LA-UR-16-28405

Title: Challenges and Accomplishments in the 201 MHz RF System Upgrade at LANSCE

Author(s): Bradley, Joseph Thomas III
Lyles, John T. Mccaw

Intended for: Workshop on Upgrading Existing High Power Proton Linacs, 2016-11-08/2016-11-09 (Lund, Sweden)

Issued: 2016-11-01

Challenges and Accomplishments in the 201 MHz RF System Upgrade at LANSCE

Joe Bradley III and John T. M. Lyles

Accelerator Operations and Technology Group

Workshop on Upgrading Existing High Power Proton Linacs

November 8-9, 2016

Outline

- Drift Tube Linac RF Requirements
- Motivation for Replacing RF Sources
- New RF Power Amplifier Design
- Development of Prototype Matching Cavity
- Test Facility
- Some Engineering Challenges
- Commercial Production of Amplifier Systems
- Installation of RF power systems at Linac
- Operating Results

DTL Requires Significant RF Power

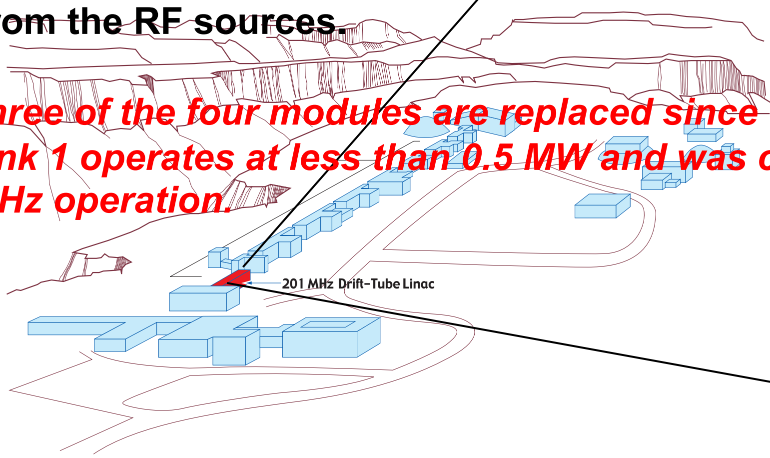
The Drift Tube Linac (DTL) consists of four Alvarez cavities which make up the first 60 m of the 760 m copper LANSCE linac.

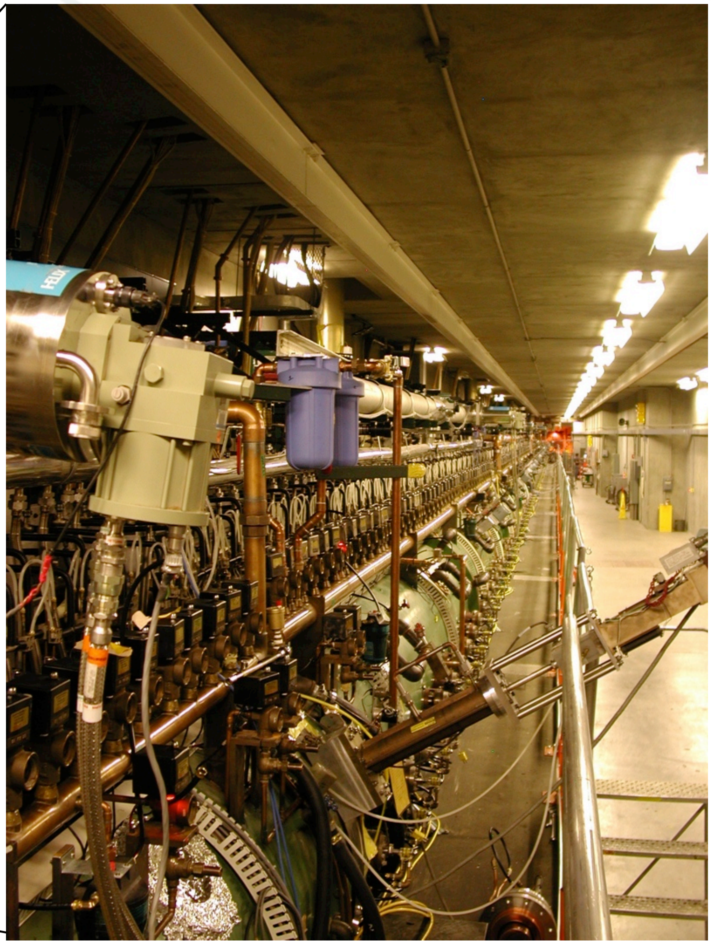
Designed/installed in 1967-1968; operating since 1970

