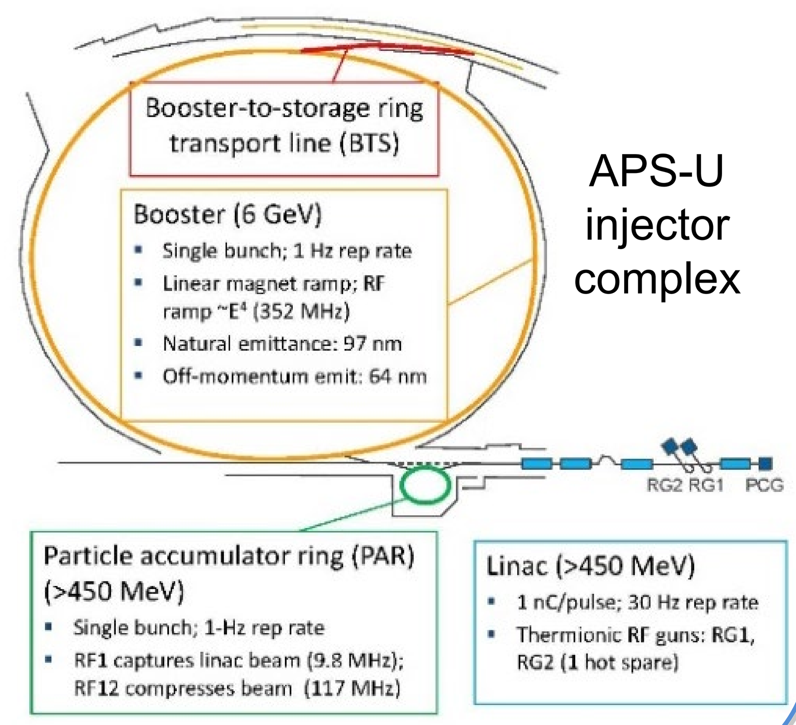
TUPA23: First Beam Results Using the 10-kW Harmonic Rf Solid-State Amplifier for the APS Particle Accumulator Ring*

Katherine C. Harkay, Tim Berenc, Joseph R. Calvey, Jeffrey C. Dooling, Hairong Shang, Terry L. Smith, Yine Sun, Uli Wienands

Advanced Photon Source, Argonne National Laboratory, Lemont, IL, USA

Abstract

The Advanced Photon Source (APS) particle accumulator ring (PAR) was designed to accumulate linac pulses into a single bunch using a fundamental radio frequency (rf) system, and longitudinally compress the beam using a harmonic rf system prior to injection into the booster. For APS Upgrade, the injectors will need to supply full-current bunch replacement with high single-bunch charge for swap-out injection in the new storage ring. Significant bunch lengthening is observed in PAR at high charge, which negatively affects beam capture in the booster. Predictions showed that the bunch length could be compressed to better match the booster acceptance using a combination of higher beam energy and higher harmonic gap voltage. A new 10-kW harmonic rf solid-state amplifier (SSA) was installed in 2021 to raise the gap voltage and improve bunch compression. The SSA has been operating reliably. Initial results show that the charge-dependent bunch lengthening in PAR with higher gap voltage agrees qualitatively with predictions. A tool was written to automate bunch length data acquisition. Future plans to increase the beam energy, which makes the SSA more effective, will also be summarized.



