352MHz RF Test Stand at the Advanced Photon Source

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RF Group

Fourth CW and High Average Power RF Workshop

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Argonne National Laboratory

Recent Test Stand Activities

It has been a busy two years:

- Coupler and tuner conditioning to produce accelerator spares
- Storage Ring rf cavity HOM damper testing and conditioning
- 100kW and 150kW tests on a 350MHz fast ferrite cavity tuner designed by Advanced Ferrite Technology (AFT)
- Pulsed rf power testing of Fermilab components
- Construction of a dedicated klystron rf power source for the test stand
- Tests on a 100kV/20A fast dc switch and “solid-state” mod anode regulator prototype
- Development of an automated conditioning program

Coupler and Tuner Conditioning to Produce Accelerator Spares

Partial Coupler Conditioning History

ANL-03 → conditioned to 100kW; in spares

ANL-12RB → conditioned to 100kW; installed in S37/C4

ANL-13RB → conditioned to 90kW; in spares

ANL-13ARB → failed during conditioning at 22kW due to hot ceramic

ANL-14RB → conditioned to 100kW; in spares

ANL-15RB → conditioned to 100kW; in spares

ANL-17RB/CS → Failed during conditioning due to hot ceramic

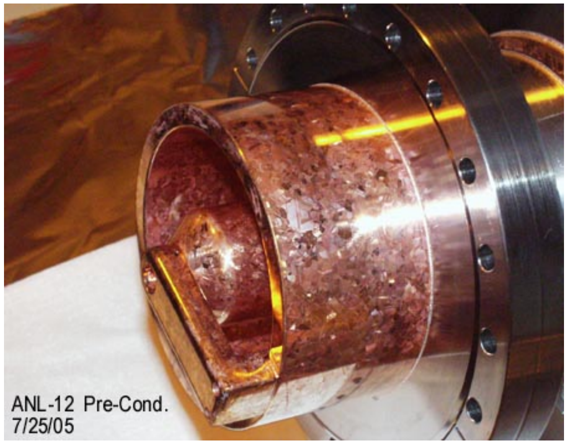
ANL-18 → Failed during conditioning at ~ 90kW; pinhole leak in ceramic (NOTE: Ceramic was titanium-coated by Thales in France)

ANL-19 → Failed during conditioning; pinhole leak in ceramic

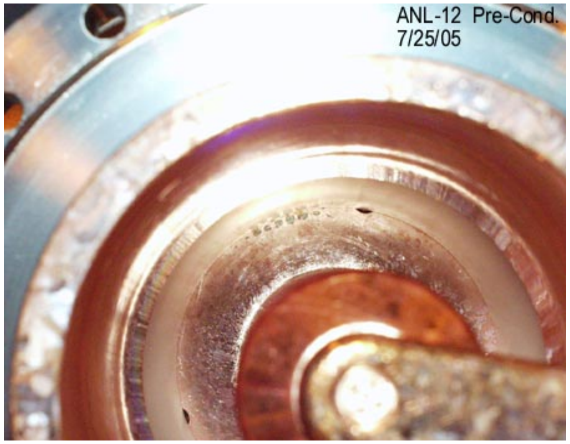
ANL-20 → Conditioned to 100kW, **but destroyed during AFT ferrite tuner tests**

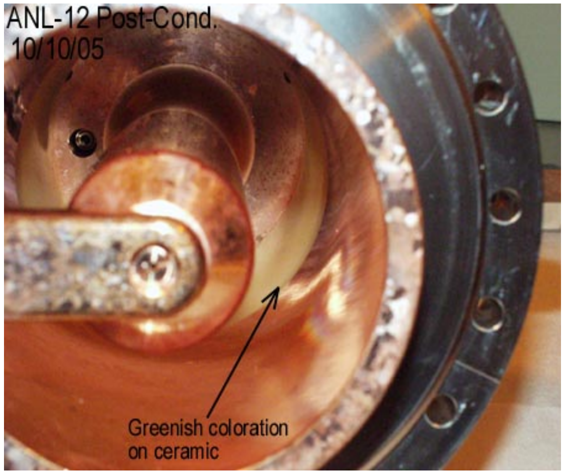
MTM-17 → Conditioned to 100kW; in spares

