1.3 GHz SOLID STATE POWER AMPLIFIER FOR THE BUNCHER IN CTFEL FACILITY*

T. H. He†, C. L. Lao, P. Li, X. Luo, L. J. Shan, K. Zhou
Institute of Applied Electronics, China Academy of Engineering Physics, Mianyang, China

Abstract

The THz Free Electron Laser facility (CAEP THz FEL, CTFEL) of the China Academy of Engineering Physics uses high-quality electron beams to generate high average power terahertz radiations. A 1.3 GHz RF buncher is used in front of the superconducting linear accelerator of the CTFEL facility to improve the electron beams quality. The RF buncher is driven by a solid state power amplifier (SSPA), and the SSPA is feedback controlled by a low level RF (LLRF) control system to ensure the high stability of the amplitude and phase of the bunching field in the buncher cavity. The SSPA operates at 1.3 GHz and outputs 0 to 5 kW of continuous wave power. This paper mainly introduces the principle and composition of the SSPA, and presents some experiments on the RF buncher driven by the SSPA.

INTRODUCTION

In recent years, with the development of science and technology, high-power terahertz sources have become more and more important in the world. A high average power terahertz radiation facility (CAEP THz FEL, CTFEL) has been developed by the China Academy of Engineering Physics. This is the first THz user facility based on free electron lasers in China [1]. The CTFEL facility is designed to produce 1-3 THz radiation with an average output power beyond 10 W.

The CTFEL facility mainly includes a photocathode high voltage direct current (HV-DC) electron gun [2], an RF buncher, an RF superconducting linear accelerator [3], a high performance undulator [4] and so on. Its general layout is shown in Figure. 1. High quality electron beams are generated by the photocathode HV-DC electron gun. When the electron beams come through the RF buncher cavity, the bunch length of the electron beams will be compressed to 4-8 ps. Then, the electron beams come into the RF superconducting linear accelerator, and will be accelerated to 6-8 MeV, passing through an achromatic section, coming into an undulator with the periodical magnetic field and generate spontaneous THz radiation. The THz radiation oscillates back and forth in the optical cavity. Under resonant conditions, the power of the THz radiation increases rapidly until reaching saturated output state.

The RF buncher is an indispensable component of the CTFEL facility, which provides a longitudinal manipulation of the electron beams and ensures that the bunch length of the electron beams to be compressed to 4-8 ps when coming into the superconducting cavity. In the CTFEL facility, the electron beams are quasi-continuously operated, so the RF buncher needs to be driven by continuous wave. The designed output power of the microwave source is about 2.7 kW. Considering the improvements and upgrades in the future, the CTFEL facility uses an L-band 5 kW continuous wave solid state power amplifier (SSPA). The bunch length and energy spread of the electron beams are directly related to the amplitude and phase of the buncher cavity. In order to ensure that the amplitude and phase stability of the buncher cavity field are less than 0.3% and 0.3°, respectively, the SSPA is cooled by a high precision water cooler and controlled by a low-level RF (LLRF) control system for real-time feedback. This paper mainly introduces the principle and composition of the SSPA, and presents some experiments on the buncher driven by the SSPA.

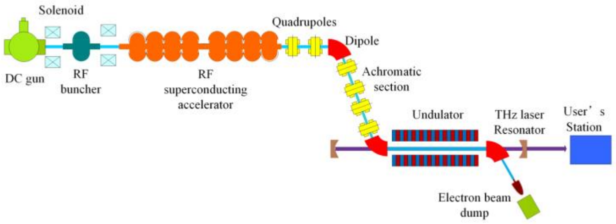

Figure 1: Layout of the CTFEL facility.

SOLID STATE POWER AMPLIFIER

The SSPA is used to drive the RF buncher, its main function is to amplify the input signal and output a continuous wave of high power. And the output power of the SSPA can be adjusted with the change of the input signal.

The SSPA consists of a preamplifier (with one-two splitter, two 3 kW final stage power amplifier arrays, two 3 kW coaxial directional couplers, two waveguide coaxial converters, a two in one waveguide power combiner, a 5 kW waveguide directional coupler, a controller and an embedded computer. The 3 kW final stage power amplifier array consists of a pre-stage power amplifier, ten final stage power amplifier modules, eleven power supply modules, a one-tenth power splitter, a ten in one power combiner and a water cooled board. Board composition. The MCU acquisition unit is integrated in the power supply modules, and the parameters such as voltage, current and temperature are uploaded to the industrial computer through the RS-485 serial ports.

