DEVELOPMENT OF AN X-BAND LINEARIZER SYSTEM FOR PAL-XFEL

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Abstract

We developed an X-band RF system for the linearizer for the bunch compressor of the PAL-XFEL. We installed a SLAC X–band accelerating structure on a precise mover stage and applied RF power by using a SLAC XL-4 11.424 GHz klystron powered by an inverter charging type modulator. We are developing a solid state amplifier controlled by an X-band LLRF system instead of using a TWTA as a driving RF source for the klystron. We present and discuss the recent test results of the system.

INTRODUCTION

PAL-XFEL is a 4^{th} generation light source generating very intense and short coherent X-ray. This free electron laser uses low emittance and high energy electron beam to make self amplified spontaneous emission (SASE) [1]. In PAL-XFEL, electrons are accelerated up to 10 GeV by using an S-band RF linear accelerator and 3 bunch compressor to make bunch length of 60 fs. Since the off crest S-band acceleration and the second order optics in the magnetic chicane make the bunch to get an energy slope nonlinearity which invokes very sharp temporal spikes to generate coherent synchrotron radiation and longitudinal wakefields in an undulator [2].

In order to this energy slope nonlinearity, we use an X-band structure which is the 2^{nd} harmonic of S-band RF in deceleration mode as shown in Fig. 1. For the case of PAL-XFEL, the required acceleration gradient is around 20 MV. This gradient is realized by using an X-band accelerating structure and an X-band klystron with collaboration with SLAC. We developed a 450 kV modulator, a 1 kW X-band solid state amplifier, and an X-band low level RF controller. We also developed a moving stage for the accelerating structure in order to align it to minimize wakefield effects.

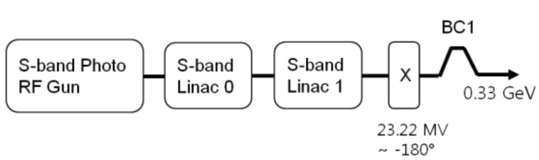

Figure 1: Schematic of the PAL-XFEL machine up to the first bunch compressor.

PAL-XFEL X-BAND RF SYSTEM

It is required a decelerating field of 25 MV in the X-band structure operated at -180° off the RF crest. We used an H60VG3 X-band accelerating structure developed by SLAC. The X-band accelerating structure is operating at the frequency of 11.424 GHz which is 2^{nd} harmonics of the S-band accelerating structure's operating frequency, 2856 GHz. Since the length of the X-band structure is 60 cm and RF power of 37.4 MW is required to obtain the acceleration gradient of 50 MV/m, it is needed more than 26 MW RF power to provide 25 MV deceleration field. The measured attenuation of the structure is about 4.8 dB or 5.5 Np.

Figure 2 is the 3D cad drawing w showing the PAL-XFEL X-band RF system. We used a XL-4 klystron which can generate up to 50 MW at 11.424 GHz when the beam voltage is 410 kV. The XL-4 klystron was had manufactured and completed the aging process in SLAC. We prepared a klystron modulator which is capable to generate over 410 kV, 5.7 μs, 60 Hz pulses. In order to minimize RF lose during transferring the RF power from the klystron to accelerating structure, WC293 circular waveguide was adapted. WC293 circular wave guide has the attenuation of 0.0035 dB/ft which is much smaller than WR90 rectangular waveguide's attenuation of 0.03 dB/ft. An X-band window is used to make ease to replace the klystron not to break the tunnel vacuum during mountainous. Since the total attenuation of the waveguide feed system has been estimated at about 0.5 dB, it is sufficient to generate the klystron output power of 30 MW.

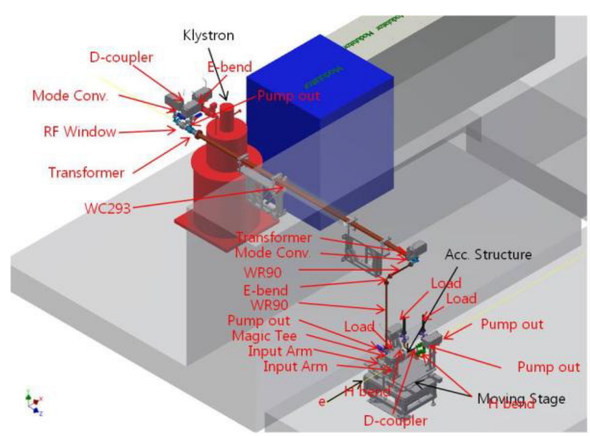

Figure 2: 3D cad drawing of the PAL-XFEL X-band RF system.