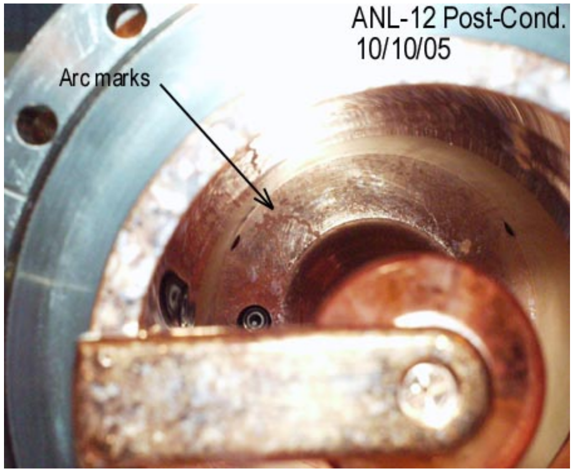
Coupler ANL-12 Photos

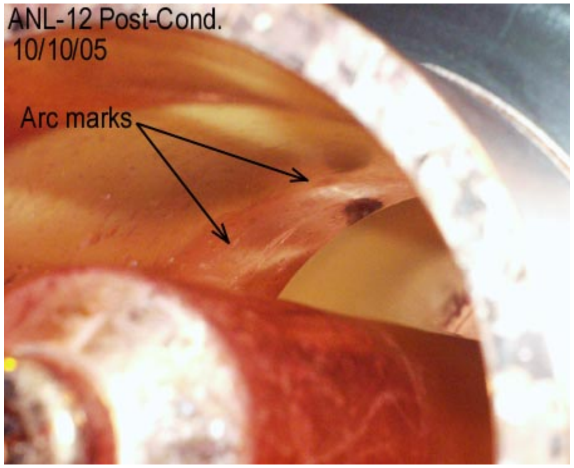


Successfully conditioned to 100kW CW and installed in storage ring cavity S37/C4





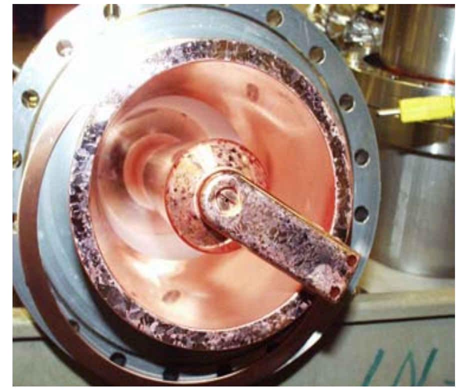


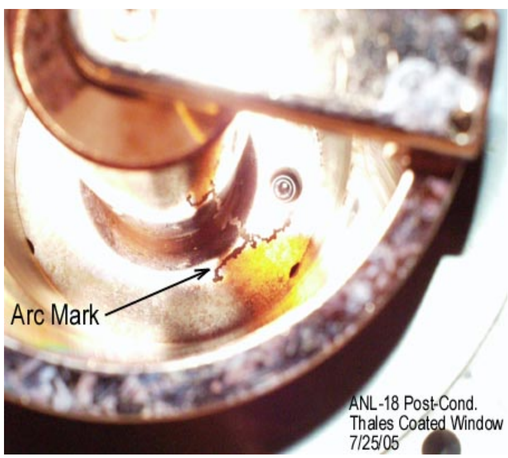


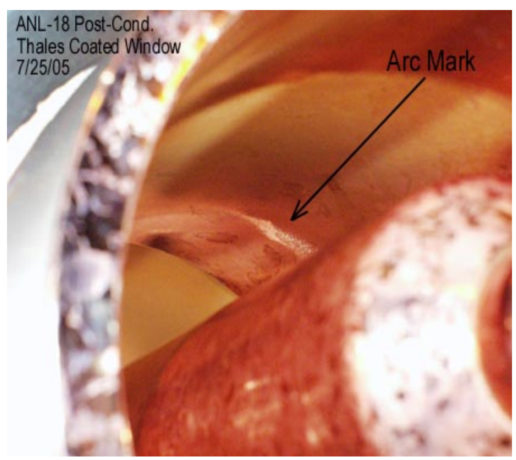
Coupler ANL-18 Photos

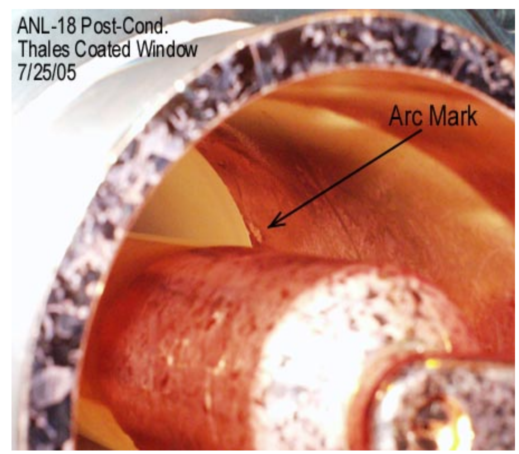
- Coupler ANL-18 was titanium-coated by Thales in France to test outsourcing of the coating process

- Conditioning went very smooth until pinhole leak developed at ~90kW









Tuner Conditioning

- Tuner ANL-09 was installed in the test stand cavity in 2002 and was conditioned to 100kW; in spares

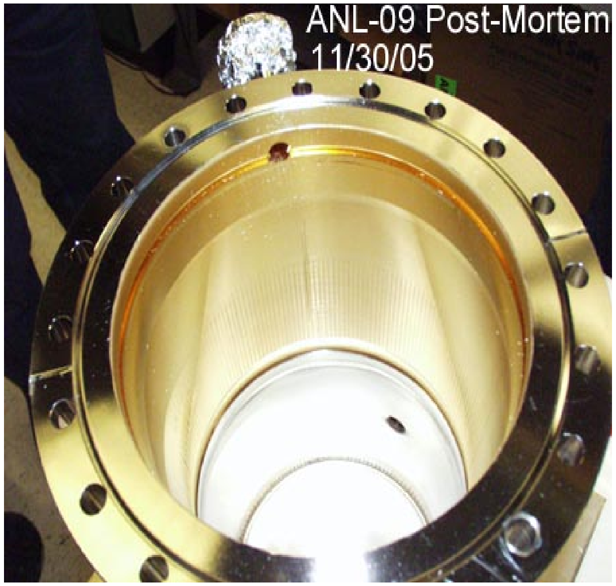
- Tuner ANL-03 was conditioned to 100kW in 2002; in spares

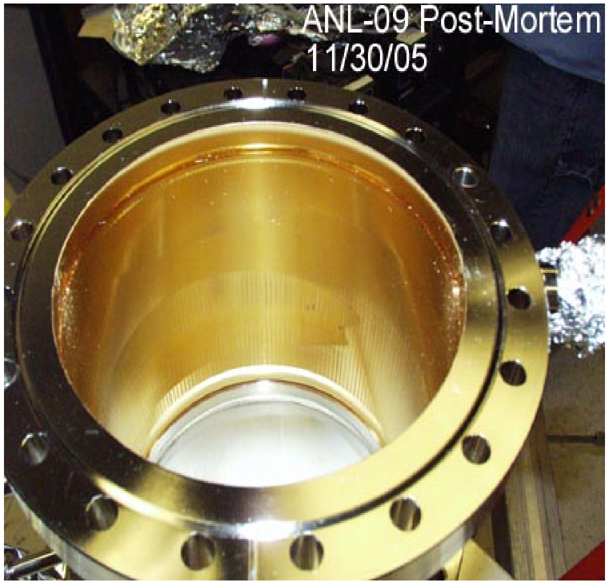
- Tuner ANL-09 was installed in 2003 and was conditioned to 100kw, but failed due to a vacuum leak November of 2005

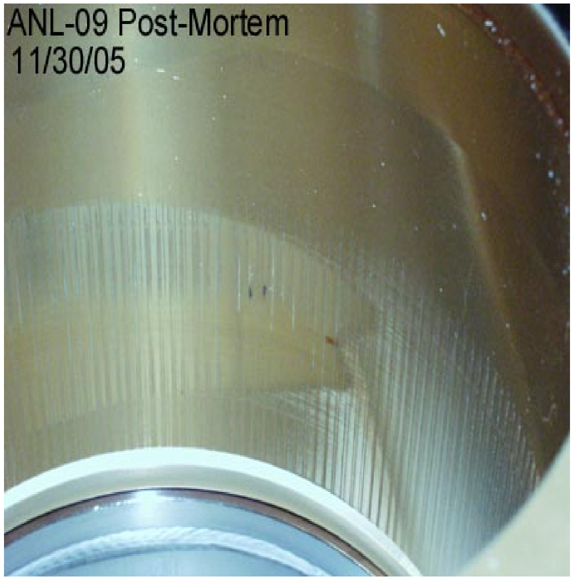
- Tuner ANL-22 installed in test stand cavity in November 2005 and conditioned to 100kW; in spares

