S-BAND HIGH STABILITY SOLID STATE AMPLIFIER FOR 10 GeV PAL XFEL*

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Abstract

In PAL, we are constructing a 10 GeV PxFEL machine. The output power of the klystron is 80MW at pulse width of 4us and the repetition rate of 60 Hz. And the specifications of rf phase and amplitude stability are 0.05 degrees (rms) and 0.05% (rms) respectively. A solid state amplifier (SSA) is used for rf driver of 80MW klystron. The measured rf stability of 800W SSA output is 0.03 degrees rms and 0.026% rms. This paper describes the microwave system and the SSA for PxFEL.

INTRODUCTION

Pohang Accelerator Laboratory, PAL, constructed the PLSII machine with 3.0GeV injector linac in 2011. We start user service in last year. Also, we are constructing 10GeV FEL machine from last year. We constructed two test facilities in last year. We need a test facility to perform the LLRF system and high power components for FEL. One is ATF (Accelerator Test Facility) to test the performance of an accelerator structure, high power rf components, and LLRF system with SSA(Solid State Amplifier). The other is ITF (Injector Test Facility) to test rf gun and injector for FEL.

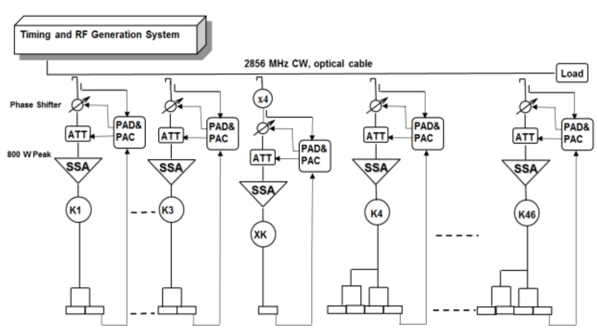

Figure 1: Microwave system for PxFEL.

The LLRF system of the XFEL consists of solid-state amplifier (SSA), phase and amplitude detector (PAD), and phase and amplitude control (PAC) units as shown in Figure 1. The function of PAC is to control the phase and amplitude of klystron drive rf, to provide pulsed rf signal, to provide PSK (180 degrees phase shifter). The rf pulse width and PSK trigger time are 4 μs and 3.17 μs respectively. The PxFEL requires rf stability of 0.05 % rms and 0.05 degrees rms respectively as shown in Table 1.

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Table 1: Design Parameters for PxFEL

Parameters	Specification
Beam Energy	10 GeV
Beam Energy Spread	< 0.05%
Operating Frequency	2856MHz
Modulator Voltage Stability	< 50 ppm
RF Phase Stability	0.05 degrees (rms)
RF Power Stability	0.05 % (rms)

The high precision phase amplitude detection system (PAD) and phase amplitude control (PAC) system was developed also needed to meet the specifications in last year [1, 2, 3]. The major function of PAC is as follows:

- Amplitude control and feedback
- Phase control and feedback
- RF pulse modulation ; 0.1 μs to 7 μs
- PSK
- Interlock and safety
- Fast reflected power protection
- Fast data transfer and storage

The developed 2 sets LLRF system with SSA is using for ITF (Injector Test Facility) from last year. The developed LLRF system is well operating from last year. But we need a smaller LLRF and SSA to install the one temperature control RF rack. One RF rack consists of timing module, rf and timing distributer, power supply, LLRF with SSA, and diagnostic system with BPM (Beam Position Monitor). So, we developed a new LLRF and S-band 800W SSA with higher performance and smaller size than SSA for ITF in this year. The size of a new developed LLRF and SSA is decreased to 2/3 and 1/2 respectivery.

SSA (SOLID STATE AMPLIFIER)

Design

The AB-class SSA amplifies an rf signal by using the multi-cascade method. We developed a new high stability SSA with rf pulse modulator. The input pulse width of the SSA is adjustable from 0.1 μs to 7 μs by itself. The output power of the SSA is adjustable from 100W to 800W also. The rising and falling times are about 0.1 μs and 0.1 μs, respectively. The design parameters are shown in Table2.

Table 2: Design Parameters of SSA

Parameters	Specification
Operating Frequency(MHz)	2856+/- 1
Input Power(dBm)	-10~ +5
Output Power (W)	0 ~ 800
Power Gain(dB)	~60
IN/OUT vswr	13/1.3
RF Pulse Width(μs)	0.1~7
Pulse Repetition Rate(Hz)	1~60
Rising/Falling Time(ns)	<100
Phase Stability(degrees, rms)	< 0.05
Amplitude Stability(%, rms)	< 0.05

The AB-class SSA amplifies 1mW input power to 800W by using the multi-cascade method as shown in Figure 2. The input pulse width of the SSA is adjustable from 0.1 μs to 7 μs by PAC system or itself.

