PLANNED ACCELERATOR IMPROVEMENTS OUTSIDE THE APS-U

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Argonne National Laboratory

OVERVIEW

- The APS-U is on track to make APS the brightest storage ring light source in the world. The project will provide a new storage ring and several improvements and changes to the injectors to adapt to the new ring.
- However, there are several needed upgrades in the accelerator complex NOT included in the APS-U project. These include:
  - Storage ring RF system: the APS-U will reuse 12 of the 16 existing RF cavities and the entire RF power infrastructure. However, the RF power infrastructure based on CW High Voltage klystrons is approaching end-of-life. We have chosen to replace this system with a solid-state amplifier (SSA)-based system over the next decade. Total cost of ~$30-40M
  - Subsystems in the APS linac have a host of obsolescence issues requires significant refurbishing to provide reliable operation for APS over the next few decades. These include RF systems, timing, magnet power supplies, etc. Total cost of $8-10M.

APS ACCELERATORS

APS ACCELERATOR COMPLEX

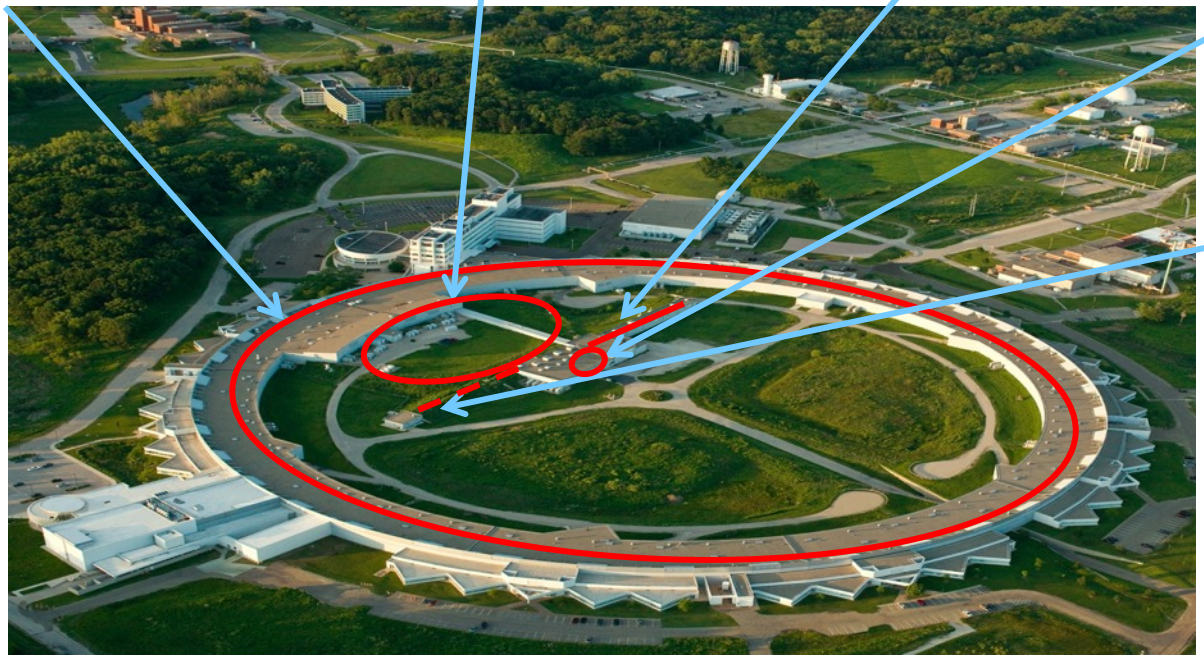
7 GeV, 100 mA, 46 ID,
21 bend magnet BL,
3 fill patterns

Linac: S-band, 400-500 MeV, 30 Hz

Booster: 0.35-7 GeV, 2 Hz

PAR: 350-475 MeV, 2 Hz, 1-4 nC

Linac Extension Area (LEA)

