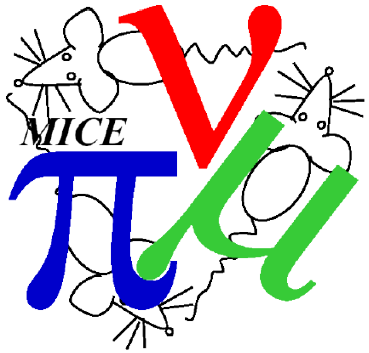



# Progress on the MICE RF High Power Drive Systems

K Ronald, University of Strathclyde

For the MICE RF team

# Requirements of the MICE HPRF system

- To demonstrate sustained cooling (MICE Step VI) requires 8 cavities at 8MV/m

- Driver system must provide 1MW to each cavity (500kW on each coupler) at 201.25MHz
  - Provide required energy with four 2MW amplifier chains
    - Duty cycle is for 1ms pulses at 1Hz
  - Relatively tight space constraints behind the shield wall
    - Not significantly eased by the switch to the return yoke
  - Distribution network must not impede service access to cooling channel
  - Proposed to use LLRF phase control of 0.5$^{o}$ with 1% in amplitude regulation
    - Use LLRF 4 system developed by L. Doolittle

- Recent work has included
  - Demonstration of the required 2MW power from the first, modernised amplifier chain
  - Transport of the amplifier to the MICE Hall
  - Installation and testing to meet the EU-TIARA deliverable
  - Completion of the major University of Mississippi MRI activity

# High Power Driver System

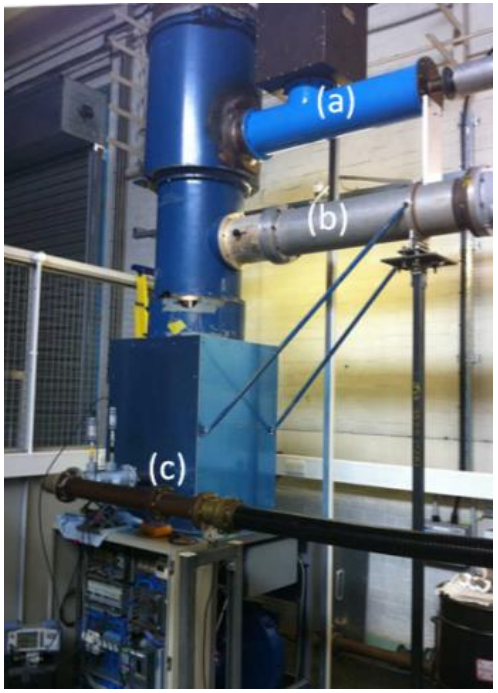
- The RF cavities are to be driven in adjacent, coupled pairs with a fixed phase angle between coupled pairs

- Each coupled pair to be driven by a 2MW, 201.25MHz amplifier chain
  - Arbitrary phase control between separate coupled pairs of cavities
  - SSPA (~4kW) driving Tetrode (~250kW max) driving Triode (2MW max)

- Since last summer all issues with the Power Supply and valve seating have been successfully resolved
  - Key difficulty was a faulty thyratron valve in the crowbar (protection) circuit
    - Temporary solutions with lower specification switch
    - Required reduced operating specification to protect TH116
  - e2v Technologies offered outstanding support
    - Three prototype thyratron valves made available to project
    - Stable operation at required bias voltage possible
    - Allowed correct tuning of amplifier to be realised

# Demonstration of required RF signal

- Once tuned the amplifier chain operated at the desired pulsed output level, 1Hz, 1ms, 2MW, 201.25MHz





