RF Power and Distribution

The MICE RF team

Requirements of the MICE HPRF system

- Driver system must provide 1MW to each cavity (500kW on each coupler) at 201.25MHz

  - Provide required energy with two 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
    - Tim Stanley will describe the installation and test at RAL

  - Distribution network must not impede service access to cooling channel

  - Proposed LLRF phase control of 0.5° with 1% in amplitude regulation

  - Require phase correlation of RF with Muons:
    - Alex Dick will discuss some aspects of the diagnostic

High Power Driver System

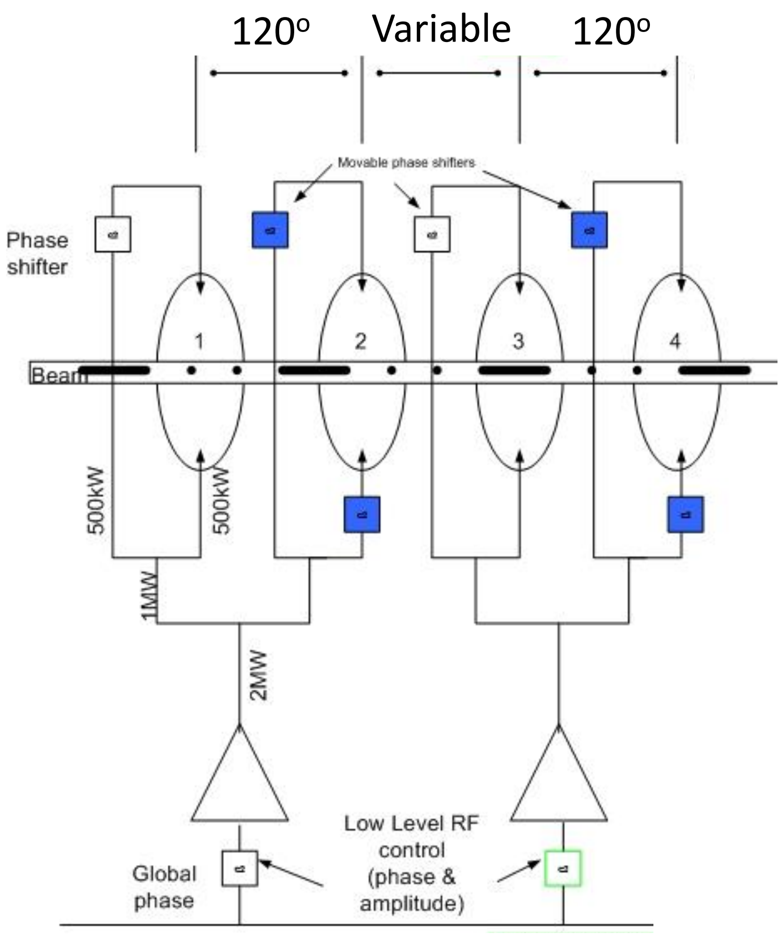
- The RF cavities are to be driven in adjacent, coupled pairs with a fixed phase angle between coupled pairs

- 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)

