APPLICATION OF SOLID STATE AMPLIFIERS IN ADS PROJECT AT IHEP *

THPO103

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IHEP

INTRODUCTION

- With the progress of transistor technology, the output power and efficiency of a single transistor has been greatly improved. The high power can be obtained by combination of numerous transistors. Recently the power capability of solid state amplifier (SSA) can extend from a few kW to several hundred kW, and the operating frequency from less than 100 MHz to above several GHz[1][2][3][4].
- Three kinds of solid state amplifier with different power and frequency have been used to feed the cavities or test high power coupler in injector I of ADS at institute of high energy and physics (IHEP), whose performance and detailed parameters are presented in this paper..

325 MHz/10 kW SSA

- The 325 MHz/10 kW SSA is used to feed bunchers and spoke cavities of injector I of ADS. The 325 MHz/10 kW SSA specifications are shown in Table 1.
- In July 2012, the first 325 MHz/10 kW SSA was delivered to IHEP by BBEF, which was used to build a workbench for the high power test of the coupler of spoke cavity. In September 2013, another one was delivered for the horizontal test of spoke cavity. In April 2014, 14 SSAs were installed and commissioned in power supply hall. In 2015, 9 SSAs were put into operation. In March 2016, another two SSAs were delivered by the 38th institute of CETC. In the end of 2016, 16 325 MHz/10 kW SSAs were used in injector I, as shown in Figure 1.

Table 1: 325 MHz/10 kW SSA specifications

Frequency(MHz)	325
Output Power(kW)	10
Gain(dB)	≥65
Bandwidth(MHz)	≥ 2
Amplitude stability	≤1%
Phase stability	≤1°
Harmonic(dBc)	< -30
Spurious(dBc)	< -65
MTBF(h)	20000
Efficiency at 10 kW	≥50%

Figure 1: 325 MHz/10 kW SSA

325 MHz/25 kW SSA

- The 325 MHz/25 kW SSA was used to feed spoke cavities of CM4. In order to facilitate maintenance, the power module and power supply should adopt fast plug and pull technology. The power module must include self-protection for overheating. The output port is 4-1/2 inch rigid coaxial line. The 325 MHz/25 kW SSA specifications are shown in Table 2.
- In the end of 2014, the contract of the prototype of 325 MHz/25 kW SSA was signed with Chengdu Kaiteng Sifang Quartet Digital Broadcasting & TV Equipment Co. Ltd (KTSF). In April 2016, the acceptance test of the prototype was completed at IHEP. In May 2017, 6 325 MHz/25 kW SSAs were installed and commissioned for CM4 in Lanzhou city, as shown in Figure 2.

Table 2: 325 MHz/25 kW SSA specifications

Frequency(MHz)	325
Output Power(kW)	25
Gain(dB)	≥70
Bandwidth(MHz)	≥ 2
Amplitude stability	≤1%
Phase stability	≤1°
Harmonic(dBc)	< -35
Spurious(dBc)	< -70
MTBF(h)	20000
Efficiency at 25 kW	≥50%

Figure 2: 325 MHz/25 kW SSA

650 MHz/150 kW SSA

- The output port of 650 MHz/150 kW SSA is WR1500 waveguide. The AC to RF efficiency goal for the SSA at the rated power is at least 45%, which reaches 51.3% for acceptance test. The 650 MHz/150 kW SSA specifications are shown in Table 3.
- In September 2016, a 650 MHz/150 kW SSA was completed factory acceptance test in KTSF. At the end of 2016, the 650MHz/150kW SSA was delivered to IHEP and completed installation. In March 2017, the acceptance test of the prototype of 650 MHz/150 kW SSA was completed, as shown in Figure 3.

Table 3: 325 MHz/150 kW SSA specifications

Frequency(MHz)	650
Output Power(kW)	150
Gain(dB)	≥75
Bandwidth(MHz)	≥ 2
Amplitude stability	≤1%
Phase stability	≤1°
Harmonic(dBc)	< -35
Spurious(dBc)	< -70
MTBF(h)	20000
Efficiency at 150 kW	≥50%

Figure 3: 650 MHz/150 kW SSA

POWER MODULES BREAKDOWN

- In August 2014, several power modules failed when the coupler was carried out high power test in standing wave mode. The ceramic absorbing load was seriously break-down, as shown in Figure 4. It indicated that the reflected power exceeded the load rated value of 800W .The principle can be expressed as follows: The reflected power due to the mismatch of output port of SSA will be equally distributed to each port of combiner. To simplify the de-sign of the power combiner, all ports are not isolated from each other. When one of the power modules fails, the wave from the other port will combine at this port in phase. So the total reflected wave of the module failed is the sum of the reflected wave from the mismatched load and the combined wave from the other port. In the worst case, these two wave will combine in phase. Then the total reflected power can be expressed as follows:

$$P_{total} = \left(\frac{N-1}{N} + \Gamma\right)^2 P \quad (1)$$

- Where P_{total} is the total reflected power, P is the output power of a single power module, N is the port number of combiner, and Γ is the reflection coefficient of the output port of SSA. When P is 550W, N is 10 and Γ is 1, the maximum reflected power is 1985.5W which is far in excess of load capacity. In order to avoid the load breakdown, a high power circulator can be used at the output port of SSA when the coupler was tested in standing wave mode.

Figure 4: Power module breakdown

SUMMARY

- The solid state amplifier has been widely used in accelerator due to high reliability and easy maintenance, which has become an important part of power source system of injector I of ADS. During the process of application, some useful suggestions were fed back to companies to improve the design. The application of solid state power source in large-scale scientific projects has greatly promoted the domestic solid state power source industry and R&D capability.

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