a) HT feedline,
b) Output 9 inch coaxial line,
c) Input 3 inch line

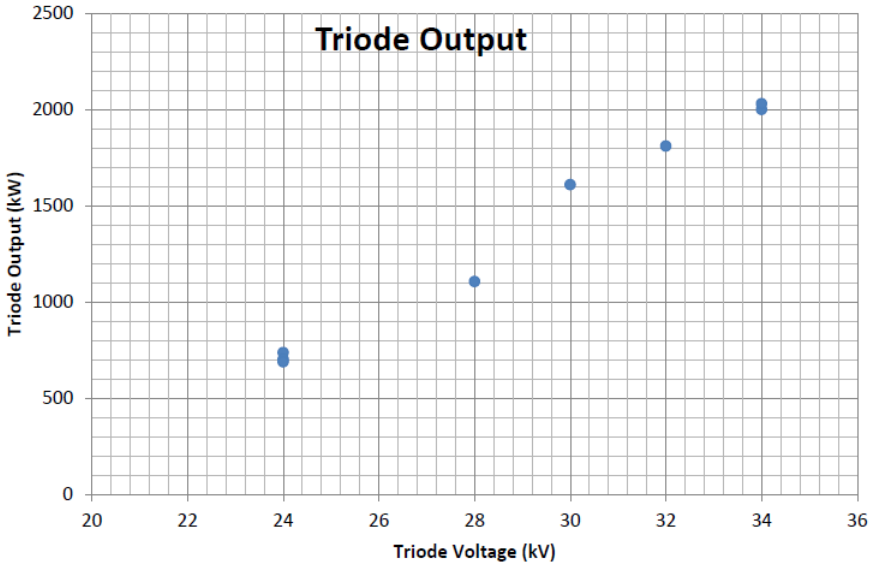
- Team developed for RF tests and installation at MICE
  - A. Moss and C. White (Daresbury) have worked with T. Stanley (RAL), K. Ronald, C. Whyte and A. Dick (Strathclyde) and S. Alsari (Imperial)
  - This provides the team required to operate the system at MICE

# High Power Driver System

- Triode DC bias and drive brought up together
  - Maintaining ~10dB gain

- Performance achieved:
  - 2.06MW output RF
  - 34kV bias voltage
  - 129A forward average current
  - η=46% (electronic)
  - Gain 10.8dB
  - Input port return loss -12.5dB
    - VSWR 1.6

- Drive from Tetrode
  - 170kW output RF
  - 18kV bias voltage
  - 15.5A forward average current
  - η=61% (electronic)
  - Gain 19dB

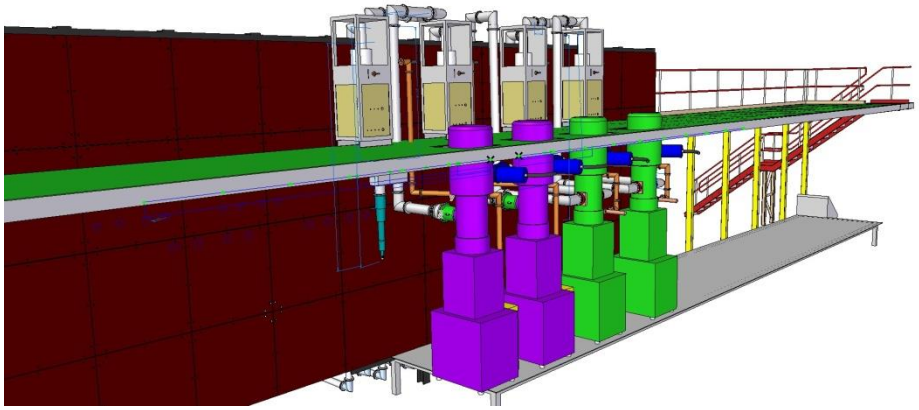



- Drive from SSPA
  - 2.27kW

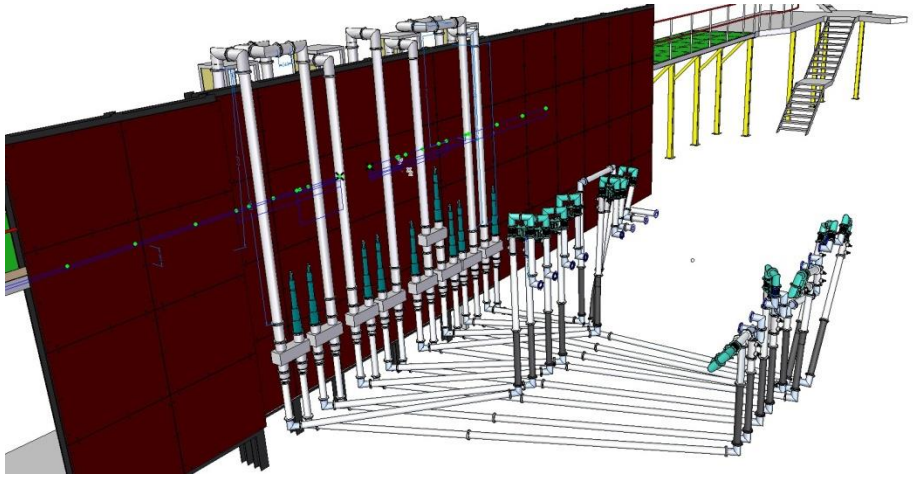
- Drive from synthesised oscillator
  - 3.7dBm