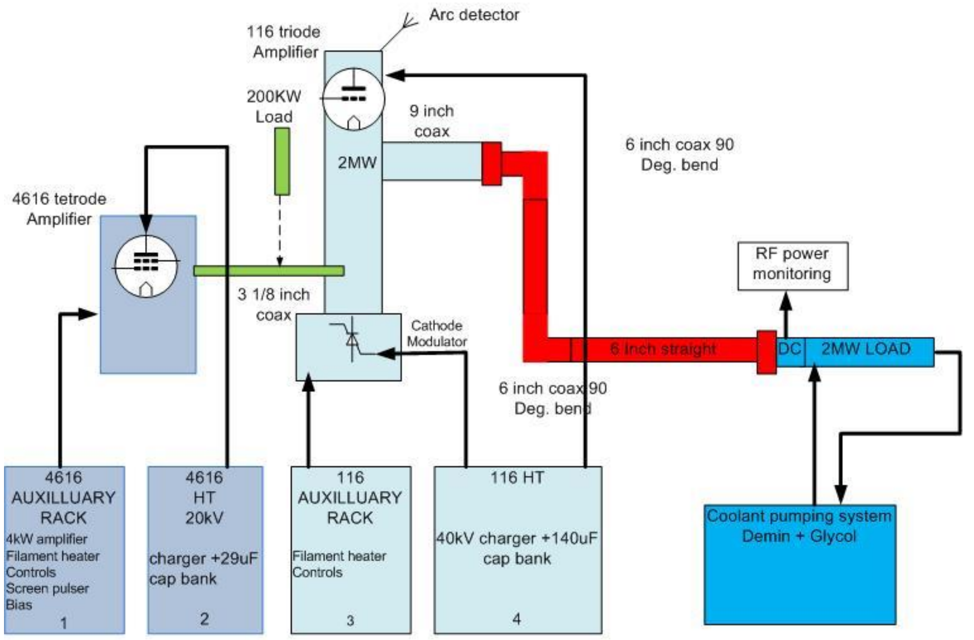
- Each vacuum amplifier system has an HT pulsed power system, auxiliary controls and power supplies for heater operation

- The first amplifier has been rebuilt and the first set of power supplies built at Daresbury
  - The amplifier and PSU was subject to tests at Daresbury
  - Check that it could develop the required peak power at required duty

Schematic of MICE RF Drive System



RF amplifier proving stand



Daresbury test setup for proving amplifiers/power supplies

Amplifier Testing

- The MICE triode tubes are nearly irreplaceable
  - Testing therefore commenced using old tubes no longer suitable for ISIS

- Tetrode amplifier commissioned first (also with old tube)

- Triode amplifier tests commenced once tetrode commissioned
  - As triodes can oscillate, tetrode drive is brought on first
  - Tests proceeded by
    - Incrementally raising the bias voltage on the triode,
    - bringing up the input drive until triode gain fell to 10dB
  - With old ex-ISIS tube 1MW was achieved at 1ms and 1Hz

- Switching to new MICE tube, power was raised to 1.2MW
  - Increasing the bias voltage further resulted in a crowbar event- which in turn flashed the main dump resistors
  - This damaged the crowbar switch (a thyratron) in a strange way
    - The switch would hold DC voltage
    - But was hypersensitive to the operation of the cathode modulator
  - It became impossible to apply more than 20kV and expect stable operation