Tuner ANL-09 Photos

This tuner failed due to an intermittent minute vacuum leak at an internal conflat flange that would begin leaking at ~ 60kW of cavity input power







Storage Ring RF Cavity HOM Damper Testing and Conditioning

E-probe dampers for installation into storage ring cavities →

Dampers dissipate HOM power in lossy ceramic dielectric in damper body

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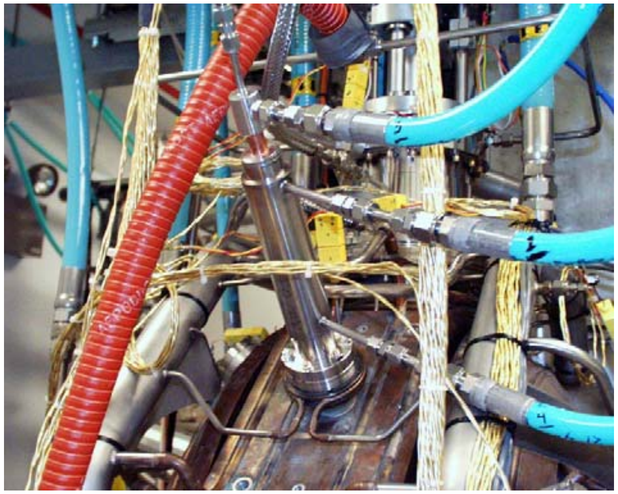
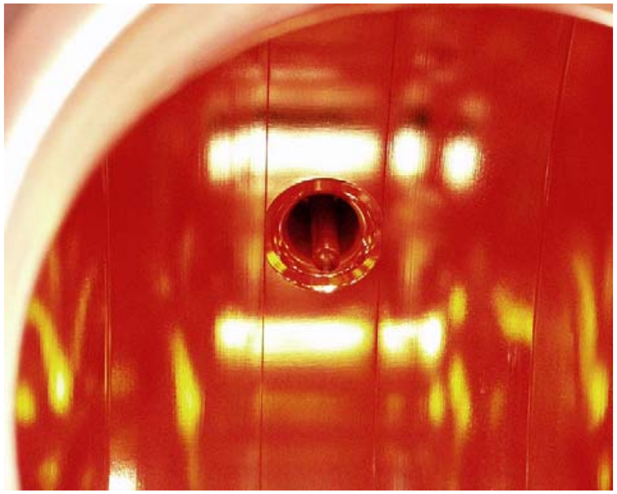


- Conditioned to 100kW input power in test stand cavity
- Tested to 5kW fundamental power on cavity sidewall



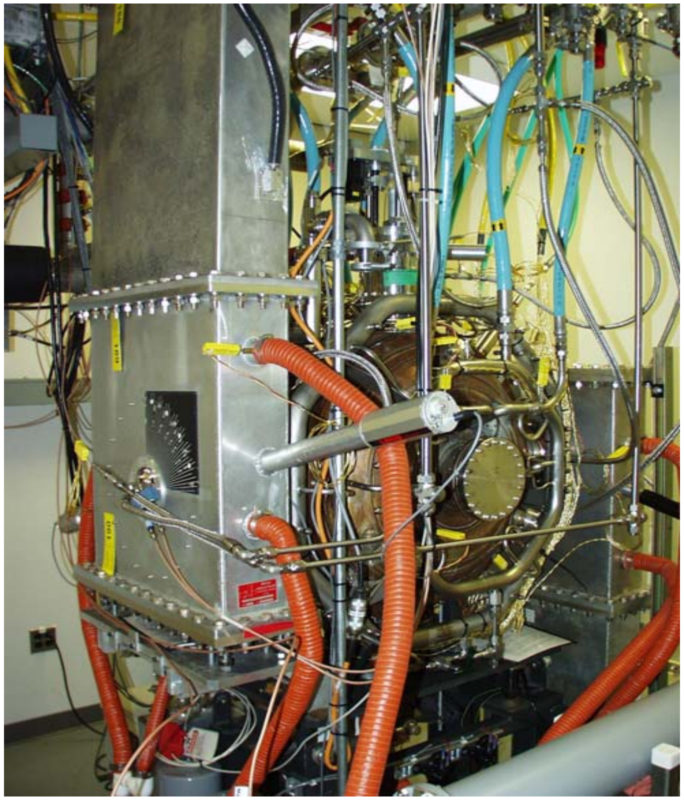
100kW and 150kW Tests on the AFT 350MHz Fast Ferrite Cavity Tuner

- **<u>100kW CW cavity tuning test</u>**
  - **-- maintain cavity resonance at 100kW CW cavity input power**
  - **-- demonstrate minimum cavity tuning range of 10kHz**
  - **-- limited to 100kW CW due to limit of cavity coupler**

- **<u>150kW CW power handling capability test</u>**
  - **-- Qualify operation of the fast-ferrite tuner at it's specified maximum power input**

