APS STORAGE RING SOLID STATE AMPLIFIER UPGRADE CURRENT STATUS*

Y. Luo†, T. Berenc, A. Goel, D. Horan, T. Madden, A. Nassiri, B. Popovic, J. Schultz, K. Suthar, G. Trento, G. Waldschmidt, Argonne National Laboratory, Lemont, IL, USA

Abstract

Radiofrequency (RF) power for the Argonne Advanced Photon Source (APS) storage ring (SR) and Booster cavities is currently supplied by multiple klystrons. APS is in the process of transitioning to 160 kW solid state amplifier (SSA) system per SR cavity [1]. Several SSA systems have already been delivered, and site acceptance testing (SAT) has been completed on four units. New 200 kW circulators have also been tested. A typical SAT waveguide setup is shown. Improvements have been implemented, including modifications to RF cable lengths to increase access clearance and reduce environmental power dissipation. During the initial tests, 60 Hz noise was observed on the monitoring spectrum. This issue was investigated, and a successful mitigation solution has been implemented. To minimize the risks and to validate both the new hardware and control software, one SSA system will be placed into operational service around January 2026. For this deployment, the SR RF system will be in a hybrid configuration, with the SSA powering one cavity while the remaining eleven cavities continuously being powered by klystrons. Several intermediate interfaces are required to bridge the existing infrastructure with the new SSA system. After the hybrid operation, RF power for the remaining three cavities in the same sector will be transitioned to SSAs too. The remaining two SR sectors, are planned for SSA conversion within the following few years, completing the multi-year APS SR RF system upgrade.

INTRODUCTION

As mentioned before, 1 MW klystrons operating at 352 MHz are no longer available for the APS [1]. SSAs offer multiple advantages over klystrons such as lower supply voltage, reduced RF noise levels, and redundancy through combining multiple individual kW amplifier units. Furthermore, by leveraging from the APS-upgrade (APS-U) digital low-level RF (dLLRF) systems, the SR can now transition from the analog LLRF to full digital LLRF control. At the end of 2025, one 160 kW SSA system was installed to provide RF power to one SR cavity (S36 C1). Since Jan. 2026, APS SR RF power is on a hybrid mode. RF power to other 11 SR cavities are provided by two active 1 MW klystrons except that S36 C1 is on SSA. Tuning and some improvements are made to the hardware and control software for actual routine beam operation. Experience and knowledge from routine operations are accumulated for next step of SSA upgrade project in APS.

WAVEGUIDE RECONFIGURATION AND SAT SETUP

The storage-ring (SR) RF systems consist of multiple normal conducting cavities. Backup klystrons were installed as hot spares. As part of the APS-U the number of cavities was reduced from 16 to 12. After the SSA sector 36 C1 cutover, one klystron is used to power 7 cavities now instead of 8, while the second klystron powers 4 cavities. Conversion of the remaining 3 cavities in S36 are planned for the April/May 2026 maintenance period. The remaining two SR sectors conversion are planned to take place in subsequent years.

The waveguide reconfiguration is shown in Fig. 1 for S36 C1 SSA cutover. A blanking plate is attached to the specific 3 dB hybrid port that allowed the SSA to drive the S36 C1 cavity. A new waveguide was installed to connect the SSA and a new 200-kW circulator to the existing waveguide section leading to the cavity.

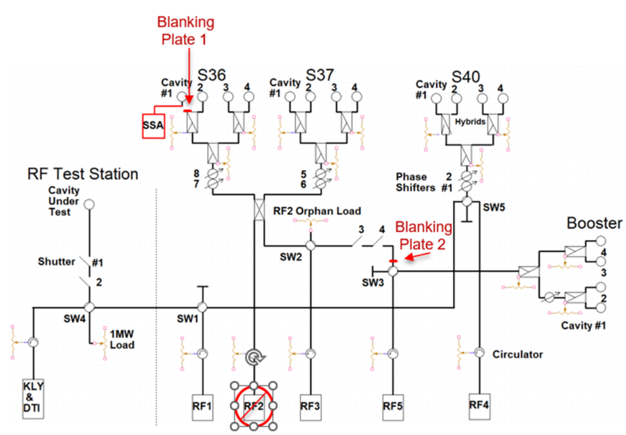

Figure 1: Waveguide and RF power system after S36 C1 SSA cutover.