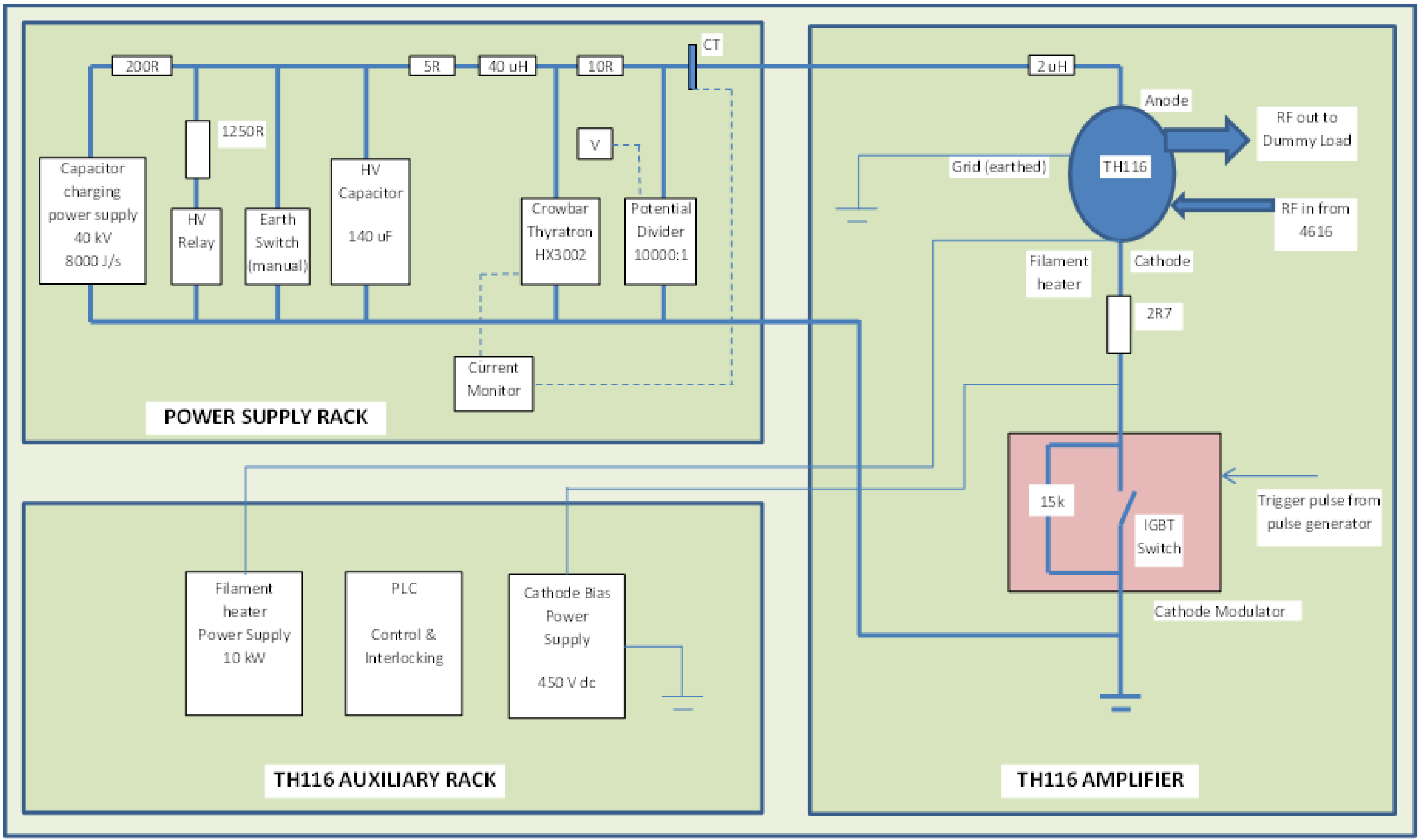
Amplifier Testing

- Since the thyratron held DC bias to 38kV, and triggered effectively, it was initially discounted as the fault

- Focus instead fell on
  - the thyratron trigger unit and the current sensing electronics
  - The triode valve itself- seating issues resolved and valve swapped back to old unit

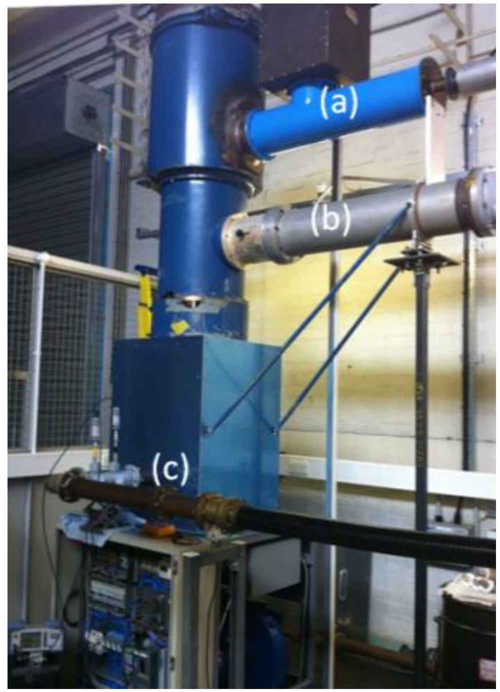
- Some issues were found and corrected, but these were not affecting the performance
  - Attention returned to the thyratron 'after eliminating the impossible….etc'
  - The energy storage in the triode capacitors is rather extreme- it needs a rather extreme switch
  - e2v technologies loaned us a prototype thyratron
    - Problem immediately cured
    - Outstanding support from e2v is much appreciated and vital to success
    - Stable operation at required bias voltage & capacitance possible
    - Allowed correct tuning of amplifier to be realised