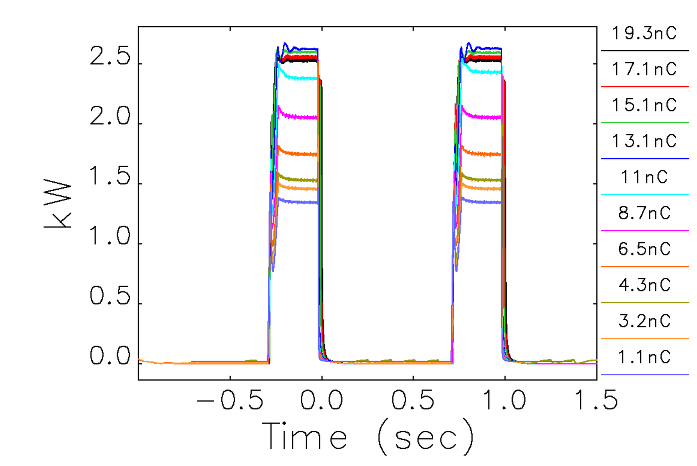
APS-U injector complex

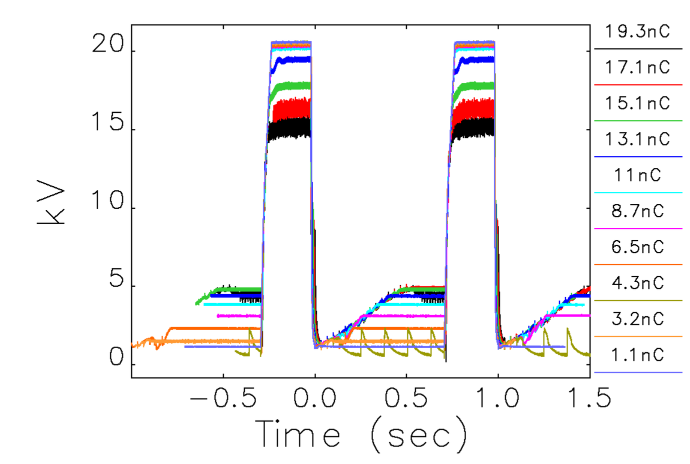
APS-U Requirements

Given harmonic rf cavity parameters frequency 117 MHz, (R/Q)a ~215.7 Ω, and Q (external) 1900, it takes 3.6 kW of power to merely cancel 20-nC beam loading at zero harmonic cavity voltage, which is representative of the PAR injection phase. During the compression phase (final 230 ms of the 1-s cycle), at 30 kV and assuming zero fundamental phase error, the estimated harmonic amplifier power requirement is ~5.5 kW.

Accounting for 10-deg. phase errors, the power requirement is < 8 kW.

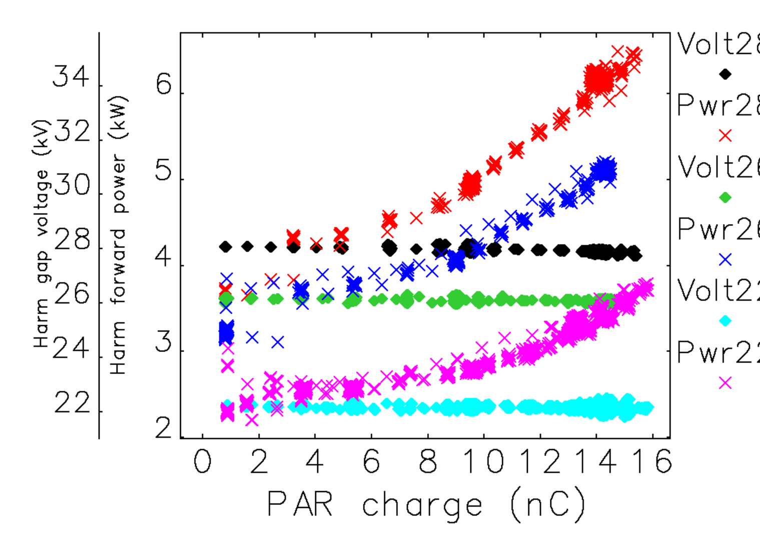
The limitation of the present 3-kW harmonic tube amplifier is illustrated below. The forward power saturates at ~2.6 kW at high charge (left). The result is that the gap voltage, nominally 21 kV, droops significantly above ~10 nC (right) and bunch compression is compromised.





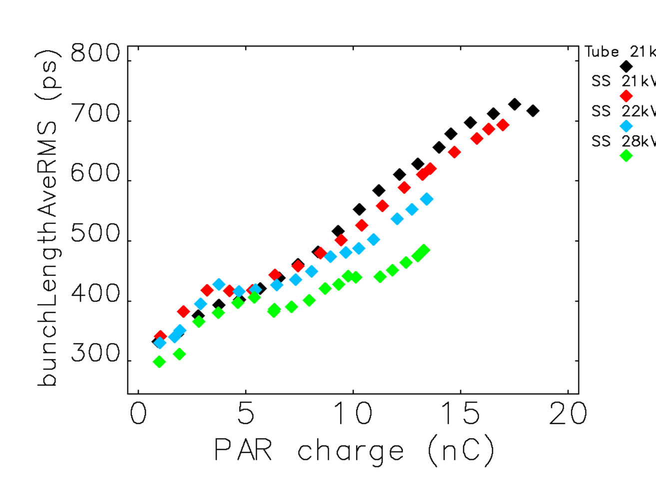
Beam Results

As expected, the SSA performs well at high charge. There is virtually no droop in the gap voltage at higher charge. The forward power is 6.3 kW for 15 nC bunch charge and 28 kV gap voltage. This is consistent with calculations to determine the APS-U requirements.