# Distribution network

*Amplifiers behind Shield Wall*



*Distribution Network to MICE*



- Amplifiers installed behind shield wall
  - Triodes on main floor, Tetrodes on Mezzanine
  - Impact of B-fields negated by yoke
    - Line installation planed before yoke support risers
  - High power dynamic phase shifters removed
- 4 off 6 inch coax lines over wall
  - Pressurised to increase power handling
- Hybrid splitters moved - more accessible
  - Minimises clutter and increases service access to the amplifier stations
- Line lengths matched using 3D CAD
- Manually adjustable line trimmers installed at cavity to take up assembly errors in coax length
- Easier to assemble – introduced flexible coax
  - Allows for small misalignments
- 2 Hybrids split output from the Berkeley Amplifiers (one on amplifier side of wall)
- CERN amplifiers have two outputs
- 9 hybrids on MICE side of shield wall
  - Split power for the opposed couplers of each cavity
- Lines will be pressurised with 2Bar Nitrogen

# Distribution network and components

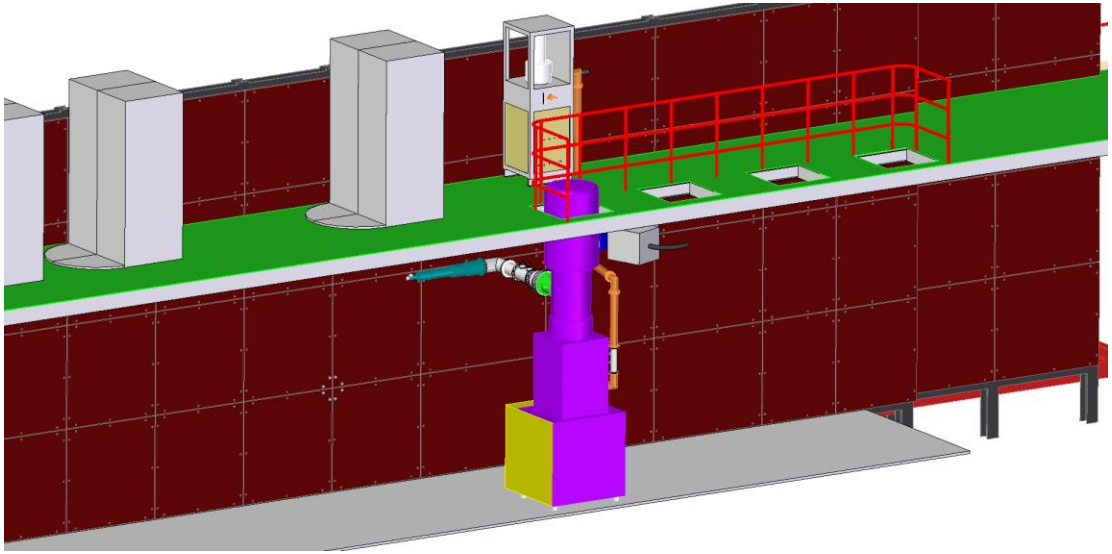
- Through work of D. Summers, Univ. Mississipi and the US NSF MRI programme:
  - Vast majority of distribution network procured
  - Encompasses Loads, Hybrid Couplers, Reducers, Gas Barriers, Directional Couplers, elbows, line trimmers, etc

- In addition Mississippi have procured key components to build further amplifiers chains and components for the RF cavities, including
  - Capacitors and Chargers
  - Tetrode valves and tetrode valve amplifier enclosures
  - LLRF boards
  - Tuner components for cavities

- Some $1M (US) delivered to RAL under MoU between STFC and Univ. of Mississippi
  - Total consignment > 6 tonnes

