

DEVELOPMENT OF THE HLS 40kW SOLID STATE AMPLIFIER*

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Abstract

In the HLS(Hefei Light Source) phase III upgrade plan, the 204MHz 40kW RF Solid State Amplifier (SSA) will replace the 25kW tetrode amplifier as the new RF power generator of 800MeV electron storage ring. This SSA contains sixty-five 650W amplifier units (one unit drives sixty-four's), with two-stage combination to reach the 40kW output. All of the SSA components has been manufactured and tested, each of them meets the requirements. The SSA system has been assembled in the end of 2012 and is in testing to date. The 45kW output power has been obtained. The SSA's design, manufacture, and test results are presented in the paper.

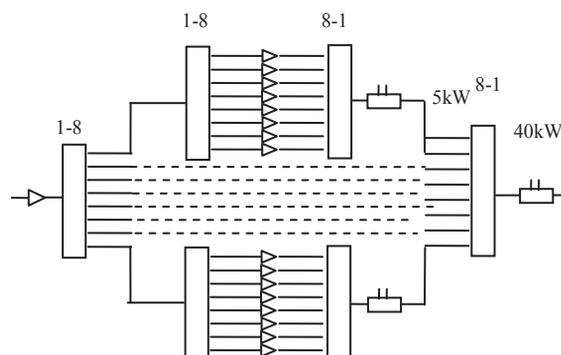


Figure 1: Block diagram of the 40kW SSA.

DESIGN OF THE HLS RF SSA

In the past ten years, more and more high power Solid State Amplifiers have been used in accelerators, since the first one was developed in SOLEIL [1-6]. In the HLS phase III upgrade plan, the 25kW tetrode amplifier will be retired, we decide to develop a 40kW SSA. The development began in 2008, when the available RF power of single SSA module was 330W, therefore 128 modules would be needed to obtain the 40kW. The power combining method is $8 \times 8 \times 2$ (twice of 8-1 and then 2-1), the corresponding power splitting way of the drive signal is $1 \div 2 \div 8 \div 8$. Ten 330W modules and samples of each kind of combiners/splitters were produced and tested in 2010[7]. However, in 2011 a new kind of SSA module manufactured by China BBEF Company can output 650W (nominal value). We decided to modify the SSA design. The sixty-four 650W modules would be used and their output be combined by 8×8 . The structure of the 40kW RF SSA is shown in the figure 1.

The 40kW SSA is designed to leave a large space for the HLS future upgrade, since the RF power requirement of the phase III project is about 22kW. But the power efficiency of amplifier module is low, when the 40kW SSA works at the 20kW level. In order to improve the efficiency, the 30kW operating model will be adopted for HLS Phase III. One 1-6 splitter and one 6-1 combiner replaces the first 1-8 and the last 8-1 respectively. the combining method is changed to 8×6 , only 48 modules will be used. The conversion from 30kW to 40kW or in turn is convenient, without too much adjustment in the main structure of the SSA.

COMPONENTS OF THE SSA

Amplifier Unit

Seventy-five units of amplifier module and 50V DC power supply have been manufactured, which are shown in figure 2. The test results are listed in the Table 1. Seventy-two units will be installed on eight water cooled dissipaters, in which 7 units are backups. If failure occurs in a unit, it will be replaced quickly.

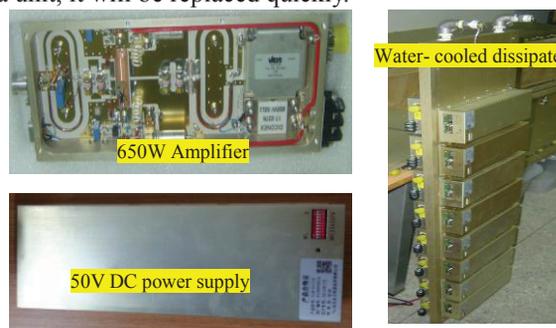


Figure 2: Amplifier unit.

Table 1: Parameters of the SSA Module

RF Frequency	204 ±10 MHz
max. Output	700 W
Gain	24 ± 0.2 dB
Insert Phase	120 ± 5°
Efficiency @ 650W	70%

The unbalance of amplitude or insert phase between the SSA modules will low down the combining efficiency. The gain deviation ± 0.2 dB will not have significant impact, but ± 5° of the insert phase error seems to impact. In order to correct it, the length of the cable connected to the module is matched with itself phase error. After correction, the phase error decrease to ± 2.5° (figure 3).

