LLRF DEVELOPMENT FOR PAL-XFEL*

J. Hu†, W. H. Hwang, C.-K. Min, G.-Y. Moon, H.-S. Kang, H.-S. Lee, PAL, POSTECH, Pohang, South Korea
O. J. Kim, H. S. Lee, Mobiis Co., Ltd, Seoul, South Korea
Y. S. Kim, J. H. Chang, J. S. Han, RFPT Co,. Ltd, Anyang, South Korea

Abstract

PAL-XFEL construction is completed. Now, beam commissioning is ongoing after RF conditioning. The LLRF and SSA systems installed and in normal operation are presented. Those structures, features, characteristics, and performances are described.

INTRODUCTION

PAL-XFEL building construction was completed, and the facilities for PAL-XFEL were installed almost up at the end of the last year with the efforts of all members. Figure 1 shows the bird eye view of the site, and Fig. 2 shows the tunnel and gallery of PAL-XFEL. During the beginning months of this year, RF conditioning was carried out. Now, beam commissioning is ongoing. On April, electron bunches are accelerated up to 10 GeV as a good start, and Fig. 3 shows the initial image of those bunches taken with a screen monitor.

Accelerating facilities including LLRF and SSA for PAL-XFEL are also installed and in normal operation. In this report, we would like to present the features and performance results of LLRF and SSA systems for PAL-XFEL.

Figure 1: PAL-XFEL Site View.

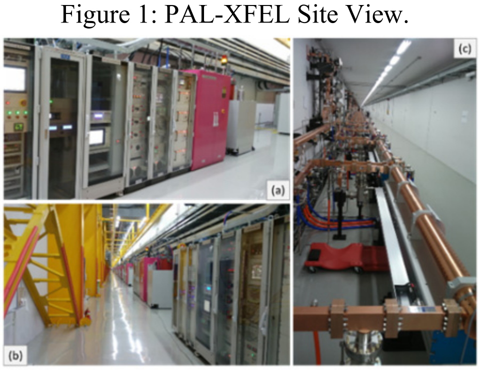

Figure 2: Gallery and tunnel of PAL-XFEL. (a) A RF station in the gallery. (b) Gallery view. (c) Tunnel view.

* Work supported by MSIP, South Korea.
† hjy@postech.ac.kr

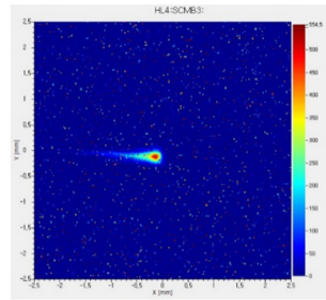

Figure 3: First 10 GeV electron bunches measured with a screen monitor.

RF SYSTEM CONFIGURATION

The PAL-XFEL machine comprises with total 51 RF stations. 49 stations among them are operated for 10 GeV acceleration and for the generation of hard X-rays (HX). The initial 19 RF stations of HX are shared for the generation of soft X-rays (SX) which use 3 GeV electron beams, and the remaining 2 RF stations are used for SX only. Figure 4 shows the layout of RF stations for PAL-XFEL.

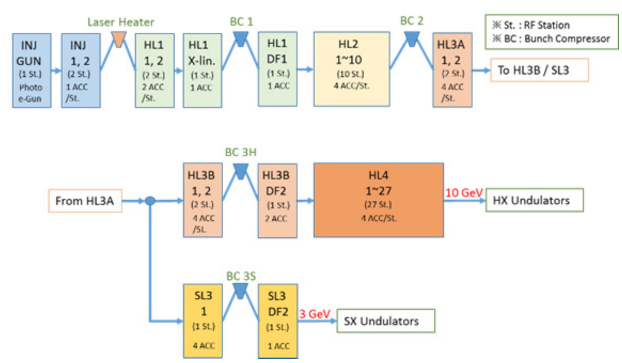

Figure 4: RF system layout of PAL-XFEL.

RF stations of PAL-XFEL machine are operated mainly in S-band (2856MHz) except for one station for X-linearizer which has X-band (11.424GHz), and all the stations have normal conducting accelerating structures. The PAL-XFEL machine is operated below 4μs RF pulses, and to be operated up to 60 Hz repetition rate.

As shown in Fig. 4, the RF stations have several types in the number of accelerating columns, and each station has one klystron, one modulator, one LLRF, and one SSA.

ISBN 978-3-95450-147-2

RF STATION

A PAL-XFEL RF station diagram is shown in Fig. 5. The figure shows the representative RF station occupying major numbers of PAL-XFEL.

Referring to Fig. 5, LLRF (Low-Level RF) receives the synchronized 2856MHz reference CW from the RF distribution system, and triggers from the event timing system. LLRF internally generates local CW signals and clock signal, and modulates RF pulse signals having specific phases and amplitudes. SSA amplifies the pulse signals up to around hundreds watts with very low noise. Klystron receives RF signals from SSA and power from modulator, and amplifies up to 80 MW. The generated high power is amplified again in SLED, and distributed to 4 accelerating columns.