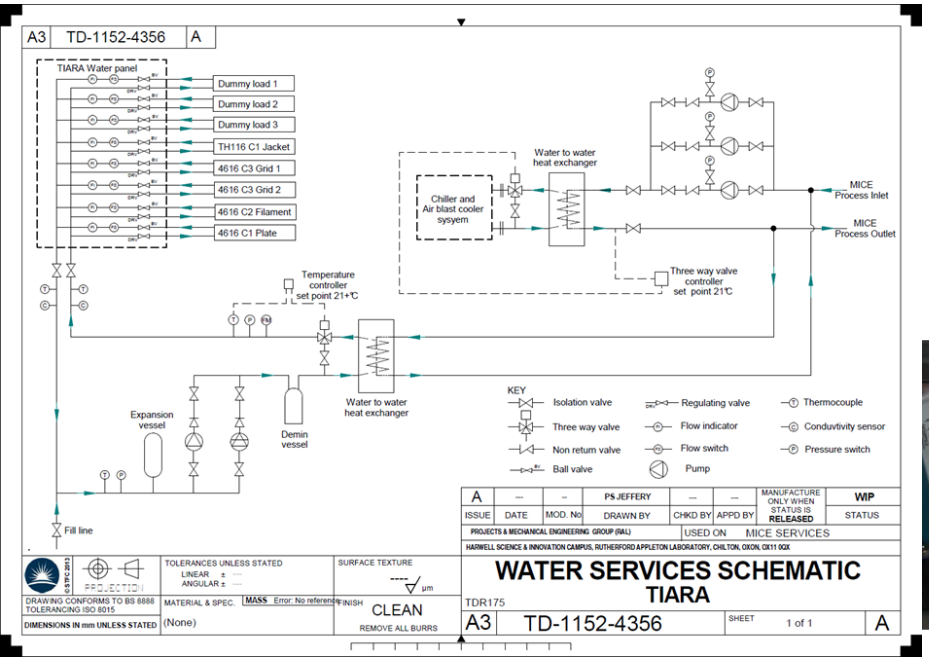
# Installation at the MICE Hall (ICTF)

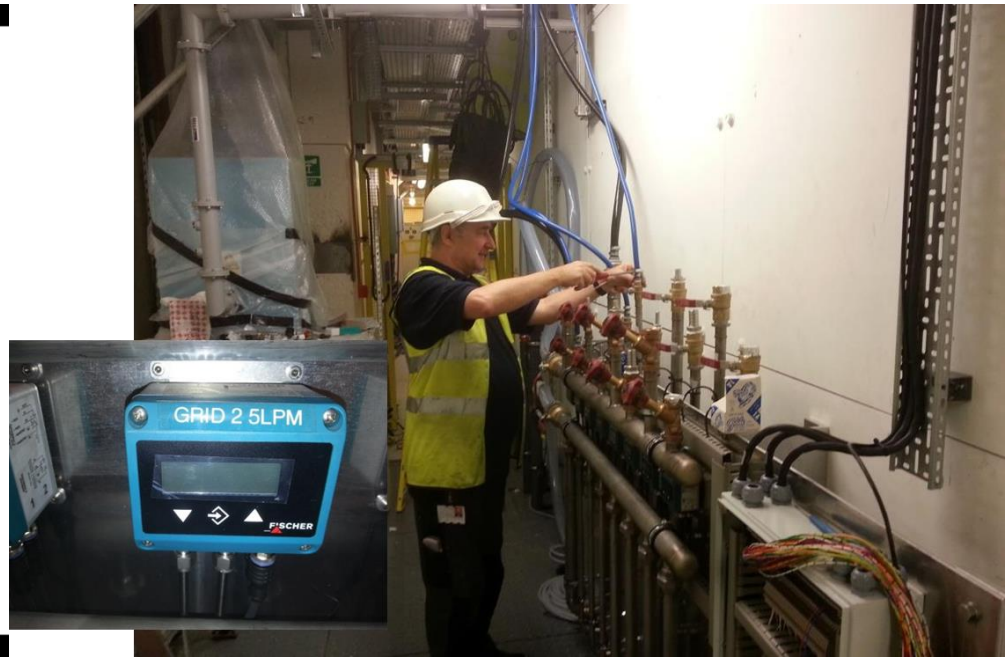
- At last report
  - Entire amplifier chain and PSU's transported to ICTF at RAL
  - Installation underway to demonstrate practicality of operation in situ
  - Due to space constraints large 2MW loads not suitable in ICTF
    - Test to maximum power rating of reject load
    - 2.06MW operation therefore previously demonstrated at Daresbury
    - Will be able to achieve full power operation @ ICTF once cavities are available
- Revised installation plan