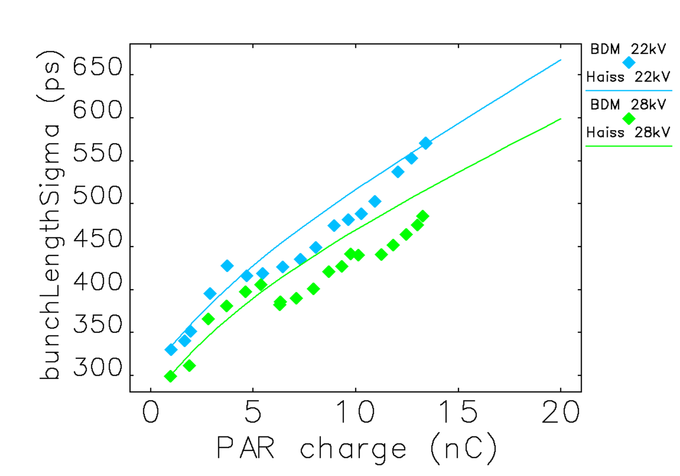


SSA amplifier forward power and gap voltage (22 kV, 26 kV, and 28 kV) as a function of bunch charge (8-kW limiter).

The highest vacuum pressure was ~1e-8 Torr, which is acceptable. The voltage transient at beam extraction can be controlled with harmonic rf tuner feedforward and is thus not a concern at the higher gap voltage. At 21 kV gap voltage, the SSA outperforms the tube amplifier because with the latter, the voltage droops above 10 nC to 19.5 kV. At 13.2 nC, the rms bunch length decreases from 640 ps (tube, 21 kV) to 488 ps (SSA, 28 kV). This is a good result, given that the beam is microwave unstable above ~10 nC. Linear predictions are shown below on the right. Simulations using the numerical impedance are in progress (THYD4).

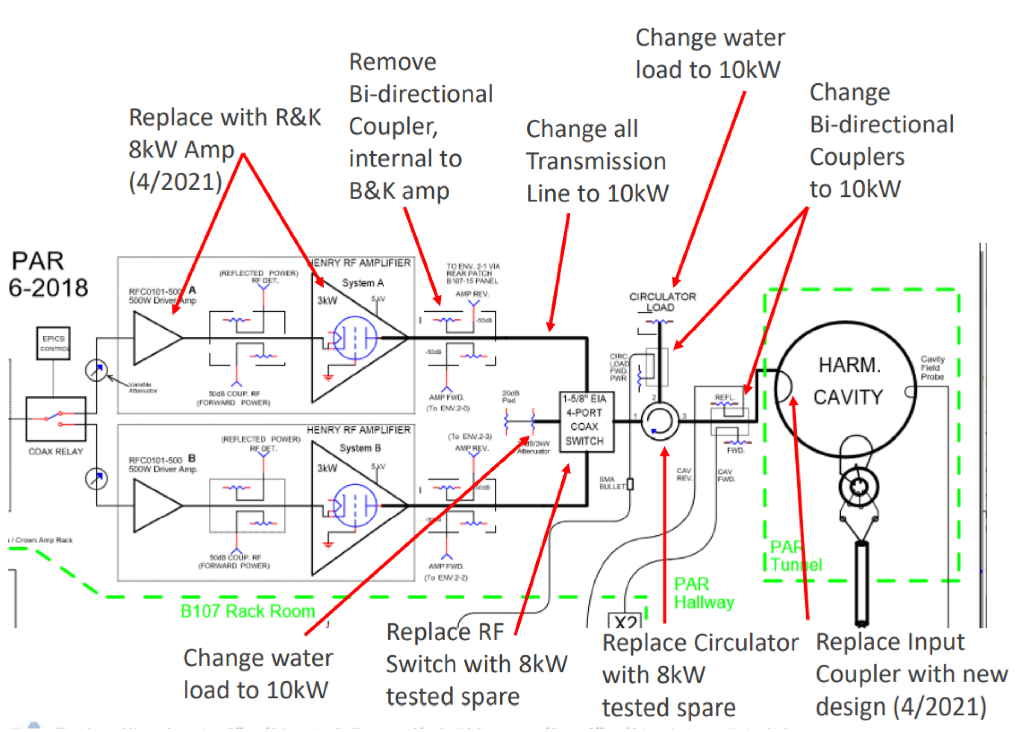


Measured PAR bunch length vs gap voltage for tube and SS rf amplifiers (425 MeV).

