

## MICE RF SYSTEM

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### Abstract

The Muon Ionisation Cooling Experiment (MICE) at the Rutherford Appleton Laboratory uses normal conducting copper cavities to re-accelerate a muon beam after it has been retarded by liquid hydrogen absorbers. Each cavity operates at 200MHz and requires 1MW of RF power in a 1ms pulse at a repetition rate of 1Hz. In order to provide this power, a Thales TH116 triode, driven by a Burle 4616 tetrode is used, with each amplifier chain providing ~2.5MW. This power is then split between 2 cavities. The complete MICE RF system is described, including details of the low level RF, the power amplifiers and the coaxial power distribution system.

### INTRODUCTION

The development of a neutrino factory requires low emittance muon beams. An approach that could produce a low emittance muon beam is ionisation cooling. An experiment at Rutherford Appleton Laboratory (RAL) is being built to test this approach. The Muon Ionisation Cooling Experiment (MICE) consists of a cooling channel that accepts a muon beam generated by plunging a target into the proton beam on the RAL ISIS machine. The muon beam emittance is measured in the first detector of the experiment. The beam then enters an absorber where the beam emittance is reduced, RF cavities are used to restore the longitudinal momentum, the beam emittance is measured again at the end of the cooling channel. In practice there are three absorbers equipped with superconducting focus coils, these are interspaced with eight RF cavities. The cavities are constructed in two banks of four cavities that are immersed in a 2.5 tesla field generated by a superconducting magnet. An accelerating gradient of up to 8MV/m is possible across the cooling channel, with each cavity powered by 1 Mega Watt (MW) of RF power. A prototype cavity has been built; it has achieved its design goals on the MuCool Test Area (MTA) test stand at Fermilab. The task of the MICE experiment is to carry out the R&D necessary so that we can learn how to build and operate the cooling channel and achieve measurable results on an actual beam. The combination of liquid hydrogen absorbers, superconducting magnets and RF cavities all in very close proximity makes for many engineering challenges. The experience gained from this experimental demonstration will provide input to the final design of the cooling channel for the Neutrino Factory.

### System Oscillator

The master oscillator for MICE consists of an Analog Devices Direct Digital Synthesiser (DDS) to provide the 201MHz reference signal. This provides a flexible, programmable (control through EPICS) and very clean (extremely low phase noise) source that can be amplified and applied to the MICE cavity's. A Wenzel Associates

Sprinter oscillator operating at 100MHz is used to provide the base reference for the system. This is multiplied to 1GHz to provide a low phase noise system clock for the DDS oscillator. From this 1GHz clock we will use four DDS oscillators to provide 201MHz directly and have the feature to adjust the frequency and phase of each amplifier system in a synchronous manner. Timing for the RF pulses which trigger various power supplies and switch on RF drive signals will be driven from the first time of flight (TOF) detector in the experimental beam line.

### Low level RF control

For the low level RF control system, an evaluation board designed at LBNL by Larry Doolittle is being tested, see Fig 1. This digital based solution will receive inputs from two 201MHz RF cavity probe signals, perform vector sum calculations and then provide a controlling action on the input to the amplifier chain. Stability of <0.5% and <0.5 deg will be achieved using this system. The ADC's used on the four inputs to the board are Linear Technology LTC2254 14 bit ADC's, which are rated to 105 MS/s sampling speed. The field programmable gate array (FPGA) where the software is operating is the XC3S1000-5FT256C from zilinx. The board can be programmed as a standard cavity controller with probe, amplifier forward and reverse RF signals or as a vector sum system controlling up to eight cavities from one amplifier.