The block diagram of the SSPA is shown in Figure. 2. When a 0 dBm signal is input to the SSPA, it can output a 5 kW continuous wave. The SSPA design targets and test

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† htth111@163.com

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results are shown in Table 1, and the test results meet the design requirements. The SSPA is shown in Figure. 3.

Table 1: Margin Specifications

Parameters	Design value	Test results
Frequency range	1300 ±10 MHz	1300 ±10 MHz
Output power	≥5.0 kW	5.3 kW
RF phase shift	≤5.0 °	3.6 °
Gain change	≤2.0 dB	1.4 dB

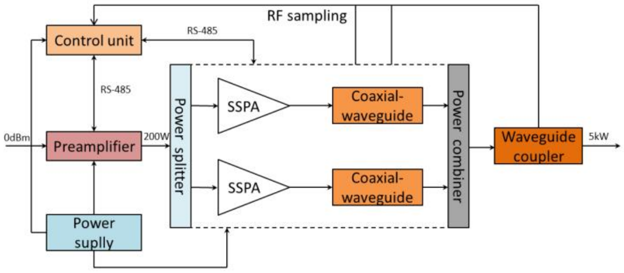


Figure 2: Block diagram of the SSPA.

A high precision water cooling machine was used to maintain the temperature of the SSPA at 20 °C, ± 0.1 °C. The water cooling machine cooled the SSPA and reduced the influence of the temperature fluctuations on the amplitude and phase stability of the output microwave.

EXPERIMENTAL TEST

Test Setup

The SSPA was connected to the RF buncher via waveguides, a directional coupler, a ceramic window, etc. to form a complete buncher system. After the installation of the buncher system was completed, an experimental platform was setup, as shown in Figure. 4.

A signal from a weakly-coupled pickup antenna at the bottom of the buncher cavity was sent to the LLRF together with the signal generated by the signal source, and processed by the LLRF to output a modulated signal to drive the SSPA. The high power RF from SSPA was transmitted through the waveguides, directional coupler and ceramic window into the buncher cavity. A water cooling machine was used to maintain the temperature of the buncher cavity at 25 °C ±0.1 °C. The water cooling machine cooled the buncher cavity and reduced the effect of the temperature fluctuations on the resonant frequency of the buncher cavity. Additionally, the forward, reflected and pickup signals were measured by a power meter and oscilloscope simultaneously. The buncher has two frequency tuners for adjusting the buncher resonant frequency. The buncher is shown in Figure. 5.

Test Results

After the completion of the buncher experimental platform, the buncher conditioning experiment, the buncher frequency calibration experiment, the buncher power calibration experiment and the bunching phase experiment were carried out.

Figure 3: Picture of the SSPA.

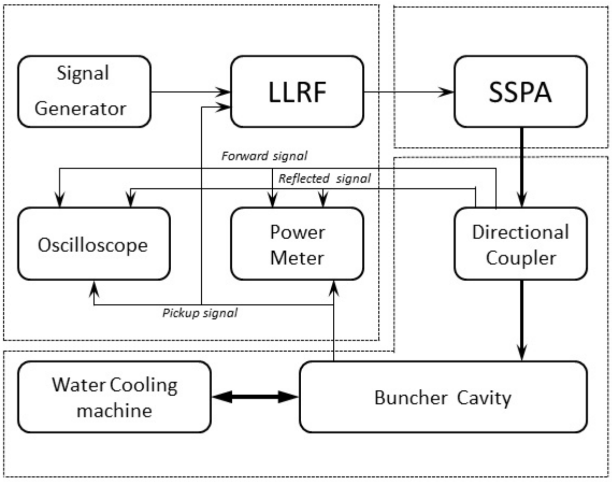


Figure 4: Block diagram of the test setup for the buncher system.