# MICE Installation Progress

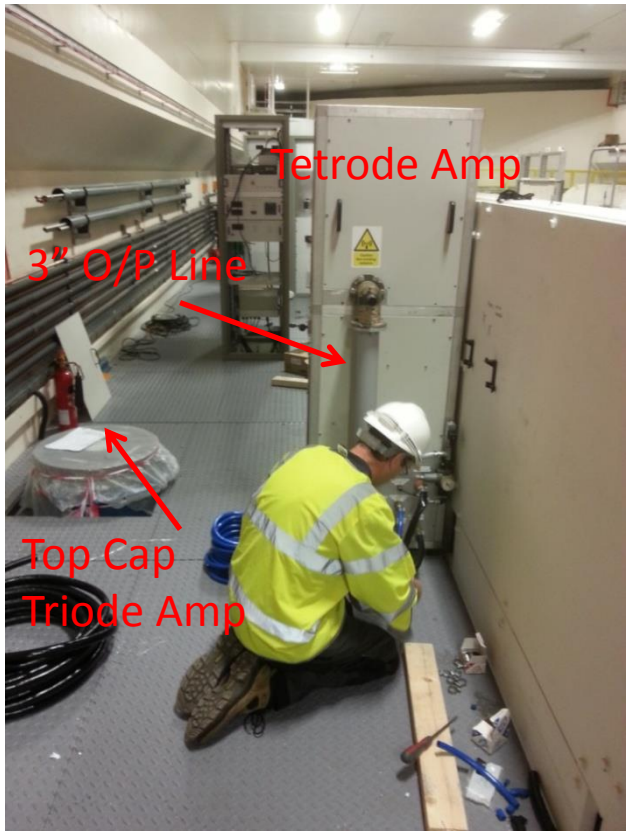
- Services
  - Water cooling (high quality de-ionised water) and compressed air installation complete
  - Water cooling distribution panel tested
  - Provides cooling to triode and tetrode systems
  - Monitors flows rate
  - Monitors coolant Temp



# MICE Installation Progress

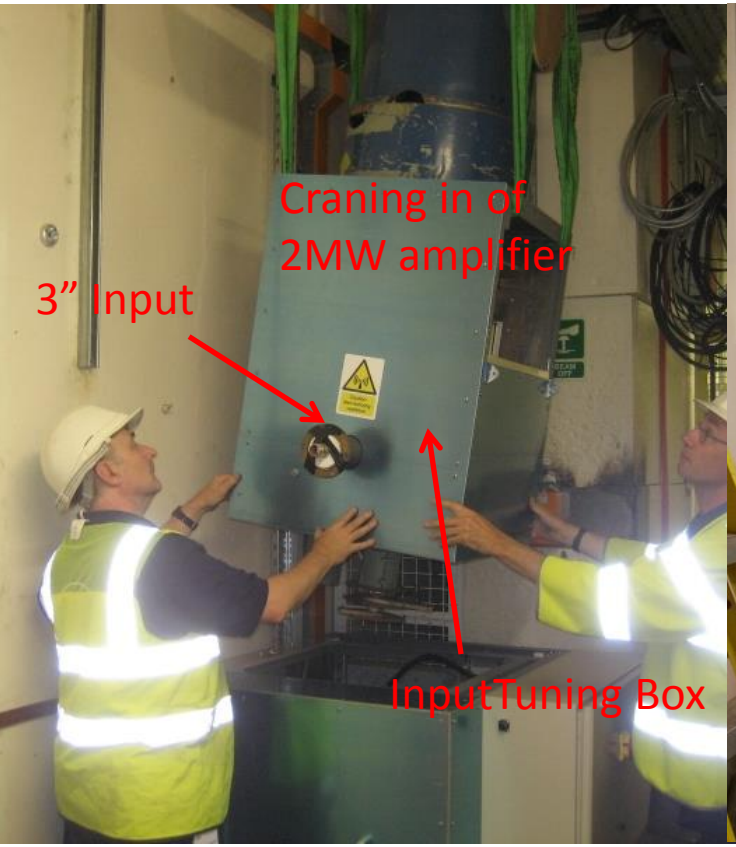
- Images showing Tetrode amplifier and power supplies installed
  - Required quite accurate alignment due to rigid coaxial wavevguides
- 3” (250kW) line installed to triode amplifier
- SSPA and synthesised oscillator installed