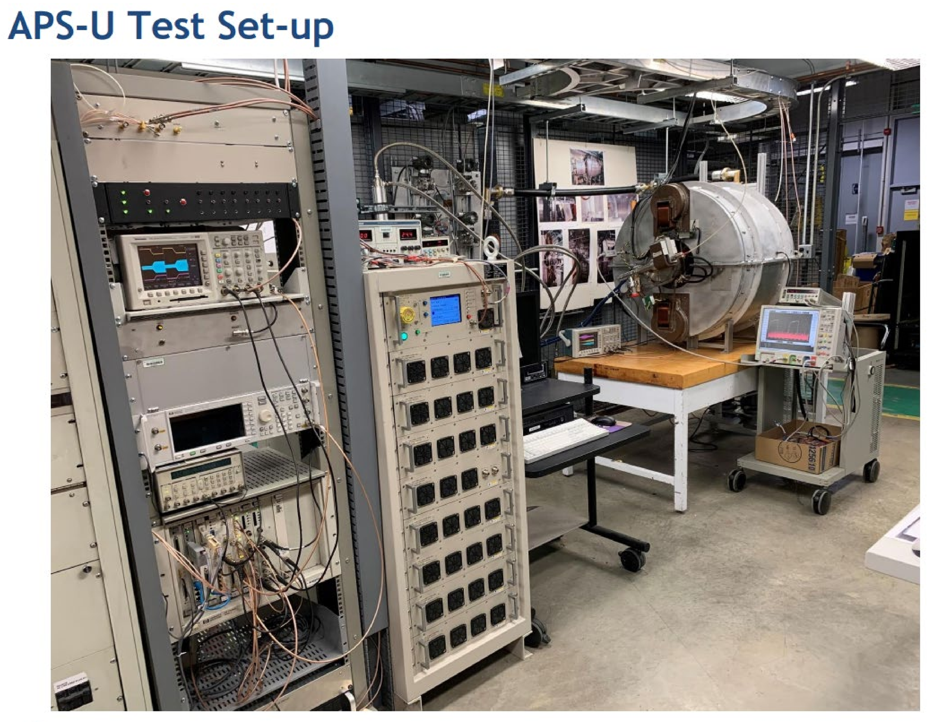


Comparison of measurements with predicted bunch lengths using Haissinski distributions (425 MeV, Z/n = 25 Ω, R = 1300 Ω).

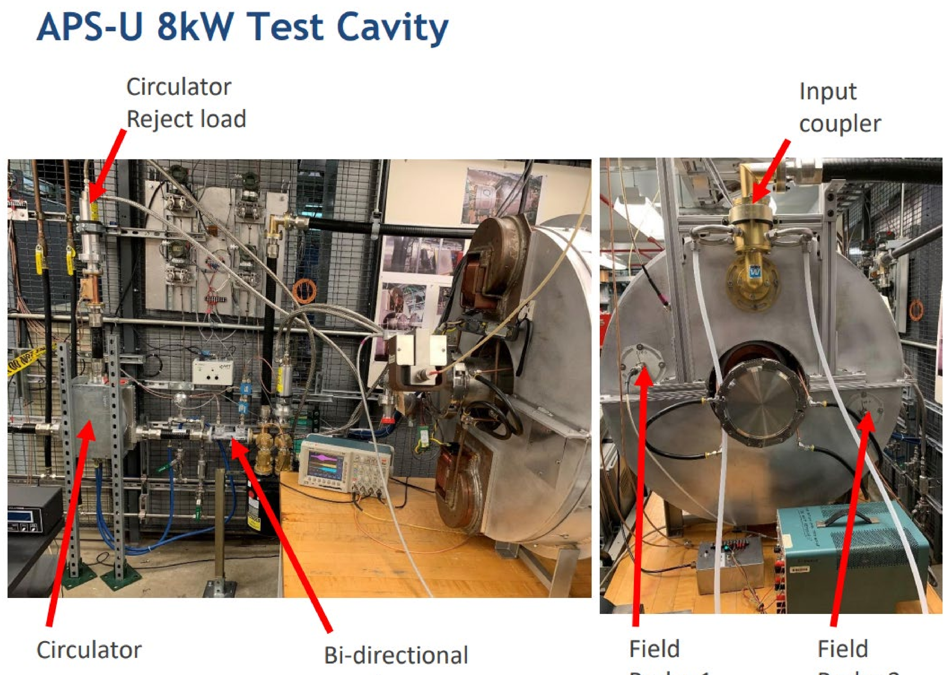
Harmonic Solid-State Amplifier (SSA) Testing and Installation