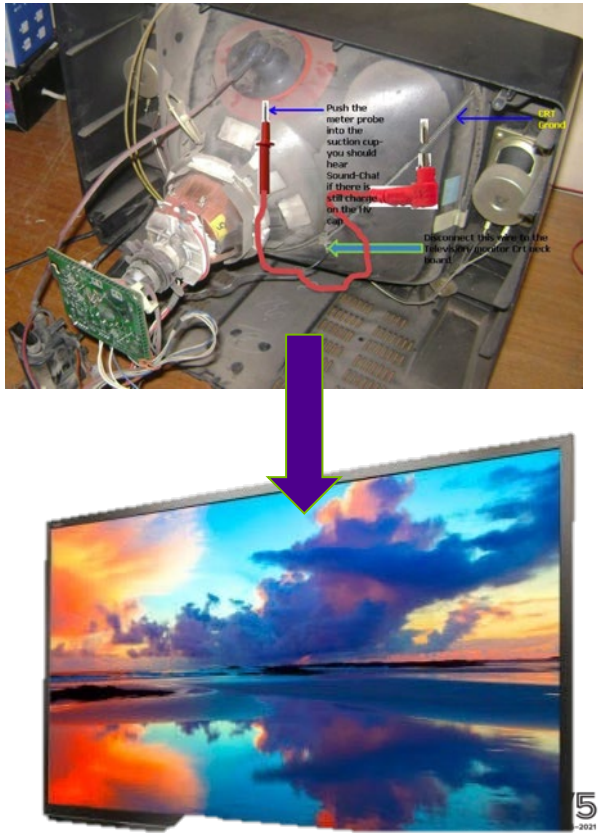


The APS Upgrade (APS-U) will replace the main storage ring but keep the radio-frequency (rf) system; injector systems will be reused but require increased performance

FROM TUBES TO TRANSISTORS: UPGRADING THE STORAGE RING RF SYSTEM TO SOLID-STATE

A critical need to maintain operation beyond the APS Upgrade

- The original APS rf system is based on MW-class klystrons that no longer are being produced; all modern telecom systems are based on solid-state amplifiers
- The APS high voltage systems are also approaching end-of-life and will need replacement if we stay with klystrons
- We are embarking on a plan to convert the APS storage ring rf system to solid-state amplifiers with goal of replacing the existing system before the last klystron fails!
- We have ordered the first 200-kW SSA with delivery expected in April 2022



THE SOLID-STATE RF PLAN IS BASED ON SEVERAL YEARS OF ENGINEERING R&D

We have settled an array of 2-kW amplifiers combined using a “barrel” cavity

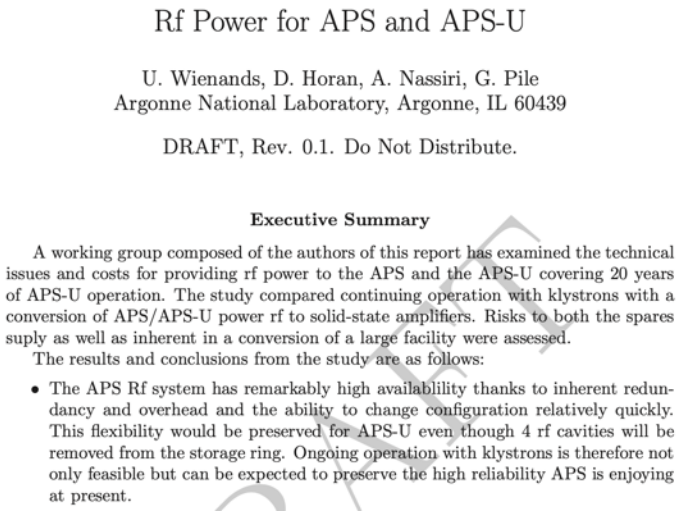
- A long campaign has validated the overall rf system concept
  - Procurement of a commercial 32-kW unit of 16 2-kW amplifiers that has been exhaustively tested
  - Validation of the “ combiner” cavity concept with measured power levels and losses agreeing well with predictions; included a “backfeed” test using 200 kW from a klystron to test at high power
  - Overall system layout concept consistent with APS space and infrastructure (i.e., power and water); led by Ali Nassiri and Doug Horan

CAVITY COMBINER DRIVEN BY 16 2-kW SSA MODULES

2017 REPORT ON ALTERNATE APPROACHES

Similar costs to refurbish with klystrons or solid-state due to end-of-life for APS High Voltage systems.

- Report details technical challenges of maintaining klystron-based and solid-state RF system.
- Slides on this report presented at 2017 Triennial Review
- Two main features:
  - No vendors offer MW-class tubes and there is no market for these tubes beyond high energy electron rings.
  - Major refurbishment of 95 MV system will cost >$25M.
  - Retuning of 3 donor EEV tubes (350 MHz) from LANL has been very successful and extended the lifetime of the existing system for another 6-7 years.



Rf Power for APS and APS-U

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Executive Summary

A working group composed of the authors of this report has examined the technical issues and costs for providing rf power to the APS and the APS-U covering 20 years of APS-U operation. The study compared continuing operation with klystrons with a conversion of APS/APS-U power rf to solid-state amplifiers. Risks to both the spares suply as well as inherent in a conversion of a large facility were assessed.