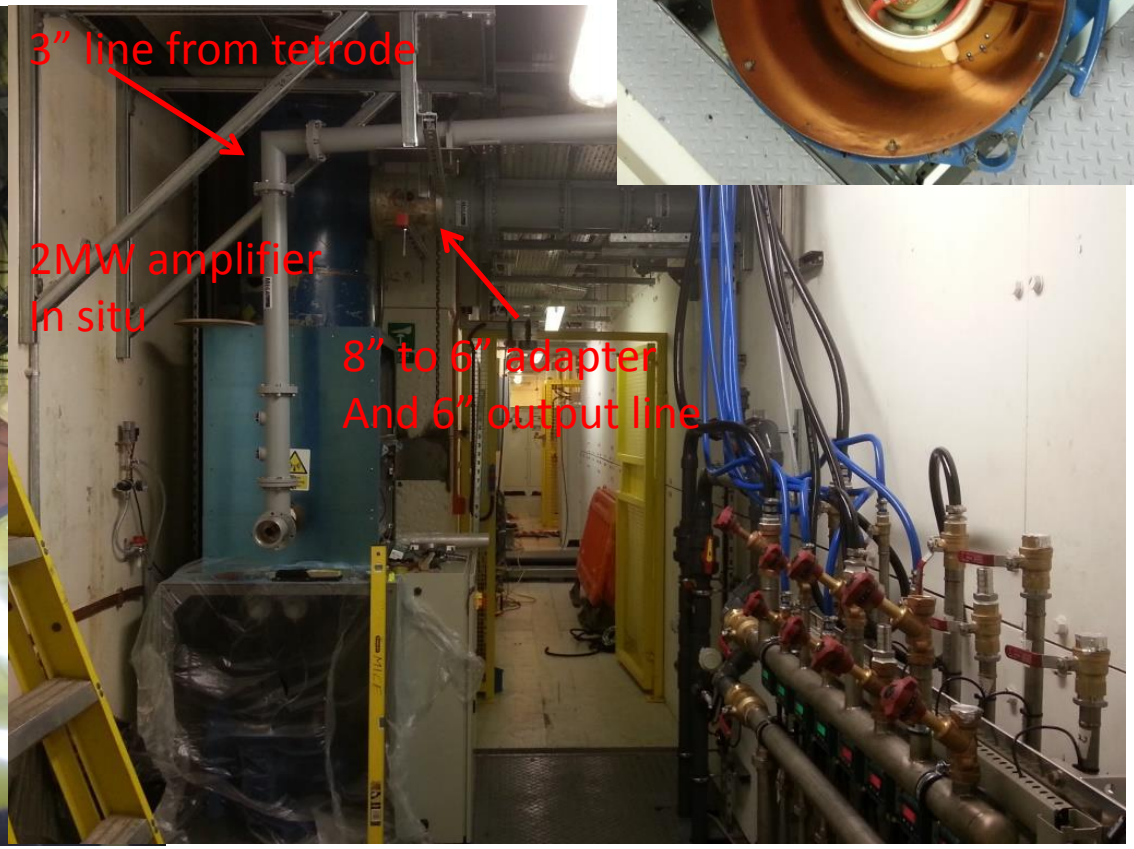




# MICE Installation Progress

- Images showing triode amplifier and valve installed
- 3” input line (250kW) line installed from tetrode amplifier
- 6” output line (2MW) installed with reject load