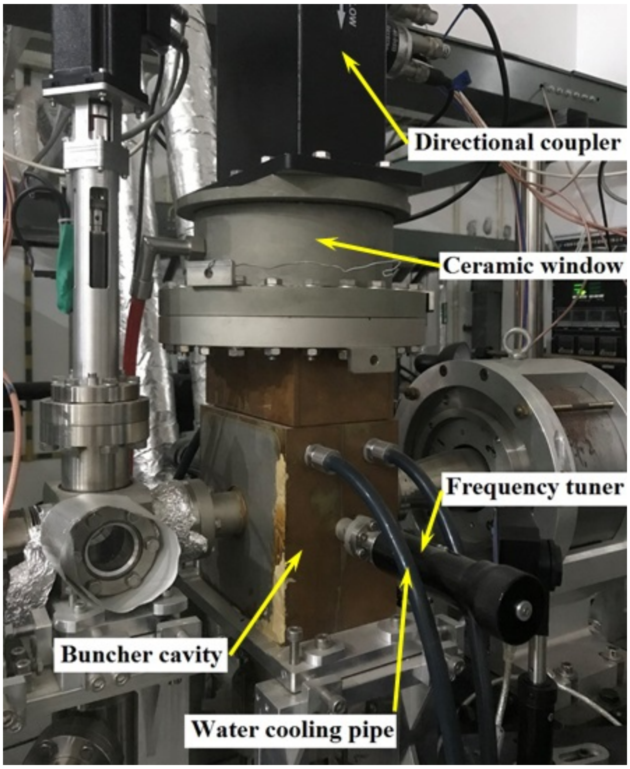
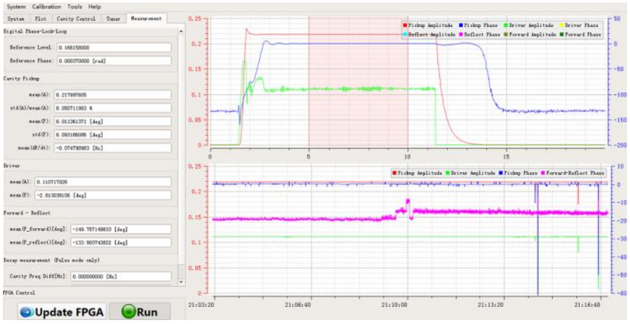


Figure 5: Picture of the bancher cavity.

The buncher conditioning experiment enabled the buncher to withstand high power microwaves without significant temperature rise and gas release. The buncher frequency calibration experiment calibrated the relationship between the buncher cavity resonant frequency and the frequency tuner. The buncher power calibration experiment calibrated the corresponding electric field gradient at different microwave input powers. The bunching phase experiment determines the optimal bunching phase of the buncher cavity when the bunch length of the electron beams is compressed to a minimum. After the beam buncher debugging experiments were completed, the buncher cavity bunching gradient was measured to reach 3 MV/m when the microwave input power was close to 3 kW, and the optimal bunching gradient of the buncher is 1.2 MV/m (corresponding to the microwave input power of about 1.5 kW), The optimal bunching phase of the buncher was at 0°. At this time the bunch length of the electron beams can be compressed from about 19 ps to a minimum.

After the above experiments were completed, the CTFEL facility was debugged and light-extracted. The amplitude and phase stability of the buncher cavity were measured to be 0.05% and 0.09°, respectively, as shown in Figure. 6.



Digital Phase-Lock-Loop
Reference Level: 0.166158000
Reference Phase: 0.000370000 [rad]

Cavity Pickup
mean(A): 0.217997805
std(A)/mean(A): 0.050711983 %
mean(P): 0.011361371 [deg]
std(P): 0.093186086 [deg]
mean(dF/dt): -0.074798983 [Hz]

Driver
mean(A): 0.110717026
mean(P): -2.613038106 [deg]

Forward - Reflect
mean(P_forward)[deg]: -149.757149833 [deg]
mean(P_reflect)[deg]: -133.903743822 [deg]

Decay measurement (Pulse mode only)
Cavity Freq Diff[Hz]: 0.000000000 [Hz]

FPGA Control

Figure 6: The amplitude and phase stability of the buncher cavity.

The SSPA output a continuous wave power of approximately 1.5 kW. The CTFEL facility received its first saturated light on August 29, 2017.

CONCLUSION

Designed and developed an L-band 5 kW continuous wave solid-state power amplifier, and introduced the experimental platform of the buncher system and related experiments. In the CTFEL facility experiments, when the optimal bunching gradient of the buncher cavity was 1.2 MV/m, the bunch length of the electron beams was compressed to the minimum. The amplitude and phase stability of the bunching field are 0.05% and 0.09°, respectively. The input continuous wave power is 1.5 kW, and the power output range is not exceeded. The experimental results show that the SSPA working index was better than the experimental demand. The CTFEL facility obtained saturated light. In the next step of CTFEL facility improvement and upgrade, the SSPA will play a more important role.

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