The results and conclusions from the study are as follows:

- The APS Rf system has remarkably high availablility thanks to inherent redundancy and overhead and the ability to change configuration relatively quickly. This flexibility would be preserved for APS-U even though 4 rf cavities will be removed from the storage ring. Ongoing operation with klystrons is therefore not only feasible but can be expected to preserve the high reliability APS is enjoying at present.

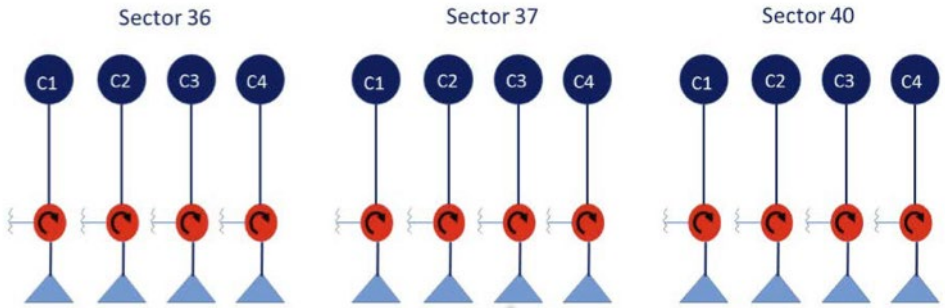
2017 Report on APS RF options

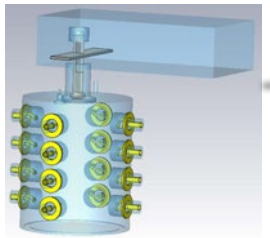
THE NEW RF SYSTEM IS DESIGNED TO HAVE MULTIPLE REDUNDANCIES

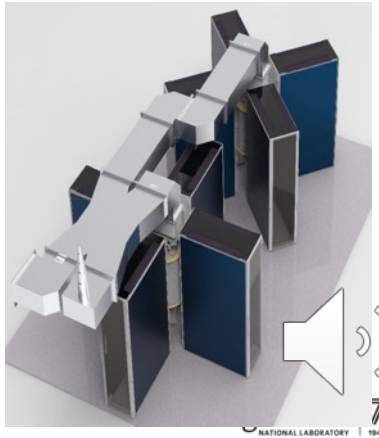
Fewer single points of failure will give higher reliability

- Each cavity requires one solid-state amplifiers (SSA) system
- Storage ring will need 3 sets of 4 cavities each at S36, S37, and S40
- Each of the 12 cavities will require 160 kW* of rf power
- 4 SSA systems are needed to replace 1 klystron amplifier
- Total of ~2-MW power needed

Cost of solid-state amplifiers is $10/W
Total cost of system expected to be $25-30M. Discussions on how to pay for this underway with BES

