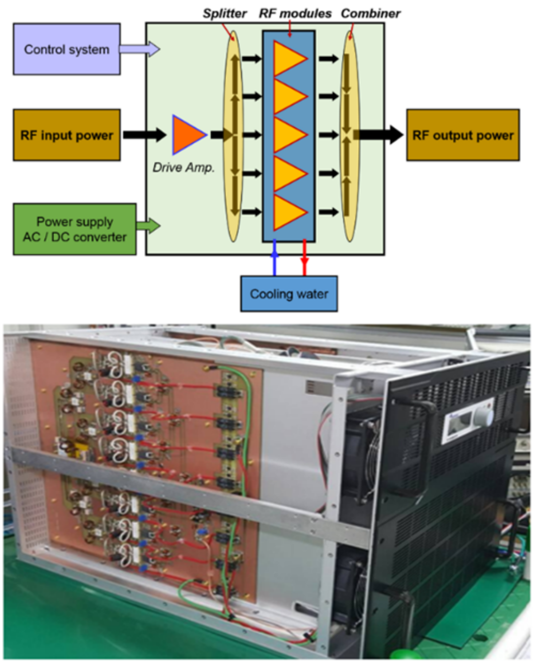

Figure 5: Block diagram and photo of IPA system.

We achieved the the RF amplitude of 67.32 dBm at the operation frequency of 165 MHz with input power of 10 dBm, 1 kHz of bandwidth, 15.8 dBc of harmonics, output power linearity of 0.6 % and efficiency of 62 %. The maximum value of gain specification is obtained 60.52 dB when the input power amplitude is 3 dBm at 163.5 MHz as shown in Fig. 6. Even though the amplitude of output power and gain are met the requirement of over than 5.0 kW, linearity and impedance matching are needed to be more optimization.

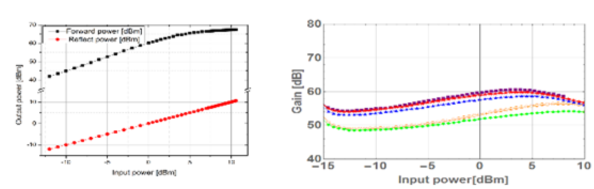

Figure 6: Result of linearity performance of IPA system.

FINAL AMPLIFIER SYSTEM

We choose the tetrode tube [4] in vacuum tubes as a high power RF amplifier due to stable operation with low cost. Tetrode tube boost RF power up to 100 kW to provide RF power into RFQ cavity. A single tetrode tube system has been developed as a first step. The FPA system consist of tetrode tube, power supplies (P/S) such as anode P/S of 10 kV and 15 A, filament P/S of 10 V and 375 A, control grid P/S of -350 V and 1.1 A, and screen grid P/S of 1.2 kV and 1.0 A, and cooling system as shown in Fig. 7.

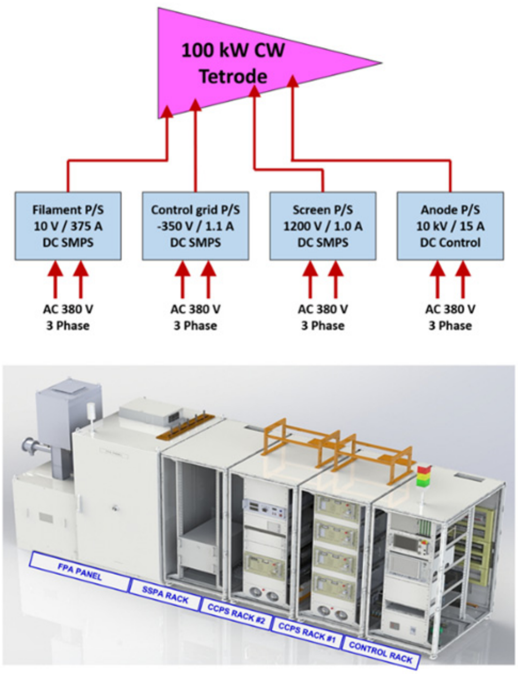

Figure 7: Block diagram and photo of FPA system.

FPA performance test was carried out by using the test bench which consists of tetrode system, dummy load, transmission lines, power meter. Linearity of FPA output was measured to confirm dynamic range of input power within protection limit of 105 kW. In order to measure the efficiency of amplifier, we measure input power such as driven voltage and current. The FPA system achieved efficiency of 72 % at the 100 kW RF output condition as shown in Fig. 8.

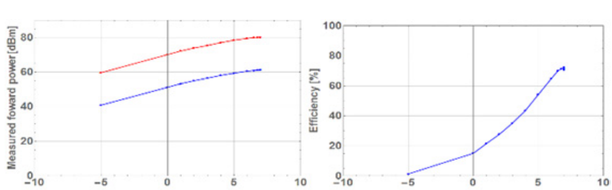

Figure 8: Result of linearity performance of FPA system.

CONCLUSION AND FUTURE PLAN

A RF amplifier system has been developed to provide RF power of 100 kW with CW mode into RFQ cavity as shown in Fig. 9. The RF amplifier system achieved high linearity of LLRF system such as less than 0.2 % PAC and PAD, first stage boost RF amplitude of 5.2 kW by IPA system, and final stage amplifying RF power of 100 kW by FPA system and circulator for reflect power protection. The efficiency of IPA and FPA were obtained as 62 % and 72 %, respectively. The developed system is needed to optimize impedance matching for upgrading the linearity of IPA output and small noise.

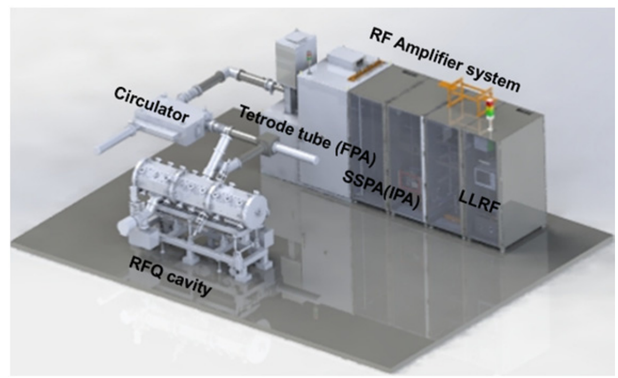

Figure 9: The photo of amplifier system for RFQ.

REFERENCES

[1] Jungbae Bahng, *et. al.*, *Proceedings of IPAC2015*, MOPTY025, Richimond, USA, 2015.

[2] J. H. Billen and L. M. Yong, "Poisson Superfish", LA-UR-96-1834.

[3] M.H. Chun, *et. al.*, *Proceedings of IPAC2015*, WEPMN036, Richimond, USA, 2015.

[4] Thales Technical Specification, Tetrode type TH781, `https://www.thalesgroup.com/`

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