100kW CW Cavity Tuning Test on the AFT 350MHz Fast Ferrite Cavity Tuner

Ferrite Tuner High-Power RF Test Setup in Test Stand Bunker

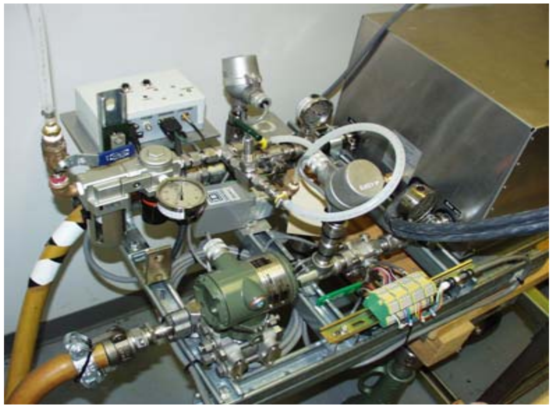


Test Stand Cavity Fitted With

Two Input Couplers

Ferrite Tuner Connected to Cavity with High-Power 360° phase shifter

Ferrite Tuner Water and Cooling Air Instrumentation



100kW CW Cavity Tuning Test on the AFT 350MHz Fast Ferrite Cavity Tuner

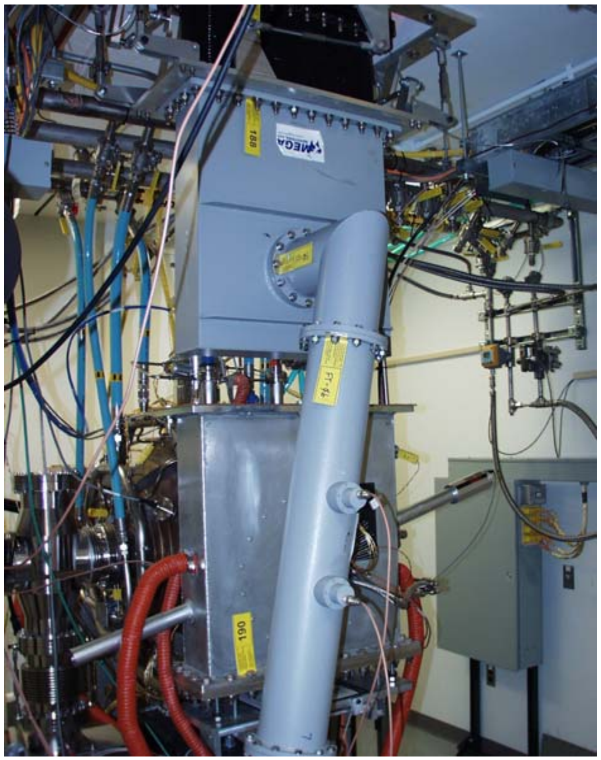
- **The AFT fast-ferrite tuner was able to maintain cavity resonance at 100kW CW into the test cavity while demonstrating a tuning range of ~ 14kHz**

- **Operated for over 24 hours at power levels over 85kW**

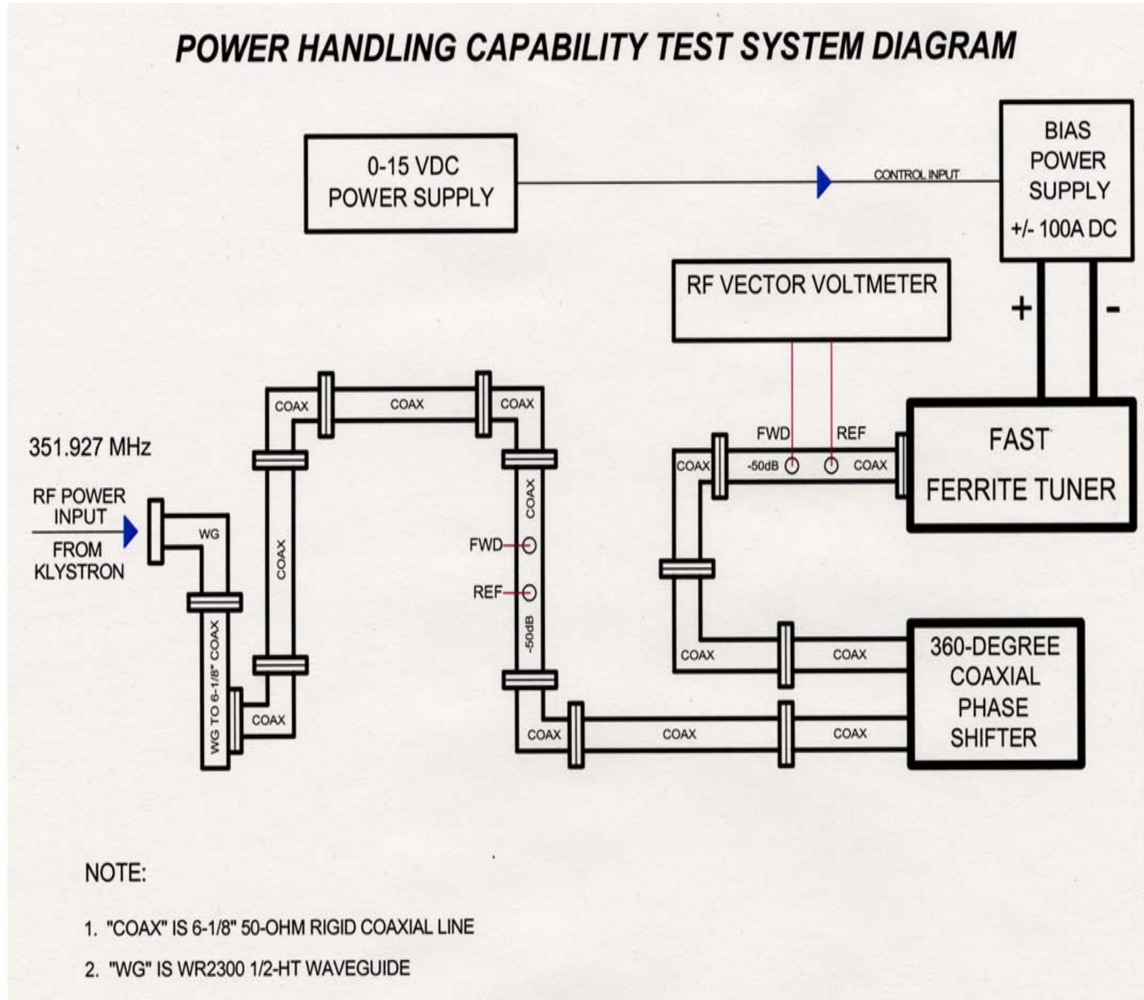
- **The rf losses in the fast-ferrite tuner were very low, ~ 400 watts with 100kW CW input to the test cavity**

- **The fast-ferrite tuner coaxial line power was measured at ~ 70kW**

150kW Power Handling Capability Test on the AFT 350MHz Fast Ferrite Cavity Tuner



Coaxial connection to
test stand input waveguide



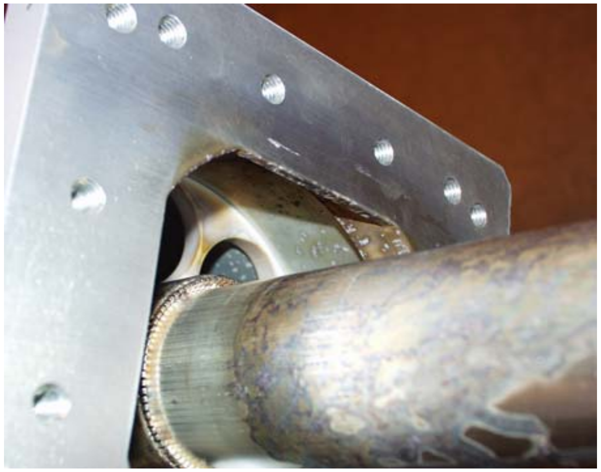
150kW Power Handling Capability Test on the AFT 350MHz Fast Ferrite Cavity Tuner

- **RF power was increased in 10kW steps over 15 minutes until 148kW forward power was achieved.**

- **The AFT fast-ferrite phase shifter survived with no problems, *but……***

- **After approximately 5 minutes at 148kW, smoke detectors inside the test stand bunker tripped, and the test was halted.**

- **After system disassembly, evidence of severe arcing was seen inside the 360° mechanical phase shifter.**