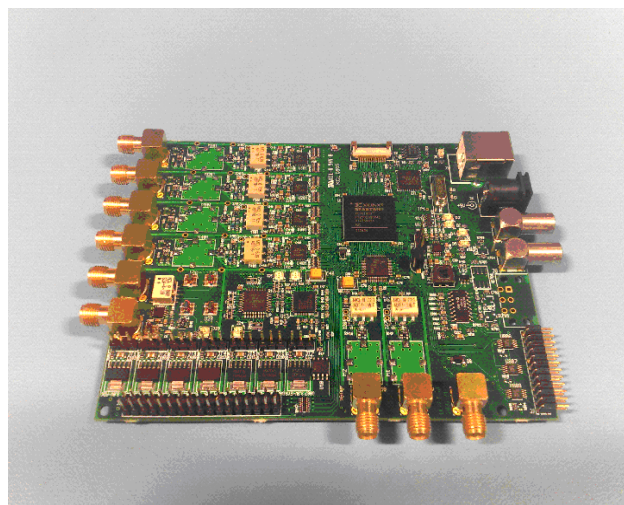


Figure 1: LLRF4 digital control board

### Daresbury test area

A test area is under construction at Daresbury Laboratory (DL) to test all the components and power supplies necessary for this amplifier chain. The paper MOPD028 at this conference, details the construction of power supplies and testing of these amplifiers. The test

area was conceived to provide method of proving the individual amplifiers and power supplies as they are completed. Each power supply or amplifier can be installed in the system and be commissioned. The amplifier systems will then be installed at RAL during 2009 in the experimental hall.

The tube amplifiers have been reclaimed from various national laboratories. The three medium power 4616 tetrode circuits and two of the 116 triode circuits originally had service at LBNL. CERN has contributed a further two 116 circuits after extensive rebuilding, they are due to arrive at DL during the summer of 2008. The further needed medium power amplifier is yet to be found but can be bought new from Burle.

### *Medium power amplifier system*

The amplifier system consists of both solid state amplifiers and triode systems to amplify the RF to the power level of 1MW per cavity.

A Dressler solid state amplifier (SSA) is used with an input level of 1mW, the output of 4kW is taken to a medium power tetrode amplifier (Burle 4616 tube). The 18 kV HT and auxiliary control power supplies for this tube are copies of the systems used on the RAL ISIS linac, this provided us with a known workable system and accelerated the design progress considerably. The tetrode can produce up to 250kW of power. We have tested this system with a used tube at 170kW with a 1mSec 1Hz pulse regime, see Fig 2, the amplifier was tested into a dummy load on loan from CERN. This proved that the basic system for operating the valve is sound.



Figure 2: Burle 4616 Tetrode amplifier

The output is then fed using 3 1/8 inch rigid coax via a rotary switch, which will be switched to a dummy load during amplifier tuning. The coax then continues to the high power amplifier,

### *High power amplifier systems*

The high power amplifiers consist of a Thales TH116 triode mounted inside a coaxial circuit. These are old systems (~1950's) and require total refurbishment all cases. New systems were investigated but the cost was prohibitive for the MICE experiment and it was decided to re use old equipment for the purpose of the experiment

Currently one amplifier is being rebuilt at DL after a total strip down and refurbishment. Another is waiting to be started and a further two systems have been completed at CERN see Figure 3.

Although the four high power amplifiers are very similar in their construction, the CERN amplifiers have been modified to run with two output taps in 6 1/8 inch coax whereas the LBNL amplifiers use a single capacitive 9 inch coaxial output.



Figure 3: Refurbished CERN amplifiers

The output from the TH116 circuit (up to 2 mega watts) is taken again using rigid coax, to feed the 201MHz normal conducting cavity.

The cavity has input couplers from both sides therefore the power to each cavity has to be split. Discussions are taking place as to the most appropriate device to use for this task. A matched 3db splitter offers a relatively small and cheap method, however a hybrid splitter with reject

load will offer slightly more isolation but increases the complexity of the system. In most applications of this sort, no account for reflected power is taken, simply relying on the triode valves resistant characteristics to keep the system operating into what is at the start of each pulse,

total reflection. The use of a coaxial trombone phase shifter to move reflected power standing waves is possible, but again these are physically large (3 meters) devices and it will be difficult to fit them into the MICE hall.