LLRF detects RF signals in 10 points as shown in Fig. 5. Due to the limited number of detection channels of LLRF, 9 points are selected, and 1 channel is used to measure internal signal. Modulator and klystron signals derived proportionally from the original signals(klystron beam voltage and current) are detected also in LLRF precisely with 16-bit ADC.

LLRF receives and sends hard-wired interlock signals with PSI (Personal Safety Interlock), and MIS(Machine Interlock System), and sends interlock signals to modulator with high speed between pulses.

LLRF communicates with two Ethernet ports, one of which is for EPICS channel access, the other for fast feedback network. LLRF additionally controls SSA and SLED de-tuners. All the LLRFs and SSAs are installed within very precisely temperature-controlled racks for stable operation.

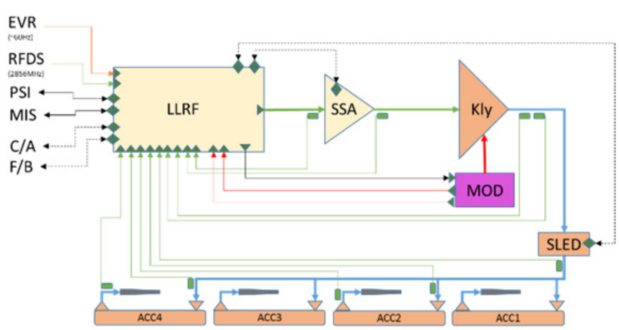

Figure 5: RF station diagram of PAL-XFEL.

LLRF

LLRF systems for PAL-XFEL were developed for the past years, and some intermediate results on prototypes were presented[1,2]. Based on prototypes, final LLRF systems are developed, installed in the gallery, and in operation, which have various advanced features.

LLRF system developed for PAL-XFEL comprises with three main parts: RF front-end modules, ADC-FPGA board, and industrial PC. Figure 6 shows the developed LLRF. RF front-end modules generate local and clock RF signals, modulate RF pulses to feed SSA, demodulates RF signals received from various points of RF station, and do PSK function with the speed of a few tens of nanoseconds for SLED operation.

ADC-FPGA board convert analogue signals from RF front-ends, and several other devices into digital signals, and vice versa. This board processes digital signals, and communicate with industrial PC with high speed.

The industrial PC has an i7-CPU and a touchscreen panel, which has cost-effectiveness and show high performance. It has RT linux OS to process all the data in real-time fashion. It runs EPICS IOC, and has local CSS client. With a local display, status monitoring, diagnosis, and data analysis are easily done at the field.

Some features of the LLRF system are stated in the previous section in the course of RF station description. Besides those, the LLRF system has the feature that it processes RF signals and klystron beam signals in real-time pulse-by-pulse way including their raw waveform data, which does not interfere with PAL-XFEL operation.

The LLRF system has the implementation to do BSA (Beam Synchronous Acquisition) in two ways. One is to send data to the master VME system in real-time, and the VME processes BSA to the received data. The other way is that LLRF collects pulse-by-pulse data including raw waveform data locally for a few minutes, and it sends the data to FDS(fast data server) when data is requested, not interfering with PAL-XFEL operation. FDS server parts are developed in cooperation with Cosylab.

The LLRF system does feedback locally within the system. It also can do feedback based on beams.

Figure 6: LLRF developed and installed for PAL-XFEL. Front view(left), and top view(right, cover is removed).

SSA

Likewise the LLRF systems, the SSA systems for PAL-XFEL were developed for the past years, and some intermediate results on prototypes were presented[1,3]. Based on prototypes, final SSA systems are developed, installed in the gallery, and in stable operation.

SSA system is mainly built with LDMOS transistor complex. It amplifies the power of RF pulses up to 900W. It has the communication capability with LLRF. Figure 7 shows the installed SSA at the PAL-XFEL gallery.

Figure 7: SSA for PAL-XFEL.

CHARACTERICSTICS & PERFORMANCE

Noise Characteristics

Noise characteristics of LLRF for PAL-XFEL are measured with signal analyser, and shown in figure 8. PAC(Phase Amplitude modulation Controller) shows phase noise ~-146 dBc/Hz at 1 MHz offset, and amplitude noise ~-151 dBc/Hz at 1 MHz offset. The big value in the lower frequency offset will be improved by the replacement of the master oscillator in the near future.

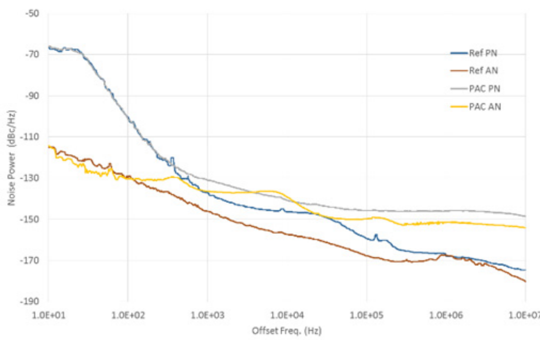

Figure 8: Phase noise (PN) and amplitude noise (AN) characteristics of a S-band LLRF.