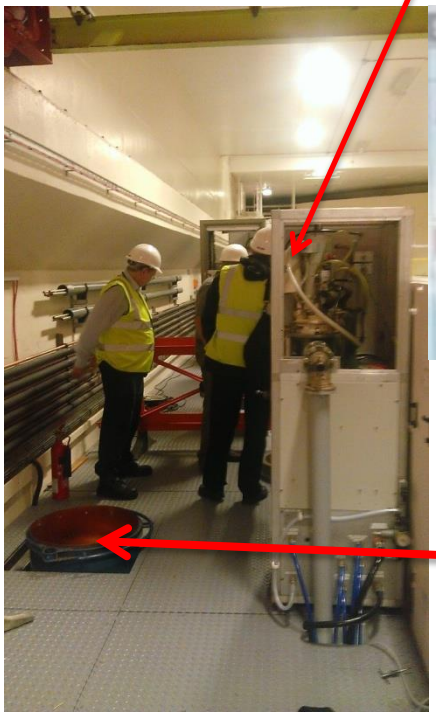



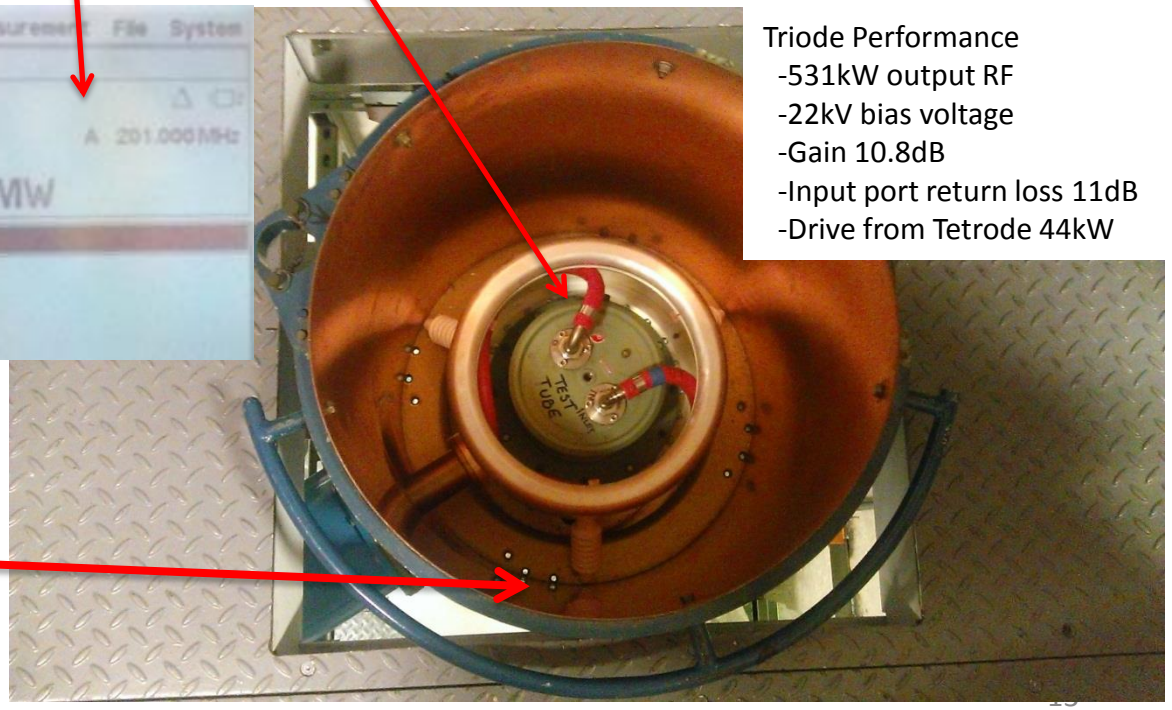
# ICTF electrical installation

- Completed during December for both Tetrode & Triode amplifiers
  - HT, Heater and control circuit installation
  - RF links between Oscillator and SSPA
  - Cabling (and cooling) installed in trays suspended from Mezzanine
  - Will be tested to maximum power capacity of reject loads