H+ and H- Protons are accelerated from 0.75 to 100 MeV in the four cavities, then transferred to coupled-cavity linac for final acceleration to 800 MeV.

The four DTL cavities receive pulses of 201.25 MHz RF power (~ 3 MW) via 35.5 cm diameter coaxial transmission lines from the RF sources.

Only three of the four modules are replaced since DTL tank 1 operates at less than 0.5 MW and was capable of 120 Hz operation.





Motivation for Replacing RF Sources

- The original 7835 triode vacuum tube manufacturer had various quality issues that shortened tube lifetime when operating at LANSCE. We had to purchase additional tubes each year for contingency.
- Manufacturer was unable to test the 7835 tubes, leaving us responsible for performing burn-in, RF/vacuum conditioning (weeks), and creating awkward warranty situation.
- The 7835 tube was designed over 55 years ago and the company subsequently changed ownership, losing skilled builders and product knowledge.
- LANL provided considerable technical resources to assist the manufacturer over the years 1988-2005. BNL and Fermilab did the same.
- In 2006 LANSCE reduced operation to 60 Hz beam repetition rate due to repeated tube failures and rapidly diminishing supply.
- WNR target users lost 60% of available beam with lower repetition rate. The decrease in beam current significantly impacted capability for semiconductor neutron damage testing for electronics industry at the WNR/ICE (Irradiation of Chips Electronics) House facility.

Options Studied for Devices to Meet Requirements

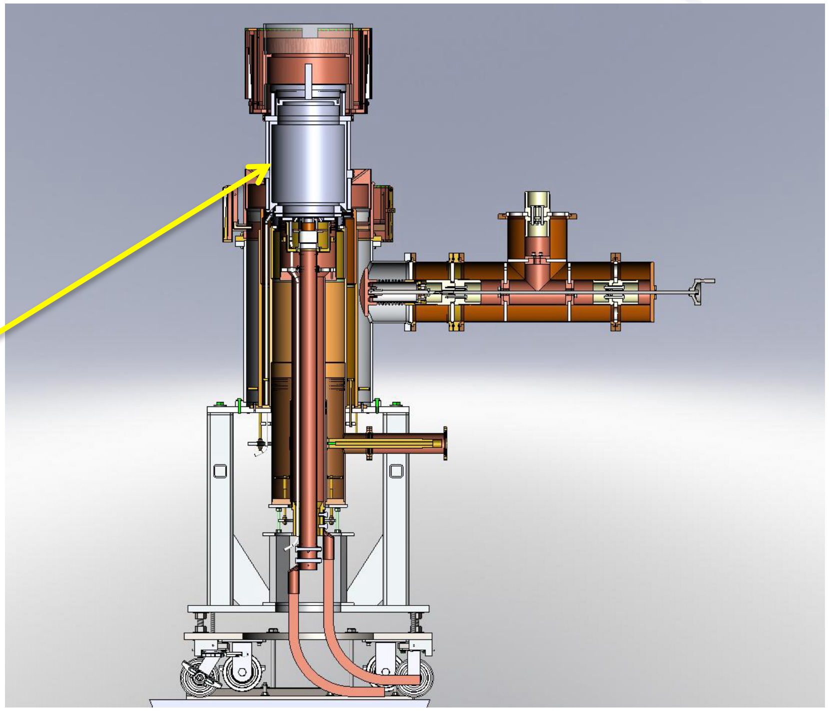
Device	Performance	Reliability	Commercial Supplier	Infrastructure Comments
Klystron	Highest power gain Simple circuit Medium efficiency	Typically long life Least complex	Development required	Replace HV systems, capacitor rooms and transformers. Physically longer device
Diacrode	Lowest power gain Requires 2 stages Highest efficiency	Medium life, depending on power derating	Tube available, but development required for amplifier cavity	Uses same HV and cooling. Fit floor space of old system
Solid State (Transistors)	Med power gain Requires >3000 devices per station Lowest Efficiency	Unknown, but complexity leads to many failure points, requires extensive protection circuits	Development required (CERN SPS) Prod. lifetime short (5-10 yr)	Replace power supplies, cooling. Enlarged building