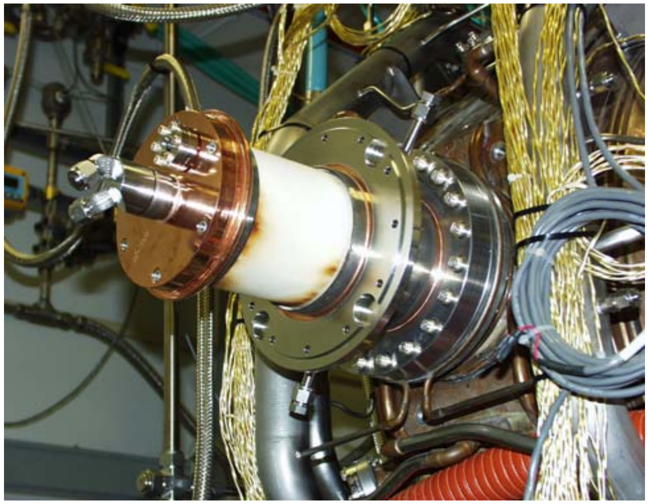


100/150kW CW Ferrite Tuner Tests – *Lessons Learned*

- **<u>Problems with the fast-ferrite tuning system</u>:**

-- Due to the high VSWR conditions in the fast-ferrite tuner transmission system, the power handling capability of 6-1/8" rigid coaxial line borders on inadequate for this application

The 6-1/8" components required supplemental air cooling to survive



-- The APS cavity input coupler will not survive the high VSWR conditions --

The cavity coupler used for coupling the fast-ferrite tuner to the cavity was severely damaged due to arcing, which resulted in a pinhole vacuum leak →

Construction of a Dedicated Klystron RF Power Source for the Test Stand

- Surplus Philips YK1350 350MHz/1MW CW klystron and lead garage installed
- Spare APS circulator installed
- Diversified Technologies prototype 100kV/20A fast switch / “solid-state” mod-anode tank is utilized to provide beam, heater, and focus power to the Philips klystron, as well as mod-anode bias
- Klystron DC beam power provided by RF1 power supply until a dedicated supply can be installed

The Philips klystron has been successfully operated up to ~ 140kW CW into a shorted waveguide for initial testing

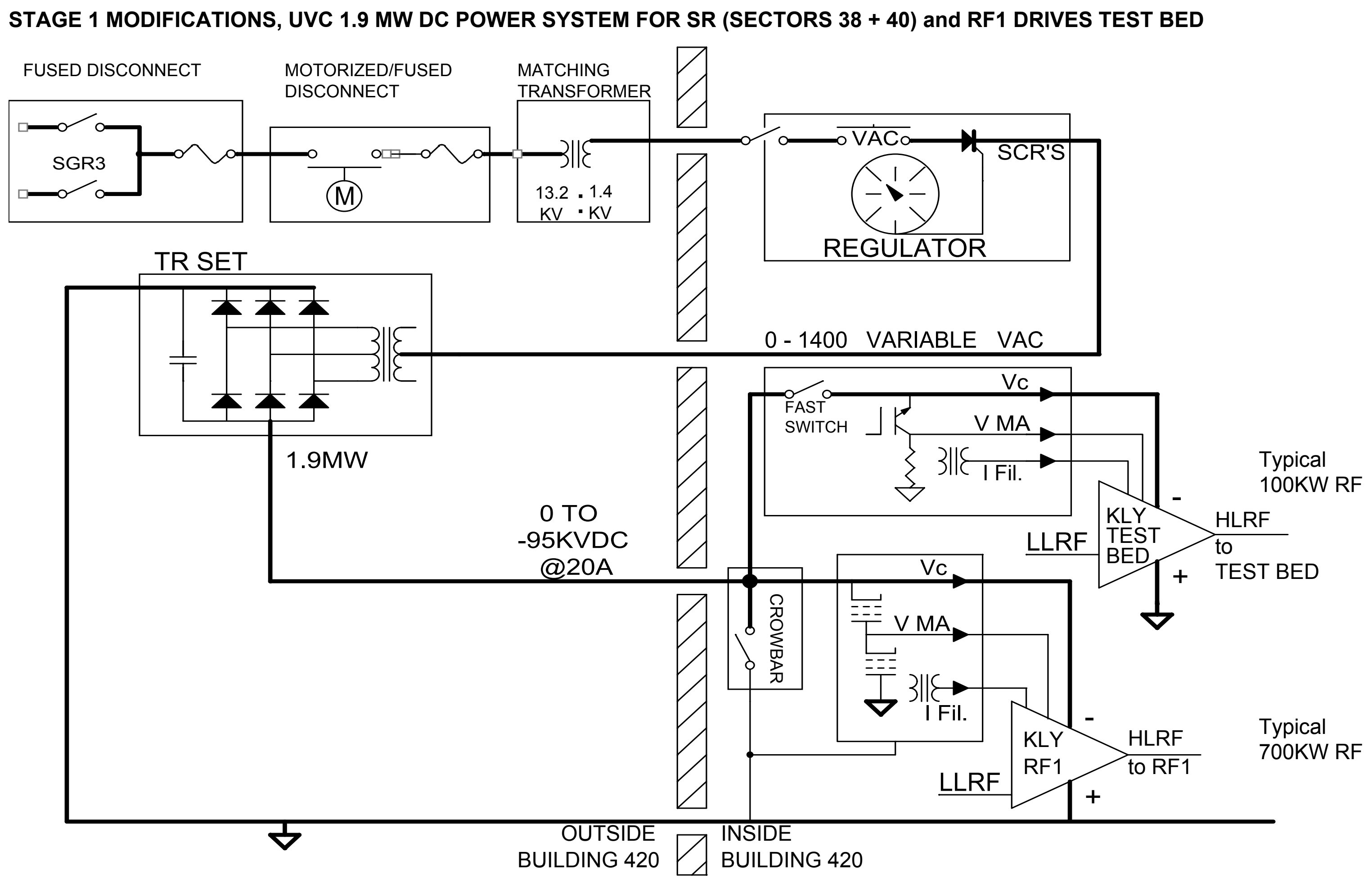
Tests of a Prototype 100kV/20A Fast DC Switch and "Solid-State" Mod-anode Regulator

- Prototype system designed by Diversified Technologies, Inc. to APS specification, funded by SBIR

- Fast series switch has significant advantages over ignitron-based crowbar systems for fault energy control

- "Solid-state" IGBT-based mod-anode regulator design is a possible alternative to the obsolete TH5188 tetrode used as an mod-anode regulator device in the existing APS rf power supplies