APS-U Test Set-up



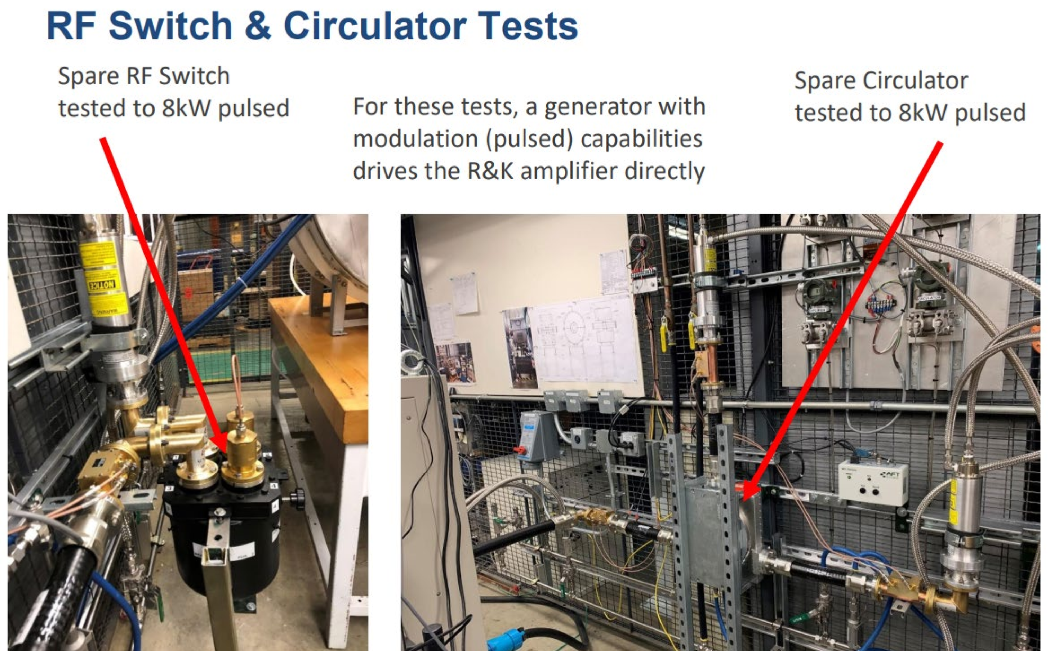
APS-U 8kW Test Cavity



← 8-kW input coupler

Rf power limiter → (3 kW, 5 kW, 8 kW)

RF Switch & Circulator Tests



As installed for operations: new 10-kW SSA (left) and backup 3-kW tube amplifier (right)

Conclusions and Future Work

A 10-kW harmonic rf solid-state amplifier (SSA) was installed in PAR to increase bunch length compression at higher bunch charge. The SSA performed as expected and the measured bunch lengths at higher gap voltage (28 kV) largely agree with predictions, even above the microwave instability. More work remains to tune the PAR charge up to 20 nC with the SSA. Measurements of booster injection efficiency with higher PAR harmonic gap voltage are also planned. Shorter bunch lengths at higher bunch charge should better accommodate the booster longitudinal acceptance. Long term, we have plans to upgrade the linac beam energy to 500 MeV, which will enable future PAR operation at 475 MeV for APS-U. Higher beam energy raises the microwave instability threshold, which is expected to further improve the effectiveness of the SSA to compress the bunch length. Linac upgrade plans are expected to be completed in the next two years.

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