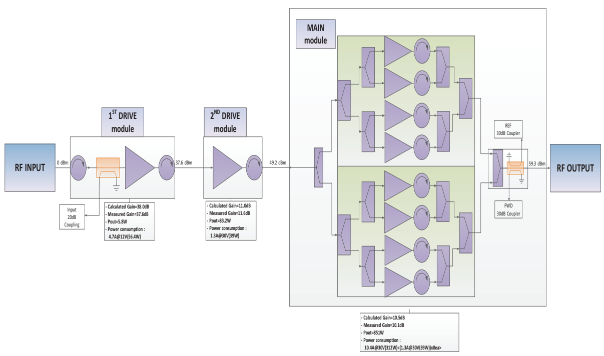


Figure 2: Block diagram of SSA.

The function of 1'st drive module is as follows:

- Amplify 1mW input power to 6W.
- RF pulse modulation ; 0.1 μs to 7 μs
- Monitoring the input power level
- Monitoring the temperature

The design gain of 1'st module is 38 dB and measured gain is 37.6 dB. Also 6W from 1'st module is amplified to 80 W in 2'nd drive module. The design gain of 2'nd module is 11.0 dB and measured gain is 11.6 dB. The main module amplifies 80W input to 800W and monitors the output power and reflected power. The design gain of main module is 10.5 dB and measured gain is 10.1 dB. The maximum power of each power amplifier in main module is 320W. We used 8 ea MRF8P20300H amplifier made by freescale semiconductor Co. in main module. To obtain the high stability of SSA output power of SSA, we reduced the gain of amplifier properly. Also we attached water cooling channel on main module to obtain the stable output.

Output Power

Figure 3 shows output power for different input drives. The maximum output power is 800 W above 1dBm drive power. The gain is more than 58 dB in overall drive power range and maximum gain is 61.5 dB at -6dBm input drive power. The input vswr and output vswr is 1.26 and 1.04 respectively as shown in Figure 4.

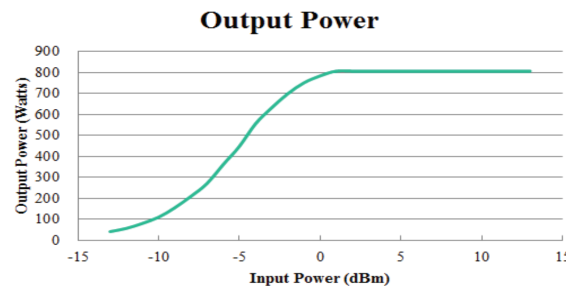
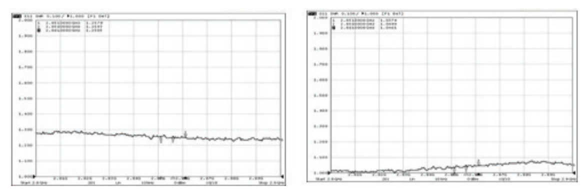


Figure 3: Output power vs. input power.

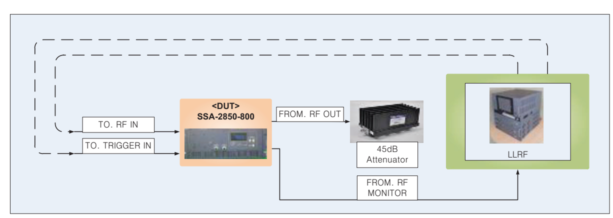


(a) Input vswr ; 1.26:1 (b) Output vswr ; 1.04:1

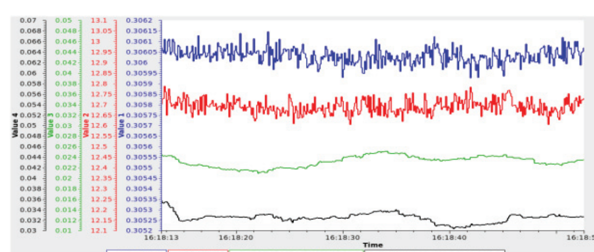
Figure 4: Input vswr(a) and output vswr(b).