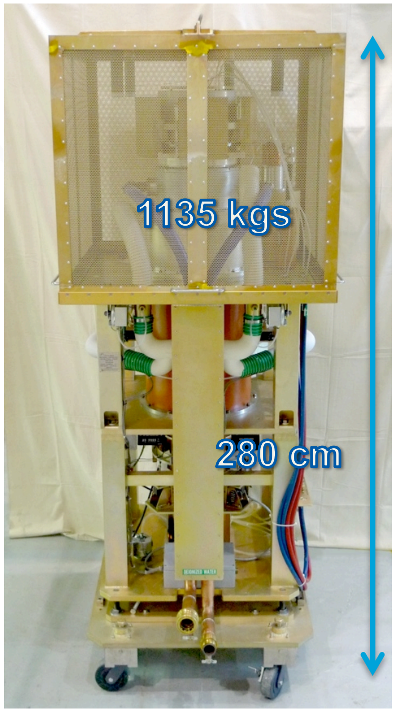
Ref. "System Considerations for 201.25 MHz RF Systems for LANSCE", J. Lyles, et. al., North American Particle Accelerator Conference, 2013, Pasadena, CA

RF Source Replacement Timeline

- 1996 - RF team proposed a new RF system based on a novel tetrode vacuum tube known as Diacrode®. It was developed for ICRH for fusion (ITER), and RF power capability was demonstrated at the factory in France.
- 2006 – LANSCE operation reduced down to 60 Hz.
- 2009 - Multidisciplinary design team formed for engineering this solution and began work on prototype system.
- 2012 - Diacrode® engineers transitioned tube from prototype to production, while testing for our requirements. They provided much guidance on amplifier construction. Tubes are 100% power tested at factory and are viable RF source for accelerator community and ITER.
- 2013 - First production amplifiers received and tested at LANL.
- 2014 - Installation of the first finished amplifier system in DTL Module 2 (with the highest power requirement). Second and third installations accomplished in 2015 and 2016 winter outages.
- Now - LANSCE has returned to reliable 120 Hz operation at full beam power, allowing for WNR successes and ensuring future viability of LANSCE.

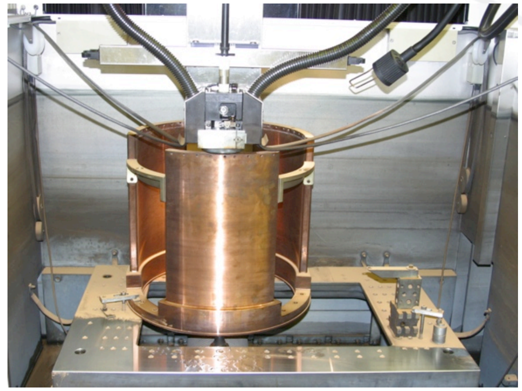
New RF Power Amplifier was Designed, Prototyped, Tested and Commercialized