The delivered SSA units and 200kW circulators are tested on-site as part of SAT. A typical SAT setup is shown in Fig. 2. Improvements have been implemented, including modifications to RF cable length to increase access clearance and reduce environmental power dissipation. The first 200 kW circulator was tested using a different setup to verify its performance. The other circulators were used in SSA SAT.

* Work supported by US Department of Energy, Office of Science, under contract number DE-AC02-06CH11357.
† yluo@anl.gov

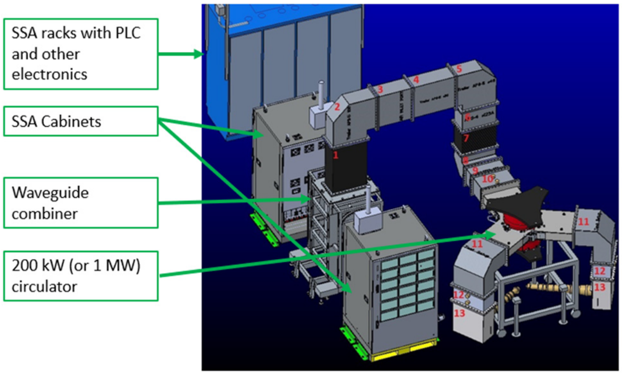

Figure 2: A typical setup for SSA SAT tests.

SSA UPGRADE OF S36 C1

Waveguide of S36 C1

New waveguide line was constructed for S36 C1 as explained above. The physical layout for the S36 C1 waveguide is shown in Fig. 3(A). Figure 3(B) shows the actual S36 C1 SSA system with its coax-to-waveguide combiner, circulator, and waveguide. The waveguide assembly alignment went well which indicates a good agreement between the design and the actual assembly.

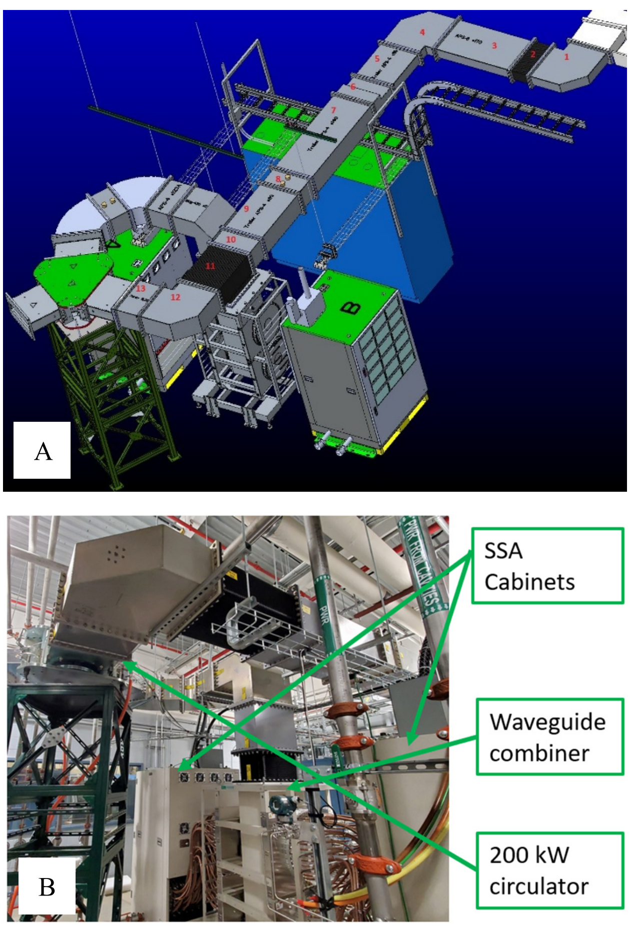

Figure 3: (A) Wwaveguide layout design of S36 C1. (B) Actual SSA system of S36 C1 with the combiner, circulator and waveguide.

60 Hz Noise

60 Hz noise (Fig. 4 (A)) on the RF output spectrum was observed and studied extensively. It turns out that most likely the magnetic field generated by AC supply introduces the extra "fake" noise on the transformer based directional couplers which uses magnetic field coupling method. Adding DC blockers at directional couplers input ports reduces the noise greatly (Fig. 4 (B)). SSA vendor's tests on SSAs with the same frequency span 1kHz shows clean spectrum without 60 Hz noise too.