# Installation and Tests in MICE Hall

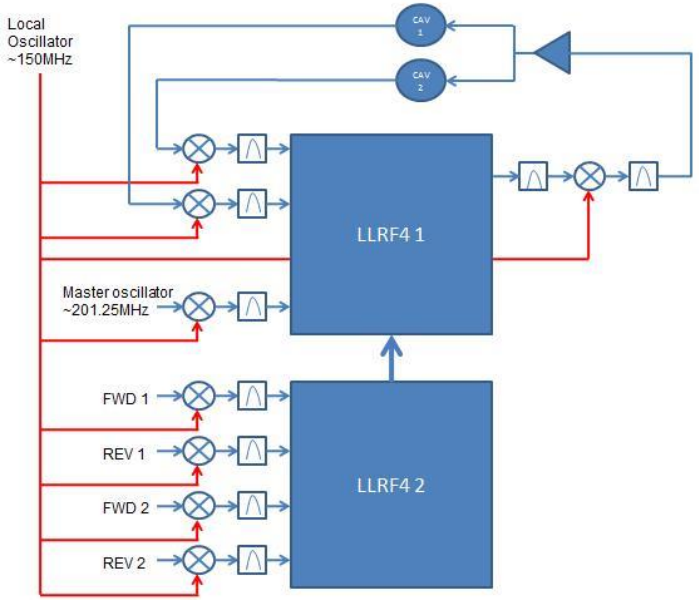
- TIARA requirement: Demonstrate the prototype amplifier operating in the MICE RF power station
  - Amplifier No.1 dismantled at DL and Transported to RAL
    - Includes SSPA, Preamplifier and Final Stage Amplifier subsystems with PSU's
  - Extensive water and air distribution systems installed
  - Pre-amplifier operating since the 4th December
  - Final stage operating since the 12th December
- Installation and operation achieved slightly ahead of a tight timetable
- Testing progressed very successfully: Power limited only by load capacity
  - At present space constraints limit size and power capacity of the RF load

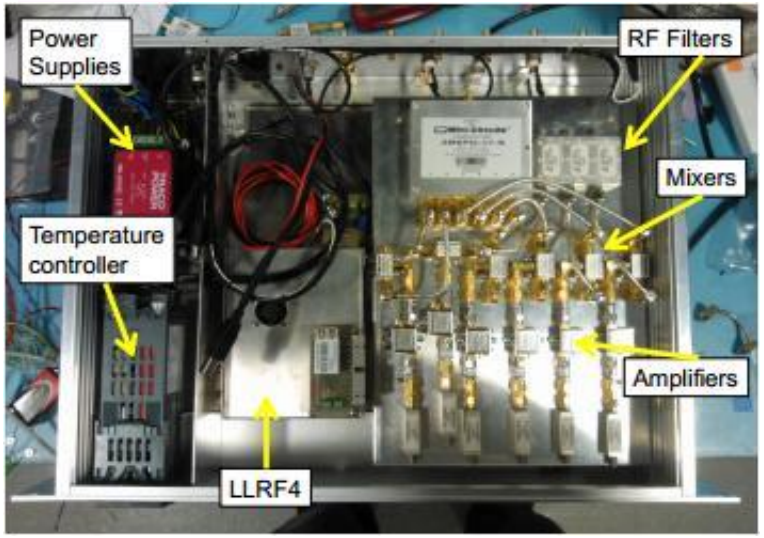



Triode Performance
-531kW output RF
-22kV bias voltage
-Gain 10.8dB
-Input port return loss 11dB
-Drive from Tetrode 44kW

# LLRF development




- Exploits two LLRF4 boards from LBNL – now purchased
- Agreements with LBNL established to develop system
- Basic design of hardware and software is done
- Daresbury have tested all major features, including the feed-forward control system on a recent 1.3GHz system (separate project)
- Design remains fundamentally unchanged
  - Hardware and software can be applied to MICE 201.25MHz
  - Requires straightforward modification of the analogue system
  - Can be achieved in ~ 3 months
  - Systems in use already with EPICS control
  - Prior to cavities arriving, can build cavity simulator
    - Allows testing of the timing diagnostic

# Summary

- High Power Drivers
  - Have achieved specification on system No.1, 2MW for 1ms at 1Hz and 201.25MHz
  - Installation of system No.1 at RAL complete
    - Tested to 500kW (limit of reject loads) in December
    - Meets TIARA deliverable requirement
    - TIARA reports submitted: Opportunity for Newsletter article
- Major procurement effort complete
  - Vast majority of components required for distribution network
  - Many components required for amplifiers and LLRF work

# Immediate Future

- Commissioning of systems No.2-4 (2nd tetrode cavity already tested to 250kW)
- Testing continuing at RAL and shortly to resume at Daresbury
- Upgrade PSU's for remote control
  - PSU's will return to Daresbury in early spring for upgrade from HT circuit prototype to 'production ready' prototype
  - Will be used to test the second amplifier system
    - Reduces the number of 'new' elements in the system
    - Makes fault finding faster and hence commissioning more efficient