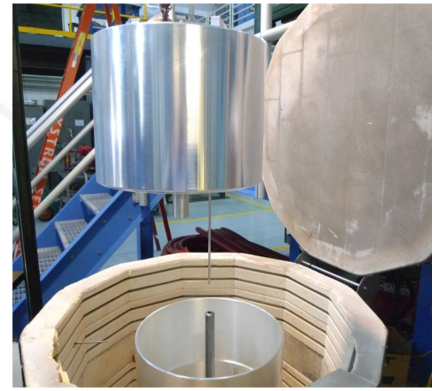


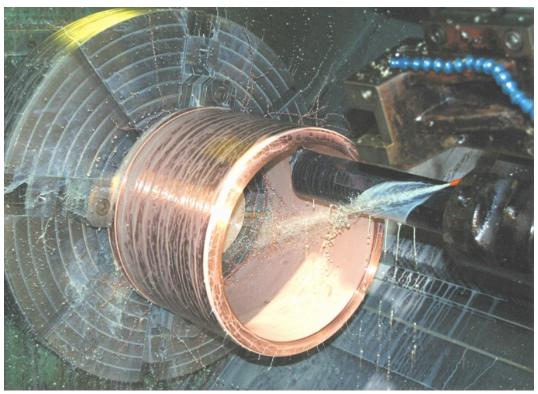


- **High power tube amplifiers require specific cavity amplifier for application.**
- **In-house design used 2D and 3D electromagnetic codes and Solidworks.**

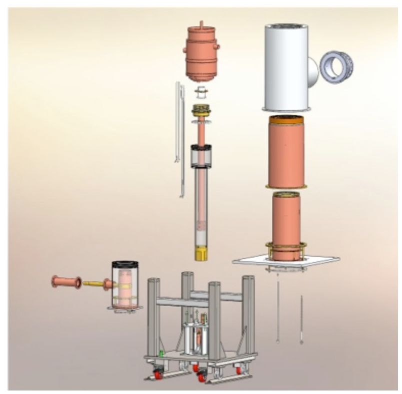
Prototype Amplifier System Built at LANL







Machining of copper forgings
LANL prototype machine shop



Nested coaxial cylinders
comprise the resonant cavity

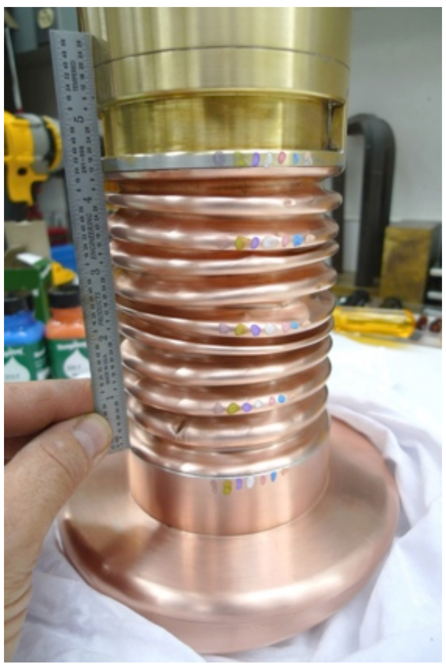
Pressing of high voltage
blocking capacitors

Technology Transferred to Industry
for Commercial Build of 7 Additional Amplifiers

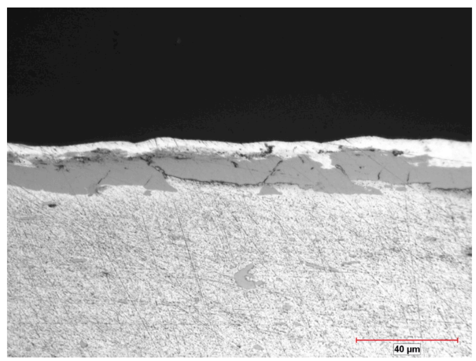
Test Facility Constructed at LANL to Pre-test All Amplifier Components