Triode Circuit



Demonstration of required RF signal

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

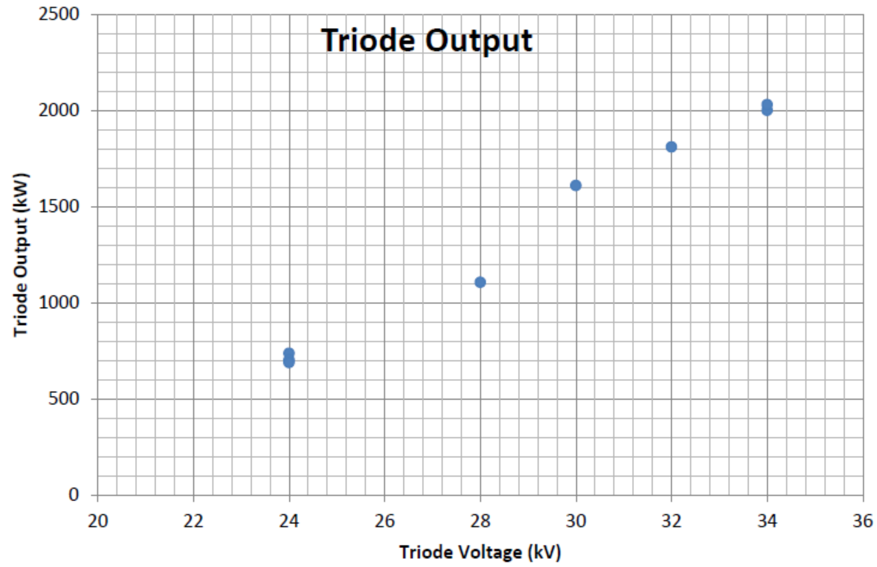


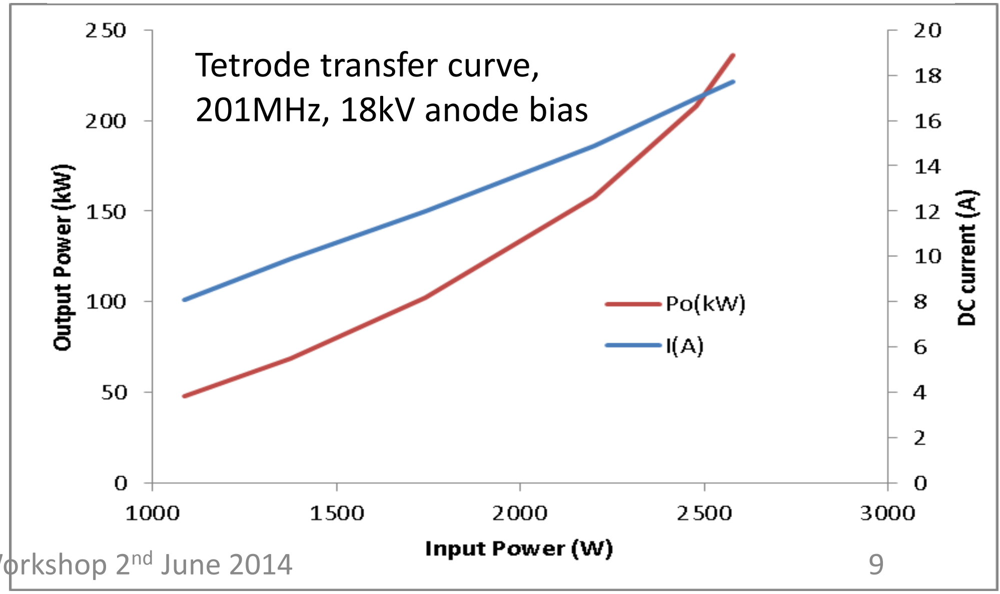
a) HT feedline,
b) Output 9 inch coaxial line,
c) Input 3 inch line

- 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 a team required to operate the system at MICE