*Work supported by NFSC-CAS(11079034)

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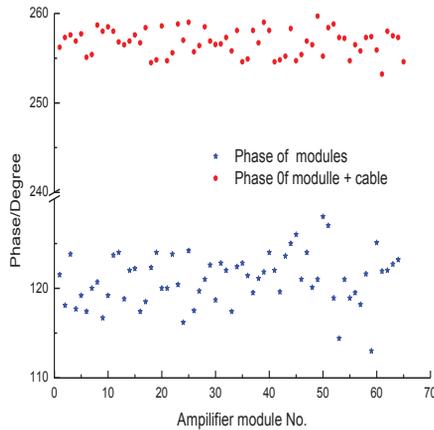


Figure3: correction of the module insert phase.

Combiner and Splitter

All kinds of splitter and combiner used in the 40kW SSA can be seen in figure 4. Their S parameter are measured by network analyzer, the typical results are shown in the following tables (the common port of splitter/combiner is labeled as No. 9, the eight symmetrical ports as No. 1 - 8).



Figure 4: Splitter / combiner

Table 2: S Parameters of 1-8 Splitter/dB

S ₁₉	S ₂₉	S ₃₉	S ₄₉	S ₅₉	S ₆₉	S ₇₉	S ₈₉	S ₉₉
-9.01	-9.02	-9.01	-9.03	-9.00	-9.02	-8.97	-8.97	-28.97
S ₉₁	S ₈₁	S ₇₁	S ₆₁	S ₅₁	S ₄₁	S ₃₁	S ₂₁	S ₁₁
-9.01	-17.73	-18.43	-18.35	-18.29	-18.36	-18.42	-17.85	-1.20

Table 3: S Parameters of 5kw 8-1 Combiner/dB

S ₁₉	S ₂₉	S ₃₉	S ₄₉	S ₅₉	S ₆₉	S ₇₉	S ₈₉	S ₉₉
-8.93	-8.94	-8.95	-8.97	-8.93	-8.92	-8.91	-9.00	-38.17
S ₉₁	S ₈₁	S ₇₁	S ₆₁	S ₅₁	S ₄₁	S ₃₁	S ₂₁	S ₁₁
-8.96	-17.67	-18.23	-18.17	-18.1	-18.15	-18.24	-17.70	-1.36

RF Coupler

A 5kW 50dB RF coupler is inserted between the 5kW combiner and the 40kW's, in order to monitor the status

of the first combination. The 40kW 50dB coupler is connected to the output port of 40kW combiner. Their pictures are shown in figure.

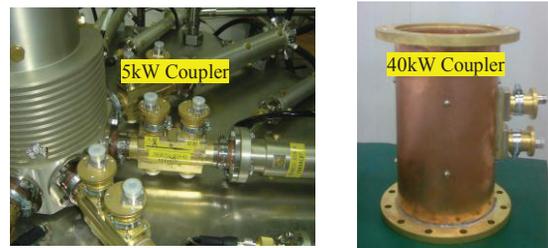


Figure 5: RF coupler.

ASSEMBLY AND TESTS OF 40KW SSA

The manufacture and test of the SSA components was completed in Oct.2012. Then we began to assemble the SSA in a RF test room according to the 40kW output model. A tower-like framework is produced to support the SSA system. The power splitting system shown in Fig.6 and the combining system shown in Fig.7 is installed in the center, and the water-cooled dissipaters with the amplifier units are hanging around the tower. The assembly has been finished in the end of 2012. After then the SSA was connected to a water-damping load for power testing (Fig.7). From early 2013 to the present, the test work has been in progress, and the 45kW output power was recorded. The SSA system has remained stable, no failure took place on any component.



Figure 6: 1-64 power splitting system.



Figure 7: 64-1 power combining system.

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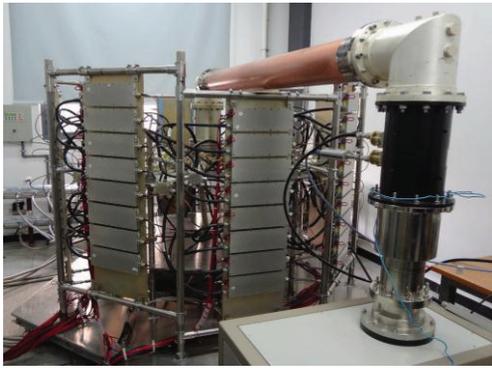


Figure 8: 40kW SSA test system.

CONCLUSION

The 40kW 204 MHz solid state power amplifier has been designed, manufactured and successfully tested, which performance meet the expected goal. In July of this year, the SSA test device will be disassembled, and be re-assembled according to the 30kW operation model, and then be installed in RF system of storage ring.

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