Engineering Challenges Were Overcome

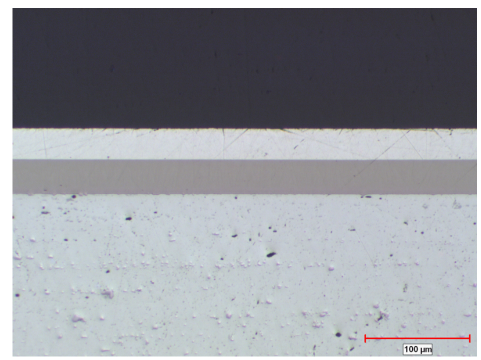
Mistakes with High Power RF are Unforgiving



Initial Prototype Copper Bellows



Vendor A

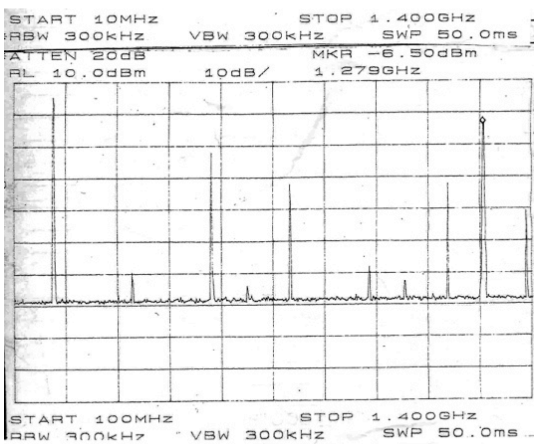


Vendor B

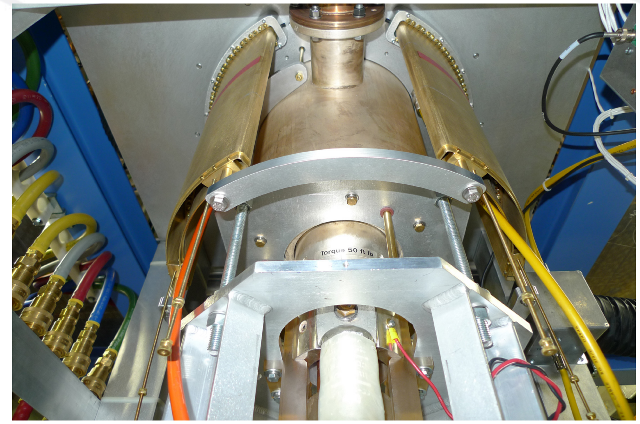
Microscopy of Test Sections
Electroplated Ag/Ni/Al cavity body
(Later switched to Ag on Cu)