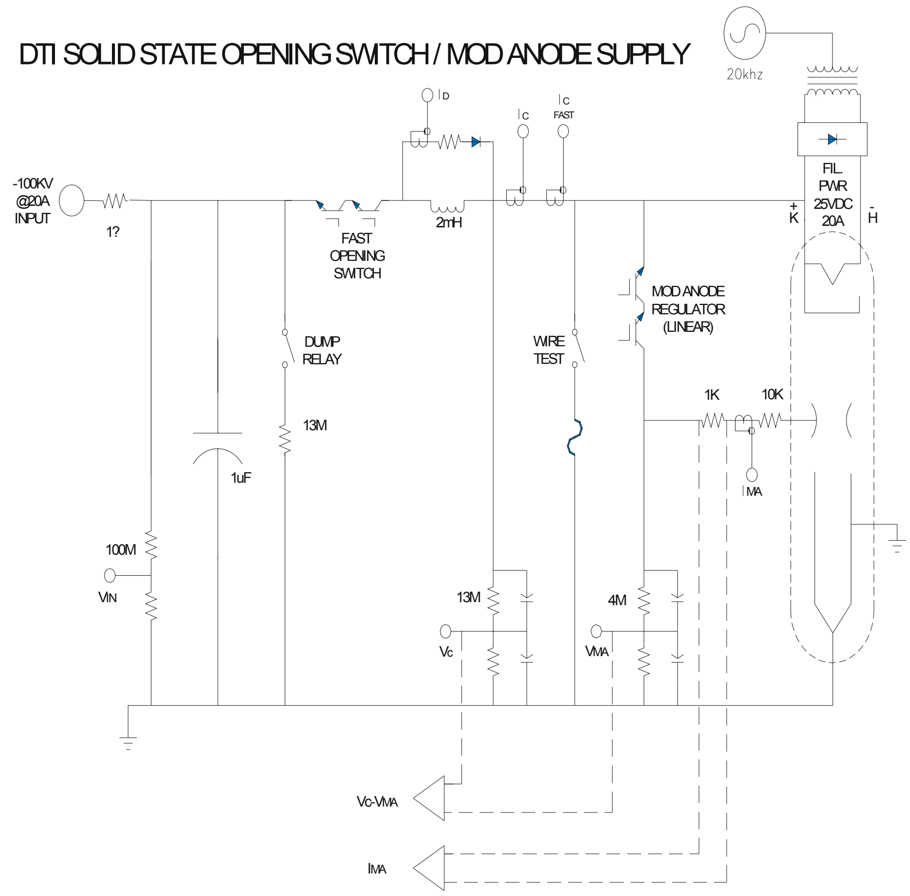
Temporary DC Power Connection to the RF1 Klystron Power Supply for Test Purposes



Temporary parallel connection with RF1 klystron at the RF1 T-R set HV output

Design Overview of Fast-Switch/Mod-Anode Tank

- 100kV/20A fast series IGBT switch
- IGBT-resistor active voltage divider for mod-anode bias
- DC heater supply for klystron filament utilizing a PWM switching power supply to reduce the size of the HV dc isolation transformer



Interior Views of the Prototype 100kV/20A Fast DC Switch and "Solid-State" Mod-anode Regulator

Chassis lifted from the oil tank

Interior Views of the Prototype 100kV/20A Fast DC Switch and "Solid-State" Mod-anode Regulator

Fast series switch is very effective in limiting fault energy

Solid-state switch plate rated at 3.3 kV, 100A continuous; 36 plates are connected in series to achieve over 100 kV switch capability
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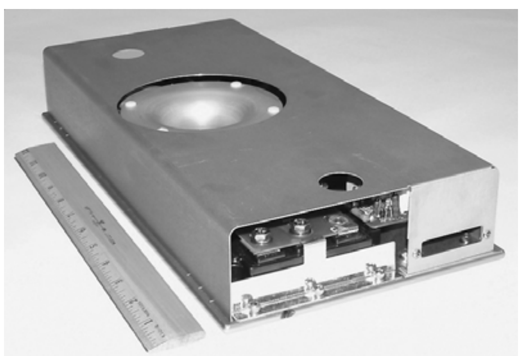
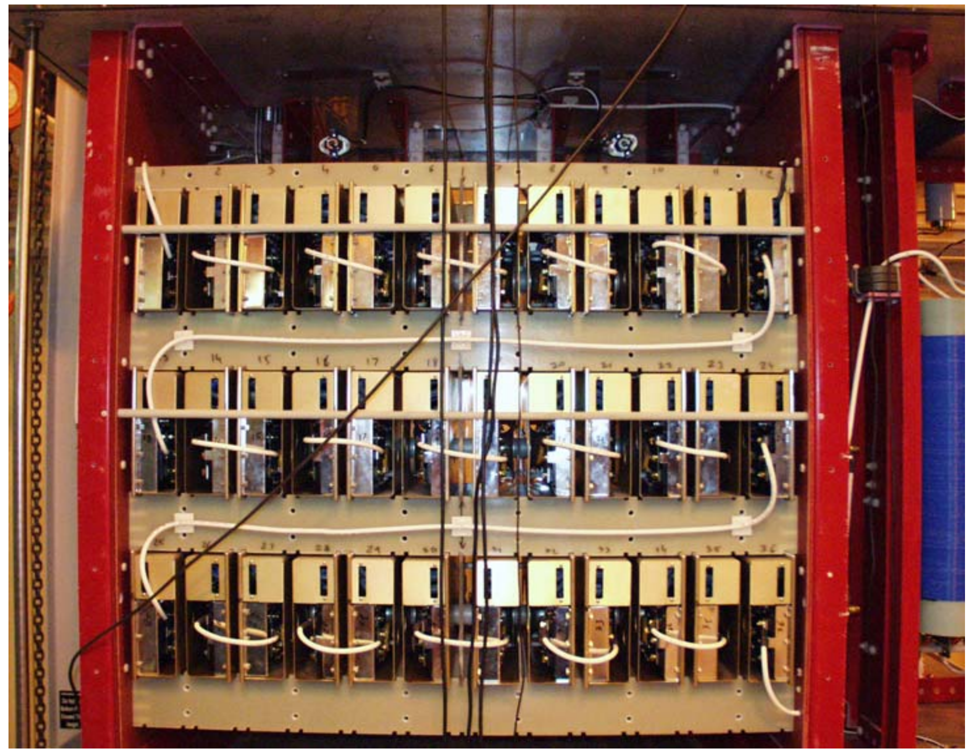