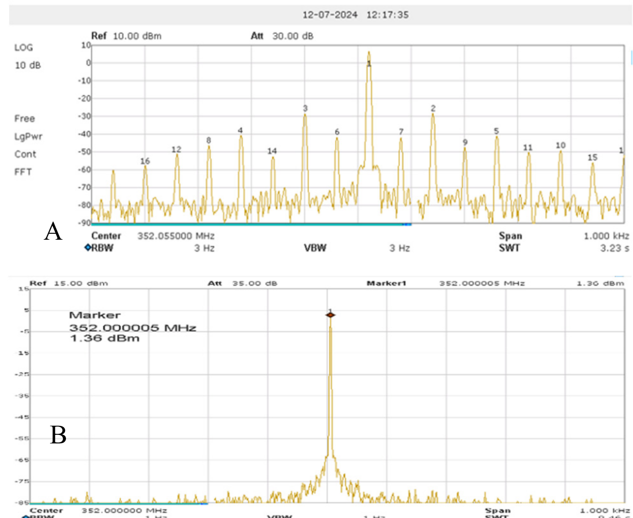

Figure 4: (A) shows the 60 Hz noise observed. (B) shows the spectrum w/o noise after adding the DC blockers.

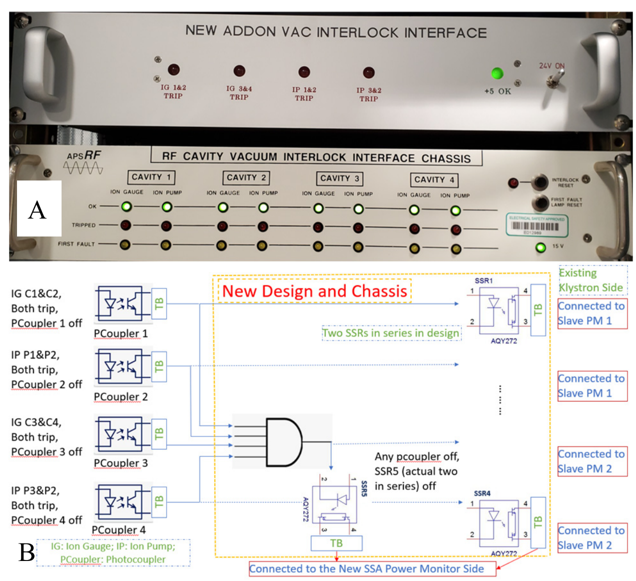

Figure 5: (A) The top chassis is the new vacuum interlock addon unit, and the bottom chassis is the existing vacuum interlock interface chassis. (B) Block diagram of the new vacuum interlock addon unit to bridge the interlock connection to existing and new power monitors.

New Addon Unit to Bridge the Existing Vacuum Interlock to PM

The existing vacuum interlock unit provides interface to the power monitors at the klystron sides. For a sector in SR, there are four ion gauges (IGs) and 3 ion pumps (Ips). Certain combination of IG or IP trips cause an interlock trip to the klystrons or SSAs through the power monitors (PMs). In order to provide the vacuum interlock interface to both the existing PMs at the klystron sides and the new PMs at the SSA sides, a new vacuum addon unit was developed to bridge the interlock function to both the existing PM and the new PM systems. Figure 5(A) shows the new unit and the existing vacuum interlock interface chassis. A block diagram of the new vacuum interlock addon unit is shown in Fig. 5(B). The portion inside the yellow rectangle is for the new addon unit, and the left portion to it is for the existing vacuum interlock interface unit.

N Cable Length Change

For the first two 160 kW SSA systems received, the original cable length of N cables is 2.2 m long as shown in Fig. 6 (left side). Due to the long length, some of the cables were coiled. The coiled cables occupy the additional space needed for easy cable installation and access to the cables ends connection to the RF module side for easy RF module removal. Subsequently, the cables were changed to shorter lengths (about 1.7 m) as shown on the right side in Fig. 6. This change provides more working space needed for cables assembly, removal, and repair. It also reduces power dissipated into the environment. The vendor saves on cables for future SSA systems too. Phases and attenuation factors of some RF output channels need minor adjustment to compensate for the different cable length after the cable change.