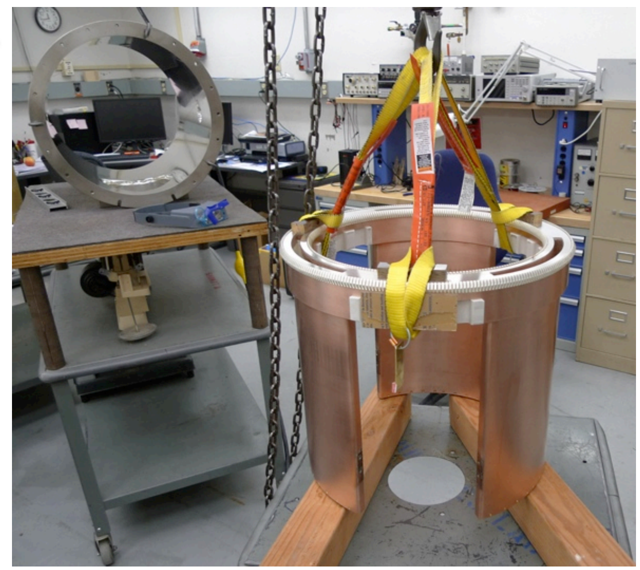
More Engineering Challenges

Frequency and Time Domain Measurements of Transient High Order Mode at 1.28 GHz



Modeling and Experiments Led to HOM Suppressor





Production of Amplifiers in Dallas

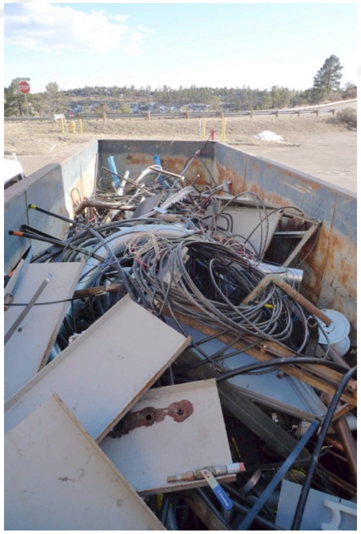
Receipt of s/n 01 at LANL in 2013

Last Batch in 2015

S/N 06 and 07

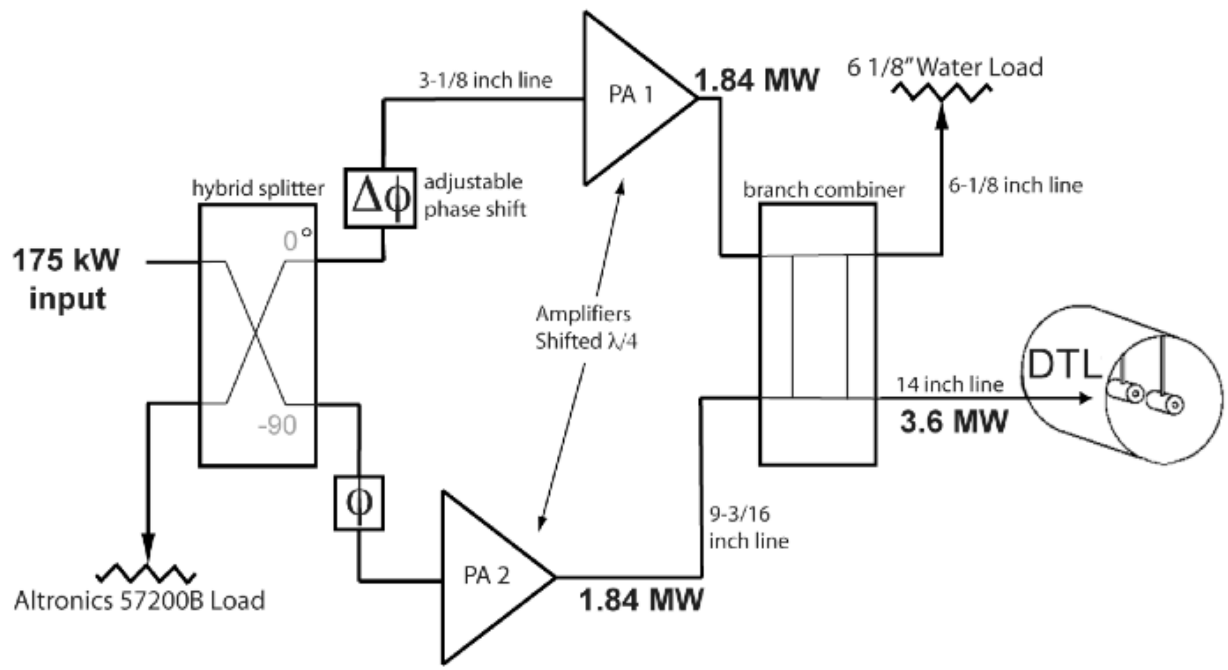
- **System had potential for other worldwide accelerator uses.**

Installation of One RF System per Year



Dual Amplifier RF System

- **Amplifiers were tested to 3.5 MW peak at 12% duty factor into water loads at the test facility, but were installed in pairs when connected to the cavity to limit maximum peak power per amplifier to 1.85 MW.**



Dual Amplifier RF System

The outputs from the two amplifier systems are combined in a 30.5 cm coaxial quarter wave branch hybrid, which then transitions to the existing 35.5 cm coaxial line to the DTL.