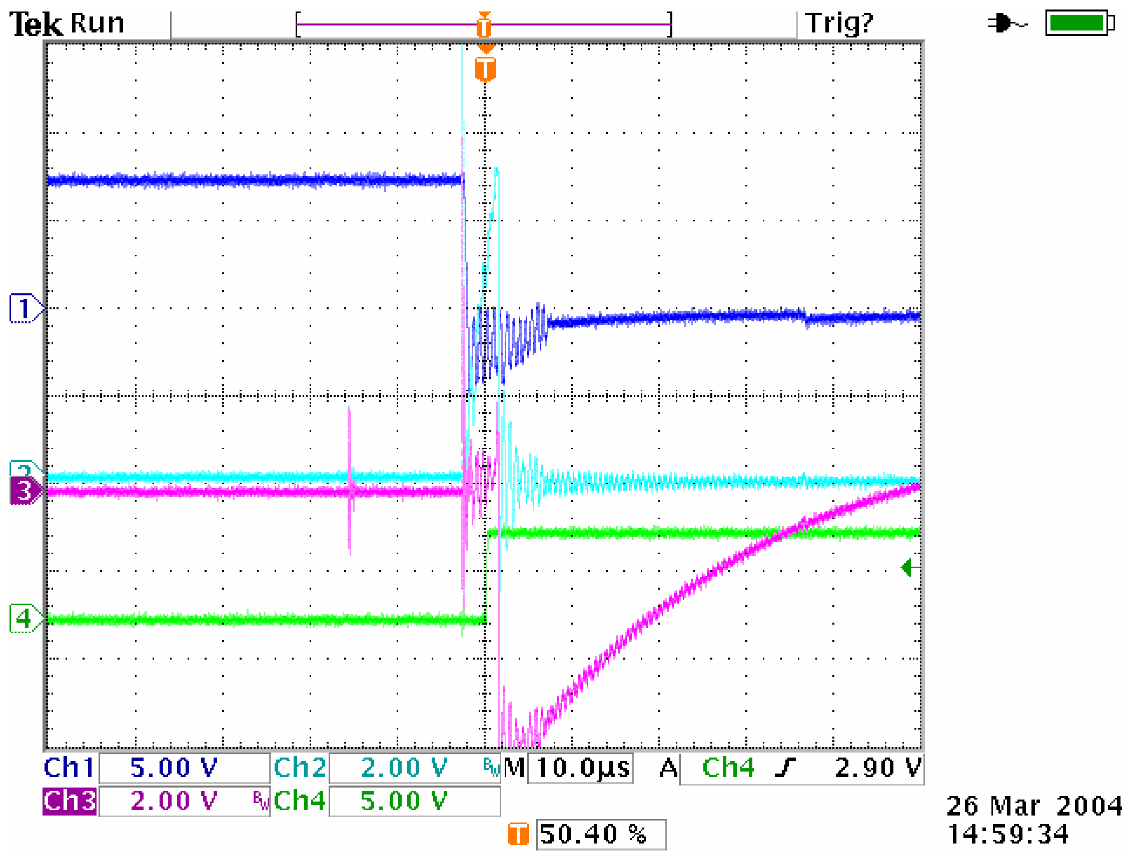
↑
36 IGBT switch plates in series to form the series output switch

Performance of 100kV/20A Fast Series IGBT Switch

Ch.1 = cathode voltage
Ch.2 = cathode current
Ch.3 = diode current
Ch.4 = over current fault

Input = 80kV from spotknocker power supply (fault caused by arc test – output to ANL dummy load)

Fast switch response time equivalent to or faster than an ignitron crowbar system



Development of an Automated Program for Conditioning Couplers and Tuners

- Provides "intelligent" operator-free automation of the coupler and tuner conditioning process:

  → operating limits set for specific application

  → monitors cavity vacuum, temperature, and forward/reflected power to determine increments and timing of power increase

  → Provides limited conditional rf restart for cavity vacuum and arc trips

  → Logs all faults for later reference

  → EPICS operator interface →

Pulsed RF Power Testing of Fermilab Components

APS provided pulsed rf power for high-power tests on several ferrite phase shifters and a hybrid coupler for Fermilab

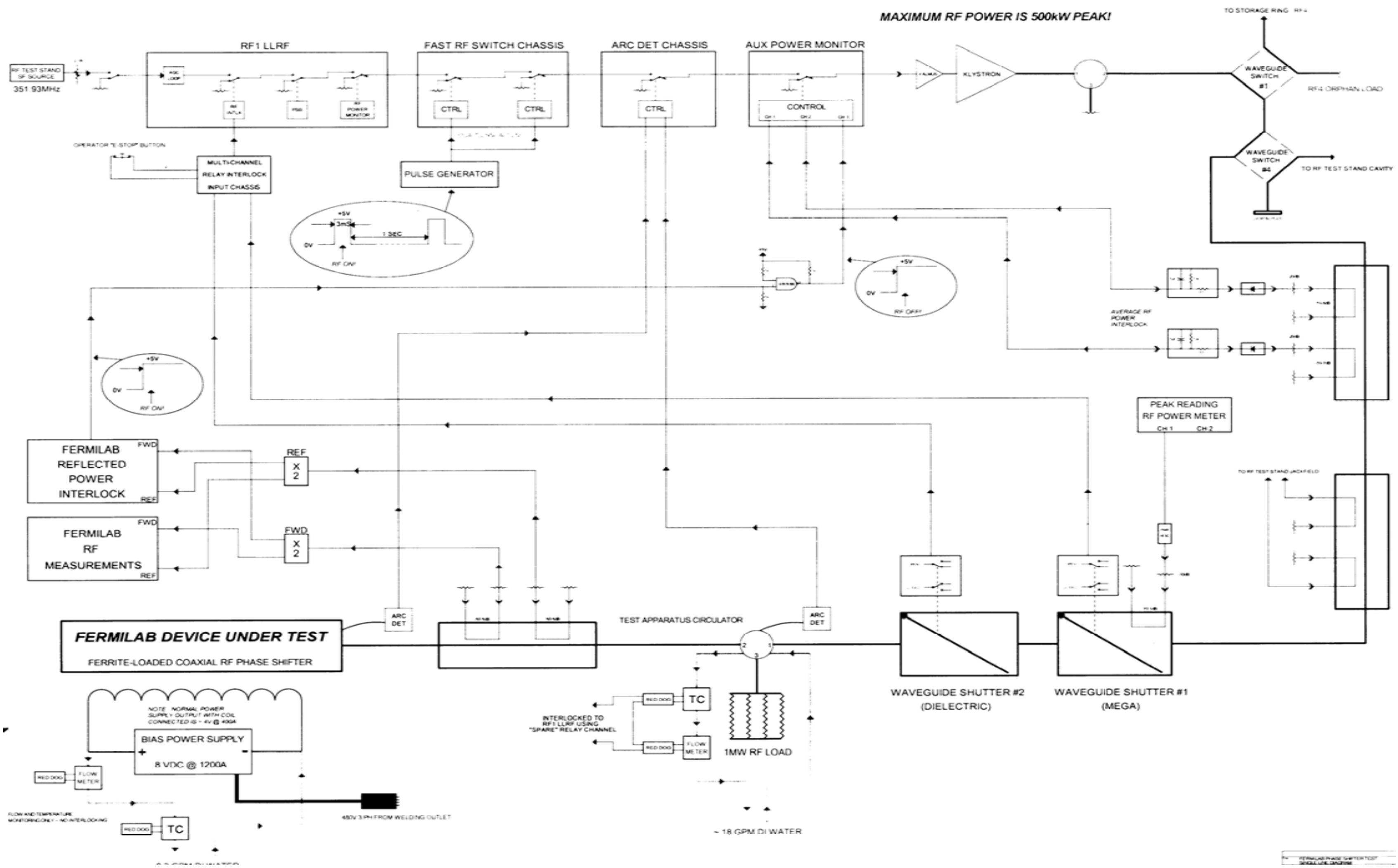
- RF1 was configured to produce pulsed rf power by chopping the klystron rf drive with a fast solid-state rf switch