High Power Driver System

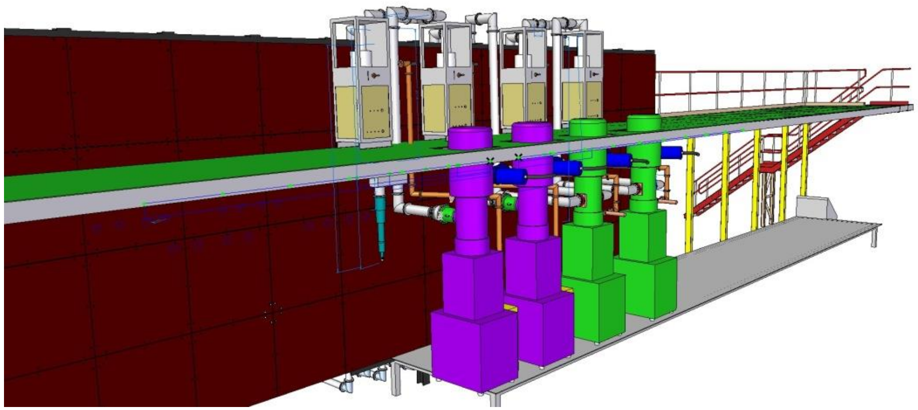
- Triode DC bias and drive brought up together
  - Maintaining ~10dB gain
- Performance achieved:
  - 2.06MW output RF
  - 34kV bias voltage
  - 129A forward average current
  - η=46% (electronic)
  - Gain 10.8dB
  - Input port return loss -12.5dB
    - VSWR 1.6
- Drive from Tetrode
  - 170kW output 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



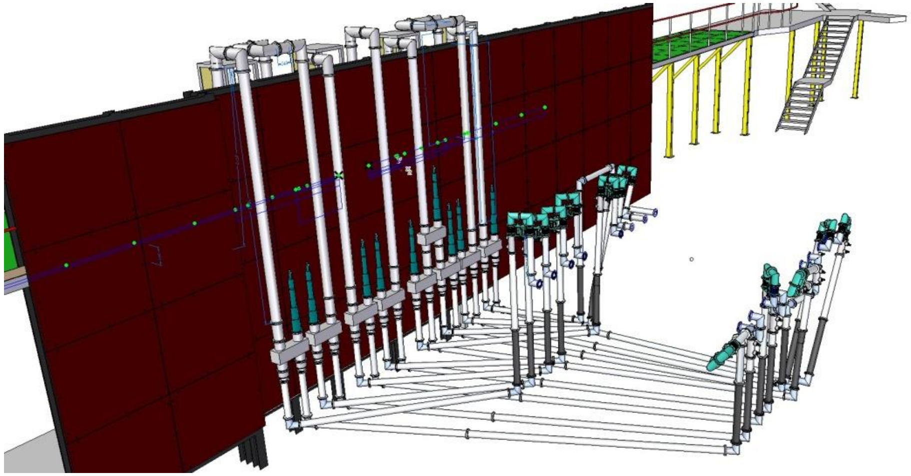


Distribution network

Amplifiers behind Shield Wall



Distribution Network to MICE

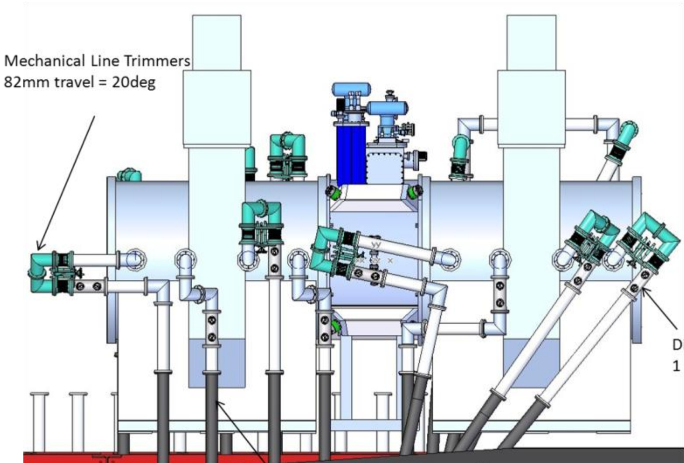


- Amplifiers installed behind shield wall
  - Triodes on main floor, Tetrodes on Mezzanine
  - Impact of B-fields negated by yoke
  - High power dynamic phase shifters removed
- 4 off 6 inch coax lines over wall
  - Pressurised to increase power handling
- Hybrid splitters moved - more accessible
  - 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 around cavities