Output Stability

The output stability is measured by using PAD of LLRF as shown in Figure 5a. The data gathering time is less than 1 minute at 60pps of rf pulse repetition rate. The short-term phase and amplitude variation of SSA output is 0.03° and 0.026% rms value as shown in Figure 5b.



(a) Measurement Test-stand



(b) Phase and Amplitude stability

Figure 5: Output Power Stability of SSA.

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RF Pulse Modulation

The cw rf input signal is modulated using pin diode in the 1'st drive module. The output waveform is measured by rf detector and Oscilloscope. The rising and falling time is 20ns at 4μs of rf pulse width. PSK switching time is 20ns as shown in Figure 6.

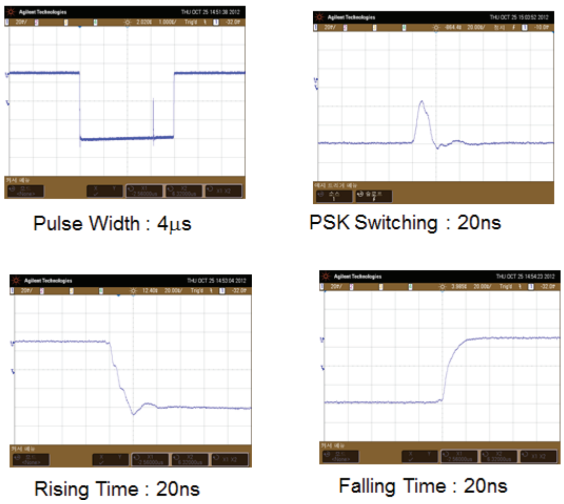

Figure 6: Waveform of SSA Output.

Harmonics and Spurious Signal

The harmonics and spurious signal of Linac RF system affects beam stability and beam spread. The unwanted signal must be minimized as soon as possible. The harmonics of 2'nd 5712 MHz and 3'rd 11.424 GHz is 49dBc and 79dBc respectively as shown in Figure 7. The spurious signal is 83dBc within 100MHz at center frequency 2856 MHz as shown in Figure 8.

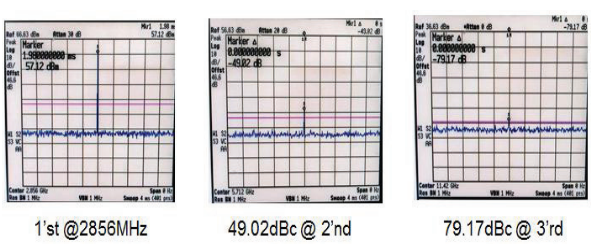

Figure 7: Harmonic Signal.

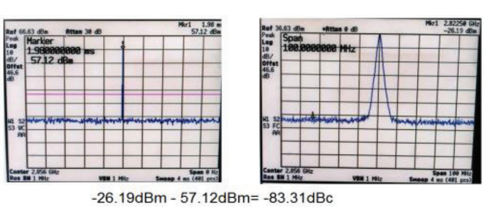

Figure 8: Spurious Signal.

SUMMARY

We are developing a LLRF system for PAL-XFEL from a few years ago. The proto-type LLRF is developed in last year. The developed 2 sets LLRF system with SSA is using for ITF (Injector Test Facility) from last year. The developed LLRF system is well operating from last year. The test results of LLRF without SSA satisfied to PAL design goal. The phase and amplitude variation of 0.017 degrees (rms) and 0.026% (rms) at PAC output is less than the design value of 0.05 degrees (rms) and 0.05% (rms) for PAL_XFEL. But, the test results of SSA did not satisfy to design goal. The phase and amplitude variation of 0.075 degrees and 0.115% at SSA output is far larger than the design value. So, we start to develop a high stability SSA from last year. We developed a SSA with high stability as shown in Table 3. The phase and amplitude variation of 0.03 degrees and 0.026% at SSA output is less than the design value in short-term. Also long-term test of the precision LLRF with SSA in temperature stable rack is needed to confirm for long-term stability.

Table 3: Test results of SSA

Parameters	Results
Operating Frequency(MHz)	2856+/- 30
Input Power(dBm)	-15~ +5
Output Power (W)	0~ 800
Power Gain(dB)	59
IN/OUT vswr	1.26/1.04
RF Pulse Width(microseconds)	0.1~7
Pulse Repetition Rate(Hz)	1~60
Rising/Falling Time(nanoseconds)	20
Phase Stability(degrees, rms)	0.03
Amplitude Stability(%, rms)	0.26
Harmonics@ P1dB(dBc)	-49
Spurious@ P1dB(dBc)	-83

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