Pulse Waveform Characteristics

RF pulse waveforms generated by one of the installed LLRF systems for PAL-XFEL are shown in Fig. 9. The waveforms are suitable for the operation of PAL-XFEL. The data and klystron beam voltage (KBV) data shown are obtained with LLRF, which is one of its features.

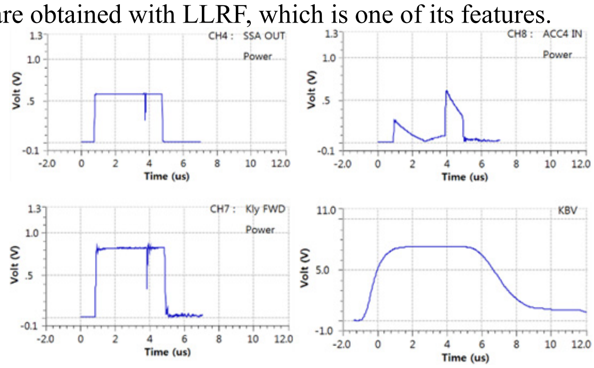

Figure 9: RF waveforms and klystron beam voltage (KBV) waveform acquired with LLRF.

Stability Results

Figures 10 and 11 show the stability results of 49 HX RF stations of PAL-XFEL after 5 hours measurement. From the figures, some stations satisfy the PAL-XFEL requirement of stabilities 0.02 % (amplitude) and 0.03 ° (phase), and the others does not. Figure 12 shows data for L2-7 showing average performance. To increase the stability performances of PAL-XFEL, efforts will be focused.

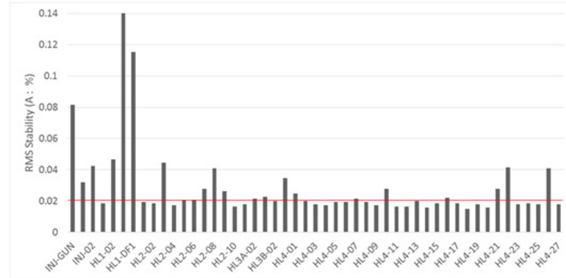

Figure 10: RF amplitude stabilities of HX stations measured for 5 hours (pulse-to-pulse).

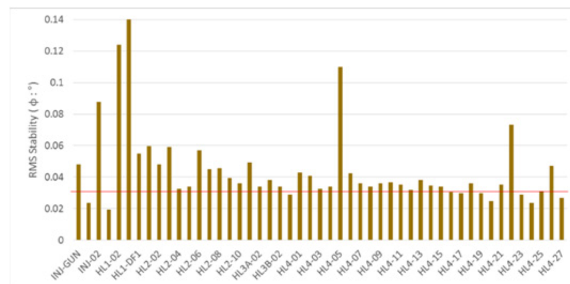

Figure 11: RF phase stabilities of HX stations measured for 5 hours (pulse-to-pulse).

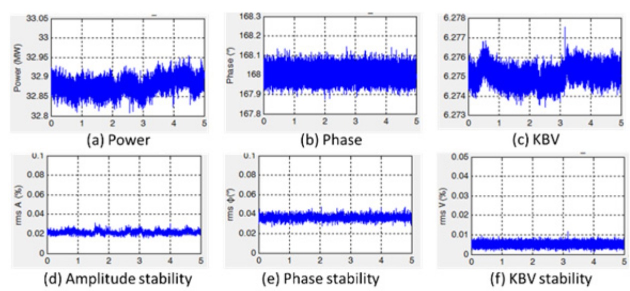

Figure 12: The RF and KBV performance of L2-7 station measured for 5 hours.

CONCLUSION

PAL-XFEL construction is completed, and now beam commissioning ongoing. The LLRF and SSA systems are properly installed and in normal operation. The structures and features of LLRF and SSA are presented, which include KBV processing, raw data processing, BSA, and fast interlock etc. The characteristics and stabilities of LLRFs and SSAs for PAL-XFEL are presented. The lack of stabilities for some stations will be overcome near future.

ACKNOWLEDGEMENT

Many thanks to I.-H. Yu, M.-H. Chun, and D. C. Shin of PAL for sharing time for useful discussions, J. Seo, and S. Lee of PAL for their assistance, J.-H. Han of PAL for reviewing this manuscripts, K. M. Oh of Vitzrotech for the installation of SLED de-tuner cables, and Yein members for the installation of interlock cables.

REFERENCES

[1] J. Hu, W.H. Whang, H.-S. Kang, H.-S. Lee, H. Heo, J.H. Hong, C.-K. Min, ″Experimental Test of the Prototype LLRF Systems for PAL-XFEL", Proceedings of IPAC2014, Dresden, Germany, WEPME078(2014).

[2] W. H. Hwang, W. W. Lee, H. S. Lee, H.S. Kang, J.Y. Huang, "S-band Low Level RF system for 10GeV PAL XFEL", Proceedings of IPAC'12, THPPC058 (2012).

[3] W. H. Hwang, W. W. Lee, H. S. Lee, H.S. Kang, J.Y. Huang, "S-band High Stability Solid State Amplifier for 10 GeV PAL XFEL", Proceedings of IPAC'13, WEPFI043 (2013).