Line Trimmer Arrangement to South Side RF Couplers

Mechanical Line Trimmers
82mm travel = 20deg



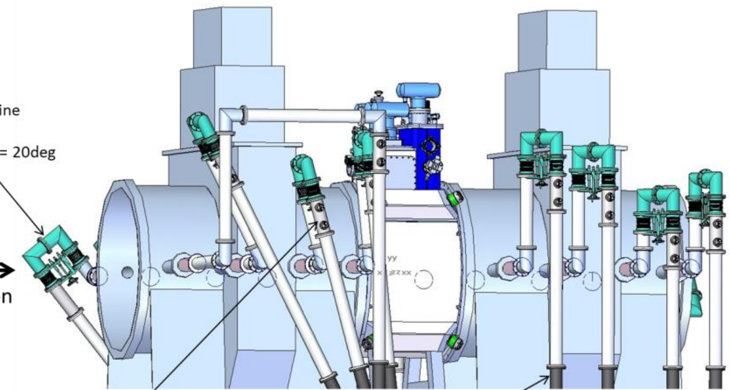
Beam Direction

Direction Coupler -
1 to each Coupler

4” Flexible coax for
any mis-alignment

Mechanical Line
Trimmers
82mm travel = 20deg

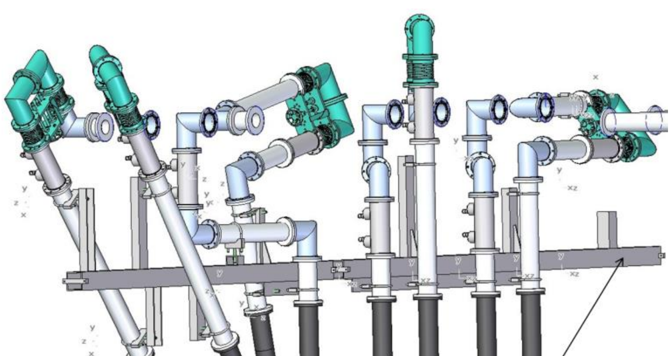
Beam Direction



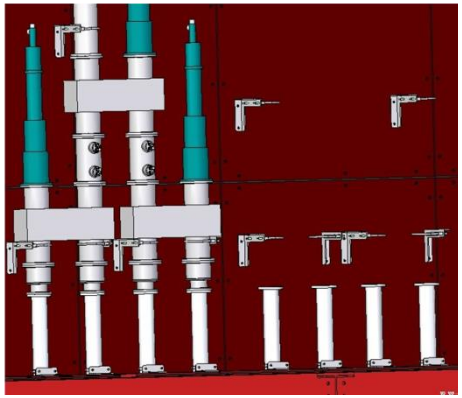
Direction Coupler -
1 to each Coupler

4” Flexible coax for
any mis-alignment

Common bracket & clamp design for
coax and hybrid splitter support
On shield wall