  → *the klystron was operated with a dc beam*

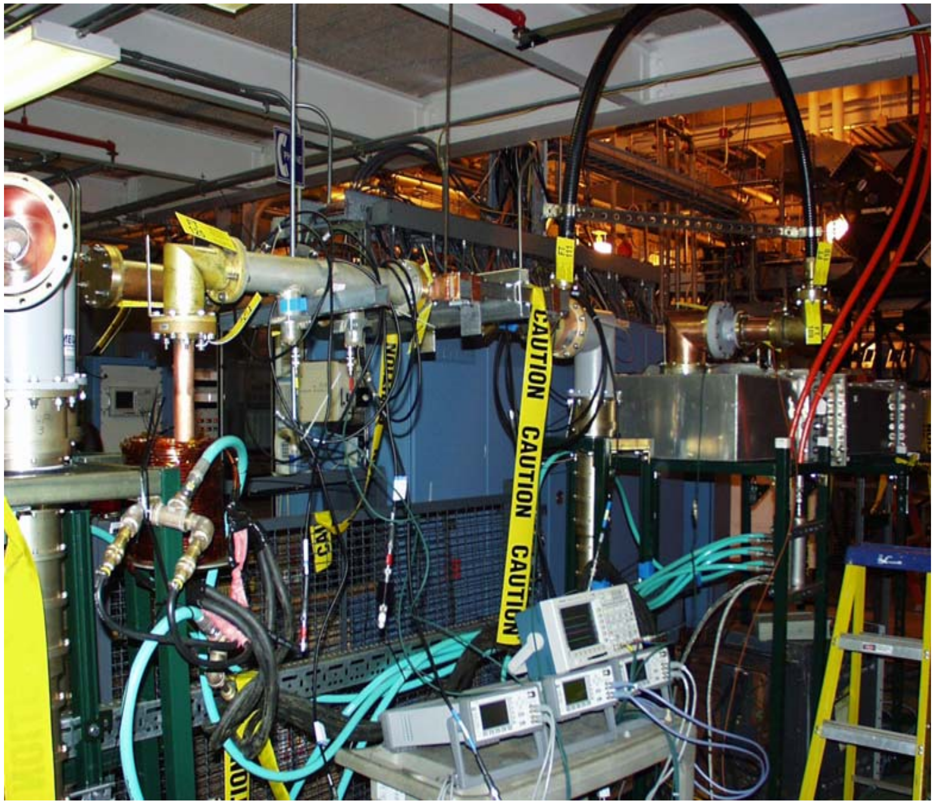
  → *careful attention was paid to interlocking against accidental generation of CW power!*

- Up to 500kW peak power in 4ms pulses at a 1Hz repetition rate was produced for the tests →

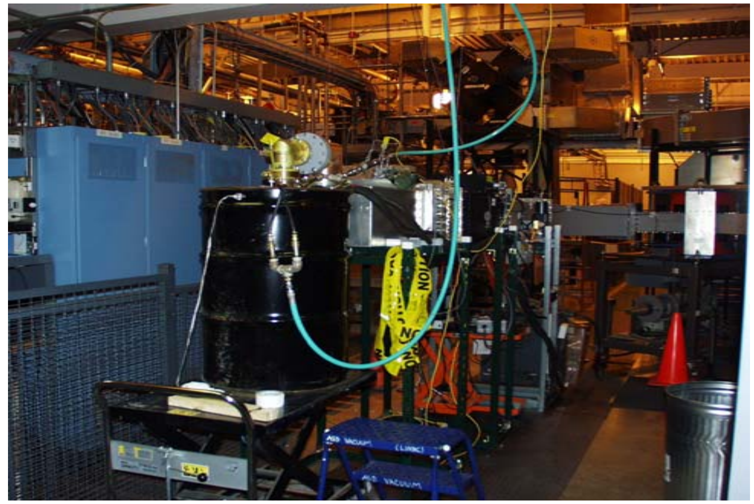
Fermilab Pulsed RF Test System Diagram



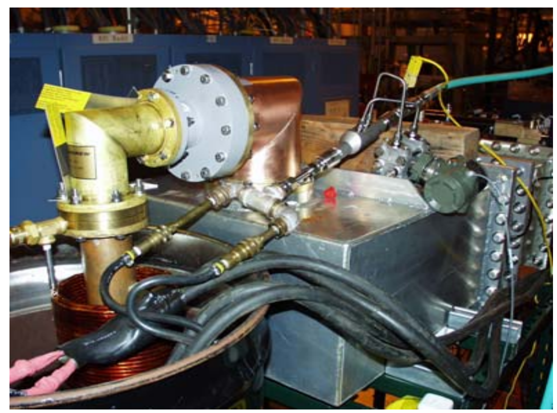
Fermilab Pulsed RF Test System



Hybrid Coupler Test System



Ferrite Phase Shifter Test System



-- Conclusion --
Future Plans for the APS 350MHz RF Test Stand

- Complete testing and evaluation of the DTI Fast-Switch/Mod-Anode Tank
- Complete commissioning of the dedicated Philips test stand klystron to full output power into test load
- Condition spare booster-synchrotron couplers and tuners
- Test and condition upgrade design of storage ring HOM E-probe dampers
- Complete design and installation of dedicated autonomous high-voltage power supply for the test stand klystron
- Utilize the test stand to test and evaluate new digital LLRF system designs and modules