Installation Experience / Lessons Learned

- Amplifiers were tested to 2.7 MW peak at 12% duty factor into water loads at the test facility, but were installed in pairs when connected to the DTL cavities to limit maximum peak power per amplifier to 1.85 MW.
- Documentation of original systems was outdated and required much field verification. Equipment age and minimalist interface design made integrating the original HV supplies and capacitor/crowbar systems with the new amplifier systems a technical and engineering challenge.
- The three high power RF stations at LANSCE were replaced, one at a time, during three consecutive annual maintenance periods beginning in 2014. The impact of the Diacrode upgrade on the beam user schedule was about 1 additional month per maintenance period.
- The removal and replacement of the original RF system for DTL cavity 2 was completed in 5 months. The second unit was for cavity 4 and was completed in 4 months and the replacement of cavity 3 was completed in 3.5 months due to experience and planning improvements.
- At the conclusion of each installation, commissioning was done before and coincident with beam tuning, followed by regular beam production for the scheduled annual run cycle.

Results Achieved

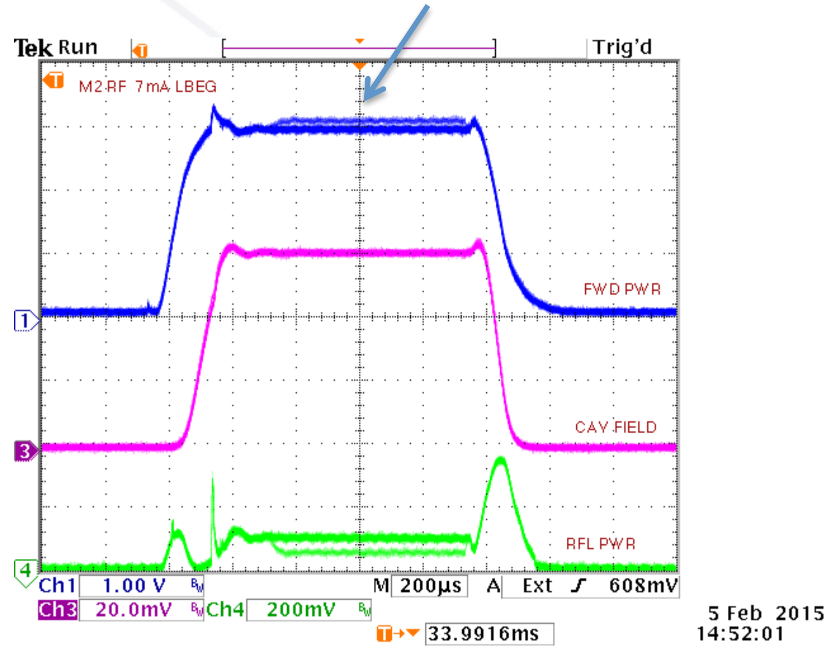
- Approximately 12,000 hours operation with first unit since 2014, 6900 hours with second unit since 2015, 1500 hours with the third unit.

- Operating at desired set points with a few problems. LLRF/HPRF/Controls system communication and coordination are always challenging.

- Restored 120 Hz beam operation.

- No tube or amplifier issues to reduce beam availability.

Flat-Topped Pulse with Beam Loading



- Scientific output increased. Increased capability for semiconductor damage testing for electronics industry at WNR/Ice House and improved reliability to the Neutron Scattering Center.

- Insured a flexible and reliable proton source for the medical Isotope Production Facility at LANSCE.

2014 DISTINGUISHED PERFORMANCE AWARD

Team for Restoring 120 Hertz Operation to the LANSCE Accelerator

UNCLASSIFIED