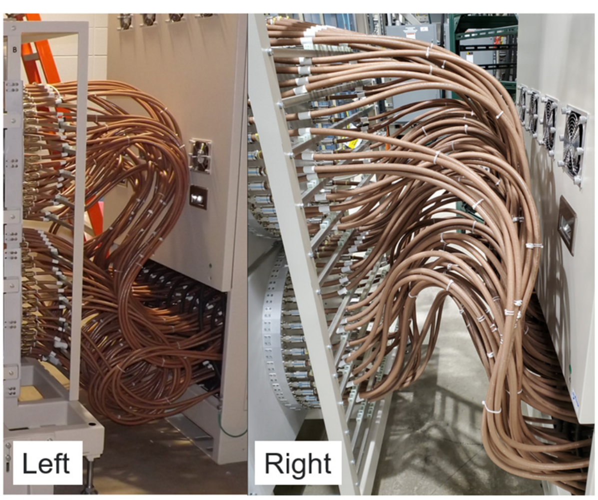

Figure 6: N type RF cable length was reduced from 2.2 m (left) to about 1.7 m (right).

PSS and other Systems

A new SSA personal safety system (PSS) interface was developed and is shown in Fig. 7. For current hybrid mode, the existing main PSS interlock unit is used. A new main PSS interlock unit with more input pins is developed and will be used in future for SSA upgrade of whole S36.

Other systems such as a new local machine protection system (MPS), new PLC systems and a new dLLRF system are also developed, tested and used in the S36 C1 SSA cutover. All of them work fairly well with some tuning and improvements upon the feedback from the operation [2, 3]. A block diagram of dLLRF system with receiver and controller is shown in Fig. 8 [4]. The new dLLRF is based upon Vadatech Micro-TCA equipment. Control software using EPICS was developed and is being used for routine operation since January 2026.

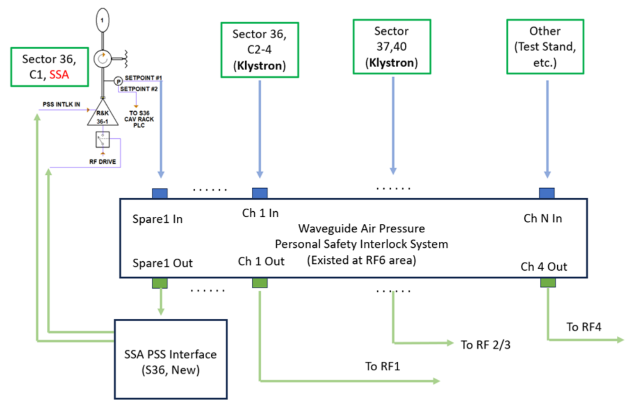

Figure 7: A block diagram of Personal safety system.

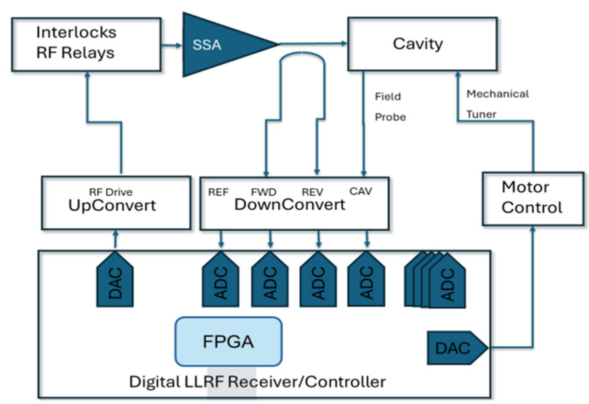

Figure 8: A block diagram of digital LLRF system with receiver and controller.

FUTURE WORK

The SR S36 SSAs conversion is being completed. The SSAs conversion of the two remaining SR RF sectors are planned and underway.

CONCLUSION

SR Sector 36 SSAs and circulators were received and tested onsite. We demonstrated hybrid mode using klystrons and S36 C1 SSA to SR routine operation.

ACKNOWLEDGEMENTS

This work is supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

REFERENCES

[1] D. Horan, "The advanced photon source 350MHz RF systems – 27 years of operation and future plans", presented at 12th CW and High Average Power RF Workshop, Geneva, Switzerland, Sep. 2022, unpublished.

[2] Y. Luo, *et al.*, "The Interlock Systems for High Power RF SSA Systems at Argonne APS and ATLAS", presented at 13th CW and High Average Power RF Workshop, Knoxville, TN, USA, Sep. 2024, unpublished.

[3] T. Berenc, "APS-Upgrade Digital LLRF Systems Summary", presented at LLRF Workshop 2025, Newport News, VA, USA, Oct. 2025, unpublished.

[4] T. Madden, "RF Data Acquisition System for the APS Upgrade", presented at LLRF Workshop 2025, Newport News, VA, USA, Oct. 2025, unpublished.