The X-band accelerating structure is mounted on a movable stage for the purpose of aligning the structure with electron beams. The inner diameter of the X-band accelerating structure is around 9 mm. Since this small size of the beam aperture makes wakefield effects if it is not aligned with the beam path, we prepared a moving stage for the structure. The full moving range of the stage is 2 mm both horizontal and vertical directions. Fig. 3 is the photograph of the X-band accelerating structure and the accelerating structure.

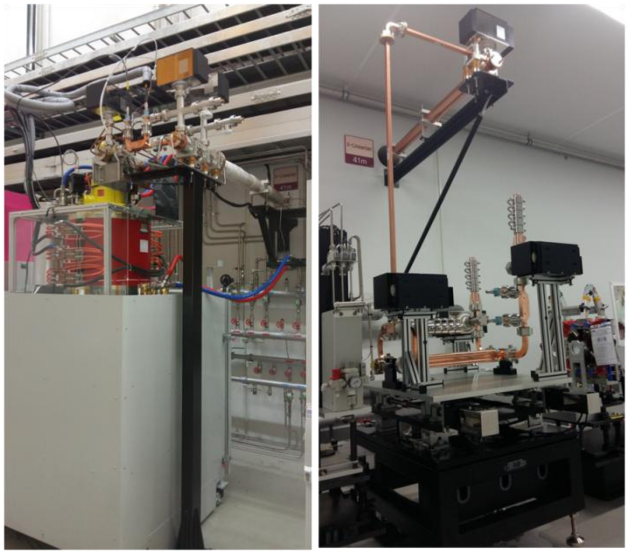

Figure 3: Photographs of installed the X-band klystron and the accelerating structure. The waveguide feed system is also shown.

Figure 4 shows the block diagram of the PAL-XFEL X-band RF system. The H60VG3 is a travelling wave type accelerating structure of which phase advance is 5π/6. The RF power is equally divided by a magic tee before entering the input couplers of the structure. The transmitted RF power was absorbed by the two dry loads cooled by cooling water. Fig. 5 shows the relation between saturated RF power and the XL-4 klystron's beam voltage. Since we need almost 30 MW, klystron beam voltage is to be 370 kV supposed that the drive power is saturated. Fig. 6 shows the gain curve of the XL-4 klystron versus the klystron driver's RF power. In order to obtain 30 MW RF power from the klystron output, we need to supply 380 kV beam voltage and 560 W driver power. Since we have to consider the cable attenuation from driver amplifier to the klystron, we used 1 kW driver sources.

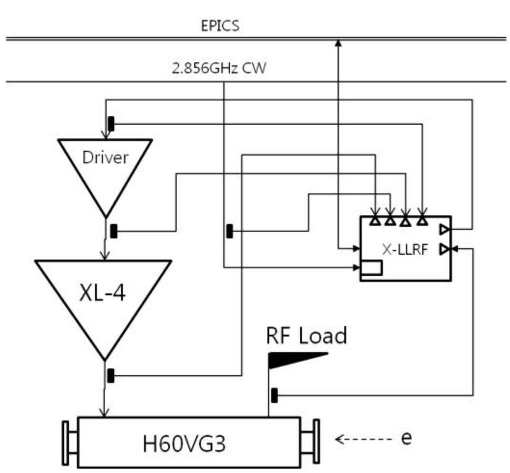

Figure 4: Block diagram of the PAL-XFEL X-band RF system.

Travelling wave tube amplifiers (TWTA) are widely used as a driver amplifier for the X-band klystron because it generates easily RF powers more than 1 kW. However, it is difficult to satisfy the requirement of the very low RF amplitude and the phase stability in X-band. For the case of PAL-XFEL, the amplitude stability and the phase stability requirements are 0.04% and of 0.1°, respectively. Recently, solid state amplifier is widely used replacing conventional TWTAs. S-band SSAs shows good performance to fulfil the tight requirements of several XFEL accelerators.

Recently, GaN HMET is developed for amplifiers above X-band. Since the power rate and gain is low, special power combining methods are used to obtain kW level RF power. Since the solid state amplifier is more stable and it life time is longer than TWTA, we developed an X-band solid state amplifier using GaN transistors and a radial combiner. Fig. 7 shows the 1 kW X-band SSA to drive the X-band klystron. Table 1 is the specifications of the X-band SSA.