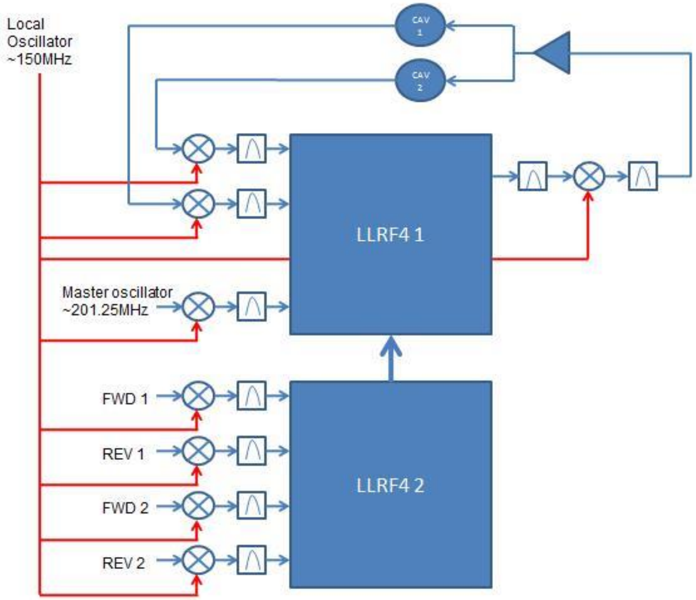


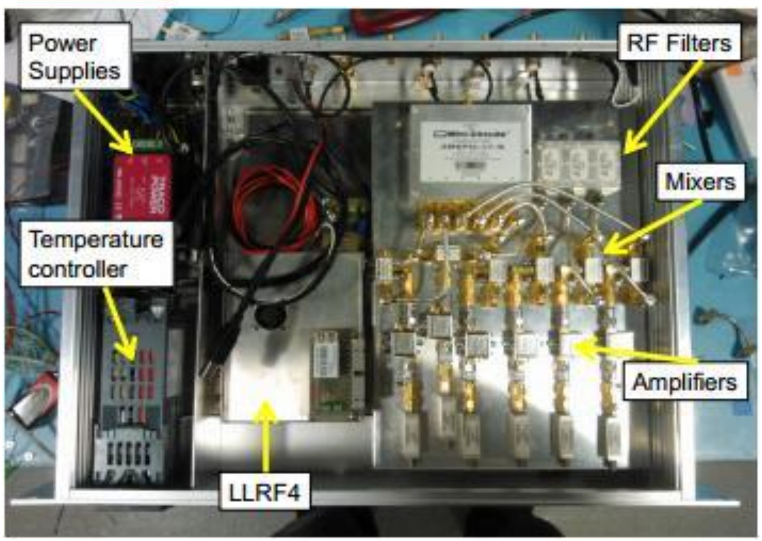
Support frame fixed to South Mezzanine support structure
Coax fixed (2 positions) to relieve stress on cavity couplers



2 off Unistrut frames for coax support
RFCC’s - North side

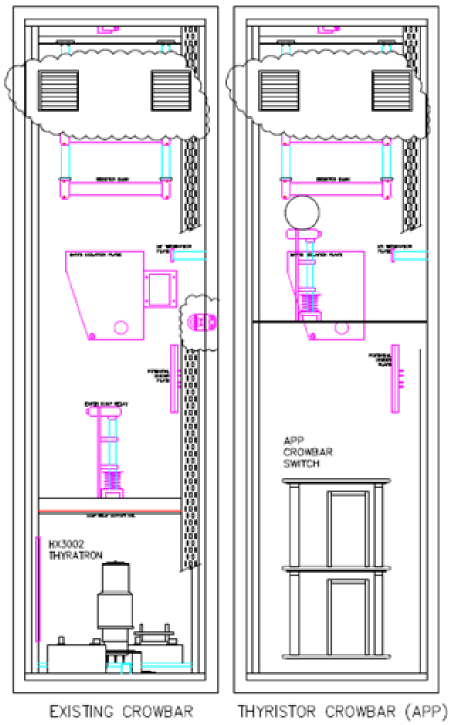
LLRF development





- Exploits two LLRF4 boards from LBNL – now purchased (through U. Mississippi & NSF/MRI)
- Agreements with LBNL established to develop system
- Basic design of hardware and software is done
- Daresbury have tested all major features, including the power ramp control 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
        - First system now working at 201MHz
        - Synergy with ISIS requirement

Power Supply Development 1: New Crowbar



- Switch to solid state APP thyristor crowbar
  - Extra headroom, rated to 40+ kV
- Can be installed in place of smaller Thyratron
  - Needs some limited re-arrangement of HT racks
- Two have been delivered and one is being tested now
  - Has switched entire main capacitor
  - Discharges stored energy in ~µsec's