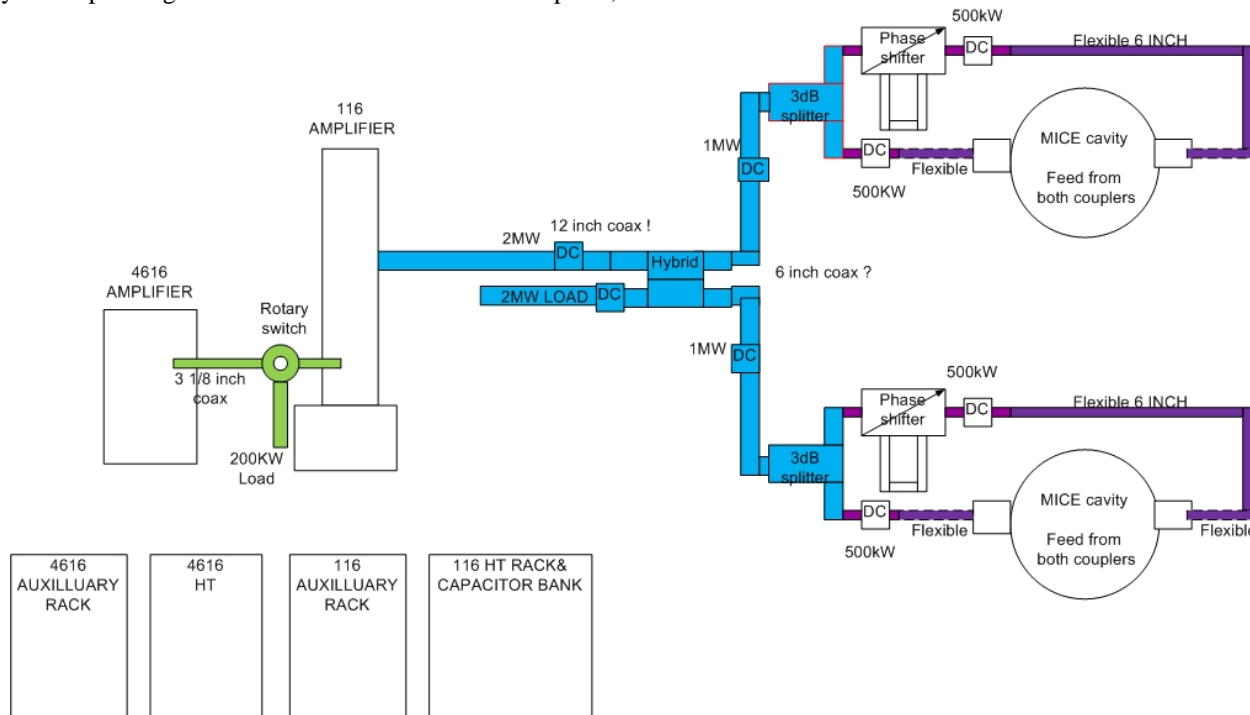


Figure 4: Components necessary for one complete MICE amplifier system

In practice each high power amplifier will feed 2 cavities to a power level of 1MW, see Figure 4. Space in the MICE hall is at a premium so the smaller the RF distribution system the better. It is likely that 6 1/8 inch coax will be used for distribution; this offer's the power handling capability required and when made of aluminium, is easy to handle.

Near the cavity it is likely we will use flexible coax to connect to the 4 inch cavity couplers, this offers the ability to take up positional errors.

The cavity couplers will require pressurising with nitrogen. This will provide two benefits, it will raise the breakdown voltage of the coupler itself and should part of the coupler break, site air should not enter the cavity itself only pressurised nitrogen.

*RF cavity*

The MICE RF cavity is based very closely on the MuCool cavity currently under test at the MTA at Fermilab. Only small dimension changes have been made to the design to raise the frequency and allow a better tuning range to be achieved. The cavity includes in its design beryllium windows in the cavity iris plates to raise the shunt impedance and provide maximum acceleration of the muon beam. The cavity has a Q0 of 53,000 and a

shunt impedance of 22MOhm/m. The cavity couplers are the same type as used on the SNS using Toshiba made windows.

With the power available, the modules should be able to produce ~ 8MV/m for the experiment based on 1MW input for each cavity.

**CONCLUSION AND OUTLOOK**

The Mice RF system design is being formulated, Aided by the test area at DL, amplifiers and power supplies can be tested to provide input into the final component and system design for the MICE hall at RAL. Some areas are well understood, the power supplies for example, whereas the final layout and type of components used in the high power coax system has still to be finalised.

**REFERENCES**

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 [2] Derun Li, "201 MHz Cavity R&D for MUCOOL and MICE", EPAC'06, Edinburgh, June 2006, TUPCH148, <http://www.JACoW.org>.