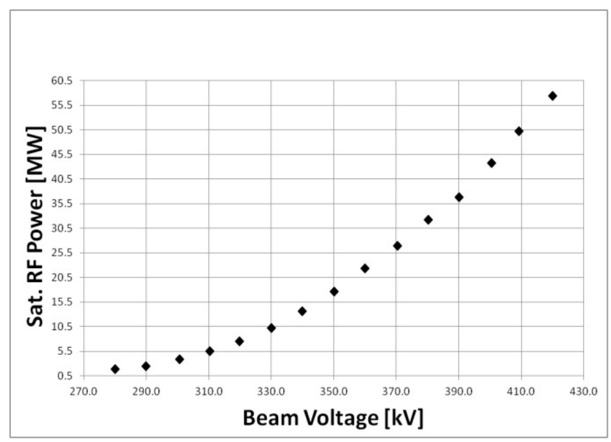

Figure 5: Saturated RF power versus XL-4 klystron's beam voltage.

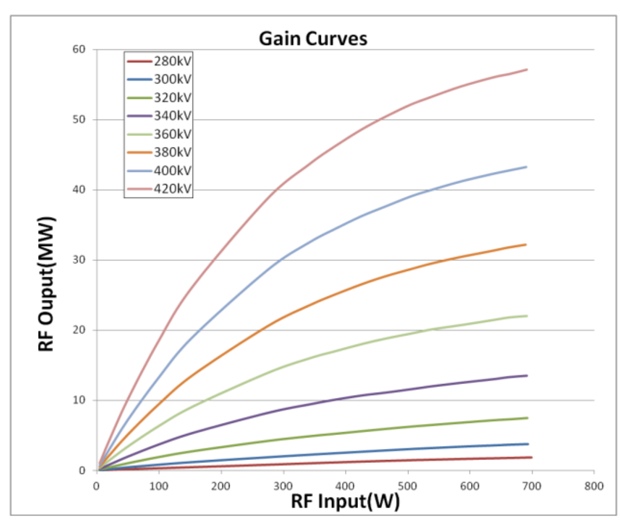

Figure 6: XL-4 klystron gain curve.

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Figure 7: Photograph of the 1 kW X-band SSA to drive the X-band klystron.

Table 1: PAL-XFEL X-band SSA Specifications

Parameter	Value
Frequency range	11.424 ± 10 MHz
Pulse repetition rate	5 ~ 120 Hz
Pulse rise/fall time	< 30 ns
Pulse width range	0.1 ~ 2.0 µs
Max. output Power	> 1 kW
Harmonics	-40 dB
Spurious	-65 dB
Input return loss	<1:1.5
Output return loss	<1:1.5
Main transistor	GaN HEMT
Power Combiner	20 ways Radial Combiner

To control the X-band RF system, we developed a low level RF controller. By using the external 2.856 GHz signals of few dBm levels supplied by the microwave distribution line (MDL), the X-band LLRF makes several X-band signals internally, as shown in Fig.5. The X-band LLRF measures X-band RF signals from several directional couplers by using the phase and amplitude modules (PAD). The controller of the X-band LLRF connected with the EPICS based control network. The X-band LLRF has phase and amplitude controller (PAC) to supply X-band RF signals with specified amplitude and phase.

Figure 8: Photograph of the X-band LLRF.

Table 2: PAL-XFEL X-band LLRF Specifications

Parameter	Value
Frequency	REF : 2.856 GHz PAD & PAC : 11.424 GHz
PAD Ch. number	10 (8 CH + 2 REF)
Phase stability	0.1 (RMS degree)
Amp. stability	0.04 (rms, Volt (%))
PAC pulse rising time	< 15 ns
PAD input power range	Ref : 0 ~ 5 dBm CH : -8 ~+8 dBm
PAC output power range	-8 ~ +8 dBm

SUMMARY

We have built the X-band RF system working as a linearizer of the PAL-XFEL linac. We installed a 50 MW X-band klystron and X-band accelerating structure through the collaboration with SLAC. Several high power X-band RF devices were developed such as the X-band klystron modulator, the X-band SSA, the X-band LLRF, the X-band circular waveguide, and the movable stage. These newly developed devices are now under the test to verify their performances.

REFERENCES

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[2] P. Emma., "X-Band RF Harmonic Compensation for Linear Bunch Compression in the LCLS", LCLS-TN-01-1, Nov 2001.

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