Power Supply Development 2: Automation

- Install automation gear into power supplies
  - Required before the amplifier can drive cavities
    - Cavities (and therefore X-rays) are colocated with the amplifiers and PSU's
  - Will enable the system to be brought to operation from the control room
    - Pierrick Hanlet will discuss controls later

- Commissioning tests revealed a number of interesting points
  - One needs to have readouts for the input tuning of the triode amplifiers
  - Remote drive is installed for the input triode stub tuners, but not for the output (nor the output tuner of the tetrode)
    - Triode input tuning appears not to be very sensitive at high beam current levels
    - Tetrode output tuning is important and varies with triode bias condition: should be provided with remote control and monitoring.

- The upgraded power supplies will be commissioned (electrical effort permitting) this project year
  - As part of the commissioning of amplifier no. 2

Questions?

- Some questions that we can perhaps answer, or start to answer, this week?

- Single Cavity tests at RAL
  - Proposal that original prototype cavity could be used for near 'full system tests' are being considered
  - Possibly in parallel with STEP IV running
    - Use fallow periods to prepare for STEP V
  - Need to understand exactly what will need to be done to get cavity operational
    - Need to define costs and resources required
    - Need to understand space requirements and possible conflicts with other priorities
    - Can experience of FNAL/LBNL with these cavities inform this?

- RFCC commissioning
  - Can we start to define the effort and costs to commission the RFCC module (from an RF perspective)

- A real time domain trace from the cavity pickup antenna to run through some of the phase determination routines

- X-ray shields required for MICE hall?

Test Plans: Single Cavity Option at RAL and RFCC

- Need to define steps to commission each system- below is my top level guess
  - This week will probably show how much is missing
- Need to define resources required at each step

Single Cavity (ex MTA Prototype)

- Repair Coupler(s)?
  - Where? What?
- Define X-ray shields
- Install lines
- Develop LLRF to lock driver to cavity freq
- Develop controls/monitoring/diagnostics
  - Install controls etc
- Prepare Vacuum system
- Assemble cavity, vacuum pumps, couplers
- Low Power RF Tests
- Pump cavity, bake cavity (quality reqd?)
- Condition cavity (couplers)
  - Test amplifiers with reactive load
  - Test LLRF power ramp capability
  - Test control and monitoring systems
- Operate at high gradient

RFCC Linac

- Define X-ray shields
- Install lines
- Develop LLRF to control cavity freq
- Develop controls/monitoring/diagnostics
  - Install controls etc
- Prepare Vacuum system
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  - Test amplifiers with reactive load
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- Operate at high gradient

Summary

- High Power Drivers
  - Have achieved specification on system No.1, 2MW for 1ms at 1Hz and 201.25MHz
  - Principle problem surrounded a major switch which developed a far from obvious fault condition (due to prior resistor fault)
  - Once power supply matter had been resolved, amplifier testing proceeded smoothly

- New upgraded crowbar switch being tested
- RF distribution network, design complete for STEP V
- Progress with the LLRF system

Immediate Future

- Commissioning of system No.2
- Testing will shortly resume at Daresbury
  - STEP IV resources demands permitting
- Upgrade PSU's for remote control
  - PSU's have returned to Daresbury 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

Speculative?

- Looking forward, with successful delivery of STEP V, is there more to be done?
  - In addition to the physics measurements?

- Possibility of an upgrade for MICE Step V

  - All four amplifiers drive into 4 cavities,
    - 2MW each cavity, ~12MV/m or 16MV/m with refrigeration of the cavities
    - Could allow off crest operation, would approach NF proposed gradient
    - Would require not in-significant effort and capital to complete amplifier chain
    - Needs to be justified by physics that could be explored

  - From Dan Kaplan's MICE summary at MAP meeting
    - Either refrigerate the cavities or use 4MW into one cavity to achieve 16MV/m
    - Understand the operation of 201MHz cavities in a near flat B-field profile
    - MICE may be best option for such a study when RFCC and focus coil arrive
      - After STEP V!
    - Would possibly need a slightly different LLRF control system

  - Both will require SF_6 in the line and revised distribution network