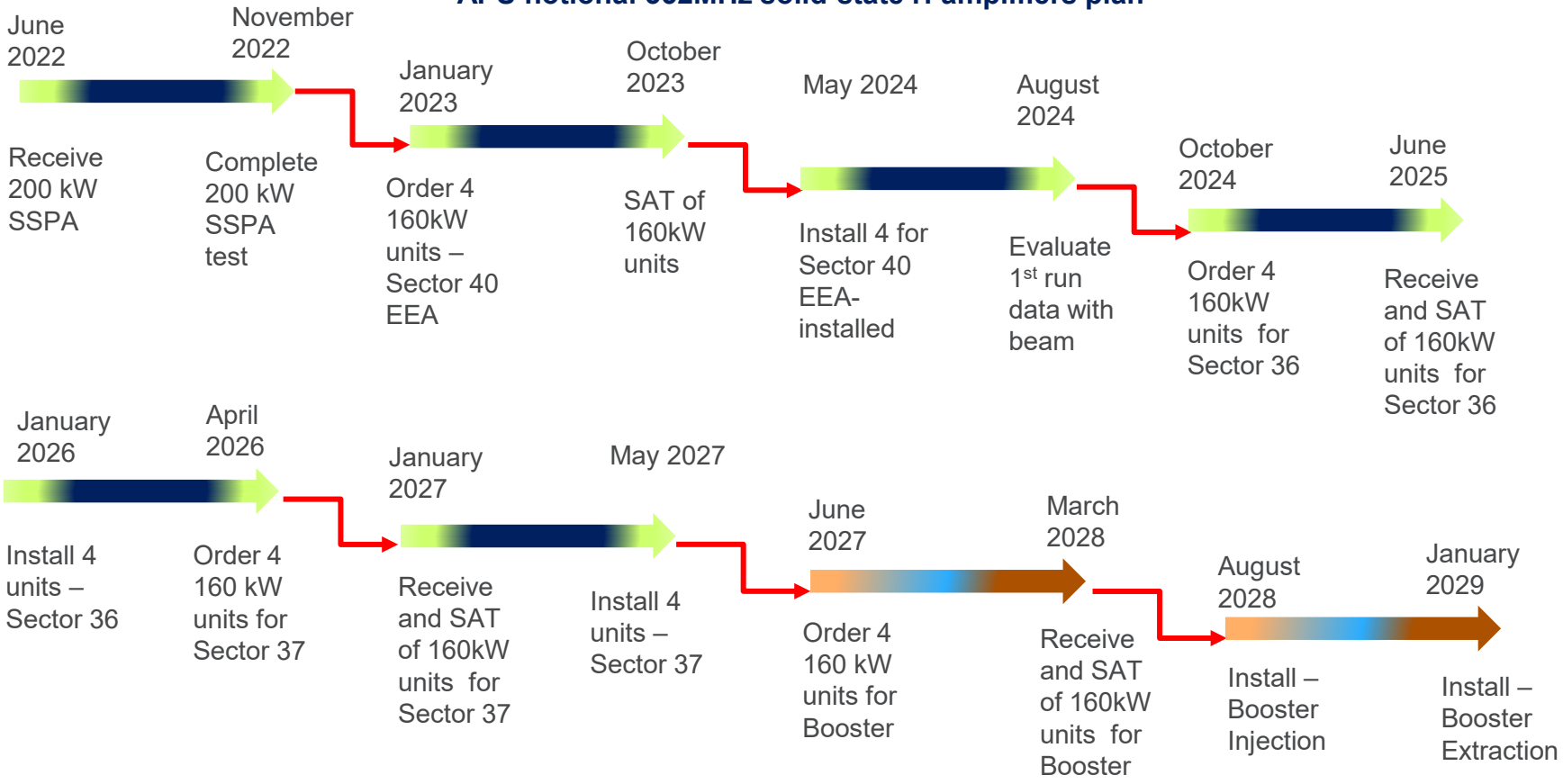






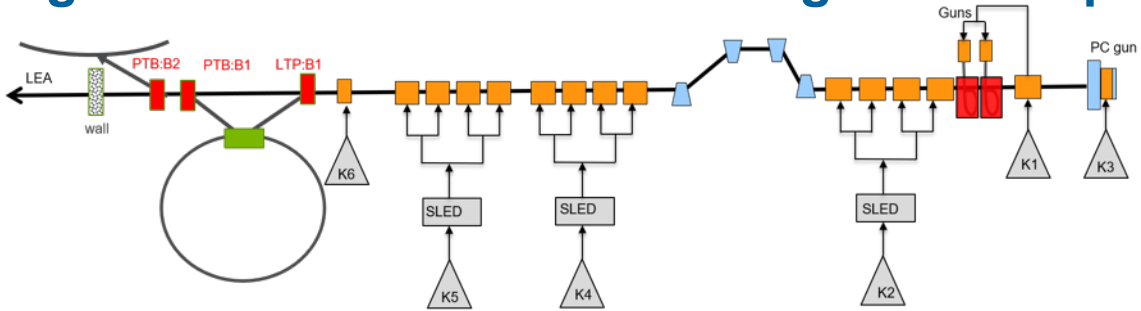
Modular concept of each rf station

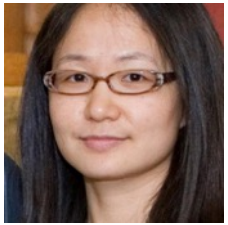
APS notional 352MHz solid-state rf amplifiers plan



REFURBISHING THE APS LINAC FOR THE NEXT 30 YEARS OF APS OPERATIONS

The aging APS linac needs refurbishing to meet operations needs





- APS-U will have frequent swapout injections of ***whole*** bunches requiring increased performance and reliability of injector system, including the linac
- The linac cannot reliably provide the anticipated beam energy needed for APS-U 48-bunch operation (475 MeV); needs an updated rf system
- Many other antiquated subsystems that are at end-of-life
- A full plan to upgrade and update obsolescent subsystems has been put together by Yine Sun

FIRST PHASE OF REFURB IS IN PROGRESS

First new HV modulator, klystron, and digital rf controller received
Second system expected later in 2021

- Testing of first received system underway in new Utility Shed constructed in APS infield
- Installation in APS linac expected later in 2021; if successful, we will move forward with more installations and procurements
- Designs and specs for new rf guns, power supplies, timing system, diagnostics, etc., are complete and awaiting funding

DETAILS OF THE LINAC REFURB PLAN

All projects initiated under guidance of APS Portfolio Management Office

1st 50MW RF klystron/modulator	Digital LLRF System	Bldg 413 LINAC High Power RF Test Stand	More 50MW RF Stations
Thermionic RF Guns	Replace Linac Water Skids	Fast Interleaving Alpha magnet	Injector Network Upgrade
Linac Corrector Power Supplies	LINAC Timing System	Linac RF Windows, Switches, SLED & Accelerating Structures	Linac BPM Electronics Replacement
Linac Current Monitors and Electronics Upgrade	Digital Cameras for Linac Flags		

Funded Project | Partially approved project | demands

Linac For APS-U

The demand from APS-U for the linac concerns bunch charge and beam energy.

Parameter	APS-U Demand	Status/Issues	Solutions/Schedule
Bunch Charge	1nC/bunch with rms variation < 5%:	Although the demand had been met before, the current Gen-III thermionic rf gun performance is deteriorating -- operating < 1nC/pulse.	Funded project: Procurement of new guns: New gun design is yet to be finalized. Procurement lead time: ~ 14 months ARO
Linac Energy	475 MeV by darktime for injector studies	425 MeV is the nominal energy; 450 MeV is available for injector studies but not on a day-to-day operation basis; 475 MeV requires 140 MW SLED power to L2, L4 and L5 sectors; Current SLED power max levels: L2→133MW L4→135MW L5→118MW	Funded project: Linac 50 MW RF Station #1 will be installed at K2 – this will help to run L2 sector with 140 MW SLED power with some headroom; Current project completion 9/2022. Funded project: Linac 50 MW RF Station #2 Installation schedule not yet discussed. New 50 MW RF stations will improve the operation reliability at higher injector energy in the APS-U era. RF group effort required to fix K5 VSWR problems at higher power level at K5 and increase SLED power to 140MW; Funded project: Bldg 413 LINAC High Power RF Test Stand for testing/conditioning of linac S-band rf components in the future.

COMPLETION OF THE REFURB REQUIRES ADDITIONAL INVESTMENT

Total of $8M needed to complete

Item	Cost	Quantity	Total
HV Modulators	$611k	5	$3.55M
Canon Klystrons	$224k	5	$1.12M
Digital RF controls	$140k	5	$0.7M
Spare klystron tube	$155	3	$0.465M
Spare Mod parts	$100k	1	$0.1M
Shipping	$30k	5	$0.15M
Therm RF guns	$250k	3	$0.75M
Linac Magnet PS	~$5k	~100	$0.5M
Linac Timing	$130k	1	$0.13M
BPM Upgrade	$20k	10	$0.2M
Diagnostics	$25k	10	$0.25M
Total			$8.0M

Linac RF system. Critical for reaching APS-U injection needs for 48 bunch mode. $6.085M

New e-guns needed for APS and APS-U ops.

Auxiliary systems are obsolescent. $1.1M.

- All costs based on recent quotes. Not fully loaded.

HOW DO WE PAY FOR ALL OF THIS?

Proposed total of ~$50M in investment beyond APS-U needed for maintaining a healthy accelerator infrastructure

- To date, all procurements have been supported by APS Operations including the Prototype 200 kW SSA ($2M) and two linac RF stations (~$2.2M).
- Guidance from DOE-BES opens the possibility for an MIE project to be submitted no earlier than FY25. We will plan to include the remainder of the Storage Ring RF and Linac Refurb work on this MIE. **There is no plan to use APS-U funding (contingency or otherwise) for this investment.**
- However, we can't wait until FY25 to begin the SSA RF upgrade. We have a notional plan to pay for the first 4 SSA systems (~$8M) on APS Ops between FY23-25. We would submit an MIE project to DOE-BES for funding of the remainder of the system (12 SSAs) and for the remainder of the linac refurb.

SUMMARY

- A major initiative is underway to replace the klystron-based storage ring rf system with solid-state amplifiers with a cost of $30-40M in procurements. A notional schedule has been made to complete this plan in late 2020s. BES is aware of this plan and the operations budget impact. Funding solutions are under discussion.
- Another large initiative to refurbish the APS linac is underway. Primary goal is to replace the linac RF sources and be able to reach 475 MeV reliably. Two modulators/klystrons have been procured with installation of first unit in late 2021. Includes upgrade to digital rf controls addresses obsolescence of many other systems. Total cost of $8-10M.