RADIO FREQUENCY POWER SOURCES FOR THE MUON IONISATION COOLING EXPERIMENT

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Abstract

For any future Neutrino Factory the accelerator aperture will be a major cost driver. Potentially the aperture can be reduced and significant capital savings made if ionisation cooling is utilised on the muon beam. In order to demonstrate the effectiveness of ionisation cooling a demonstrator needs to be built and operated. MICE, the Muon Ionisation Cooling Experiment is that demonstrator. The RF requirements of MICE will be met using high power vacuum tube based RF circuits donated by LBNL and CERN. This paper will discuss these circuits, their refurbishment, the construction of HT power supplies and ancillary equipment and high power testing.

INTRODUCTION

Ionisation cooling is the process by which a particle beam is passed through a material medium (absorber) and individual particles lose energy (momentum) through ionisation interactions. The particle beam is then accelerated longitudinally using RF cavities. As the particles are losing both transverse and longitudinal momentum, but the RF cavities are only replacing the longitudinal momentum this results in an overall reduction in the particle beam emittance.

The MICE experiment consists of three liquid hydrogen absorbers and eight RF accelerating cavities. Detectors and tracking devices before and after the cooling channel are used to measure the effectiveness of the ionisation cooling process (see Figure 1).

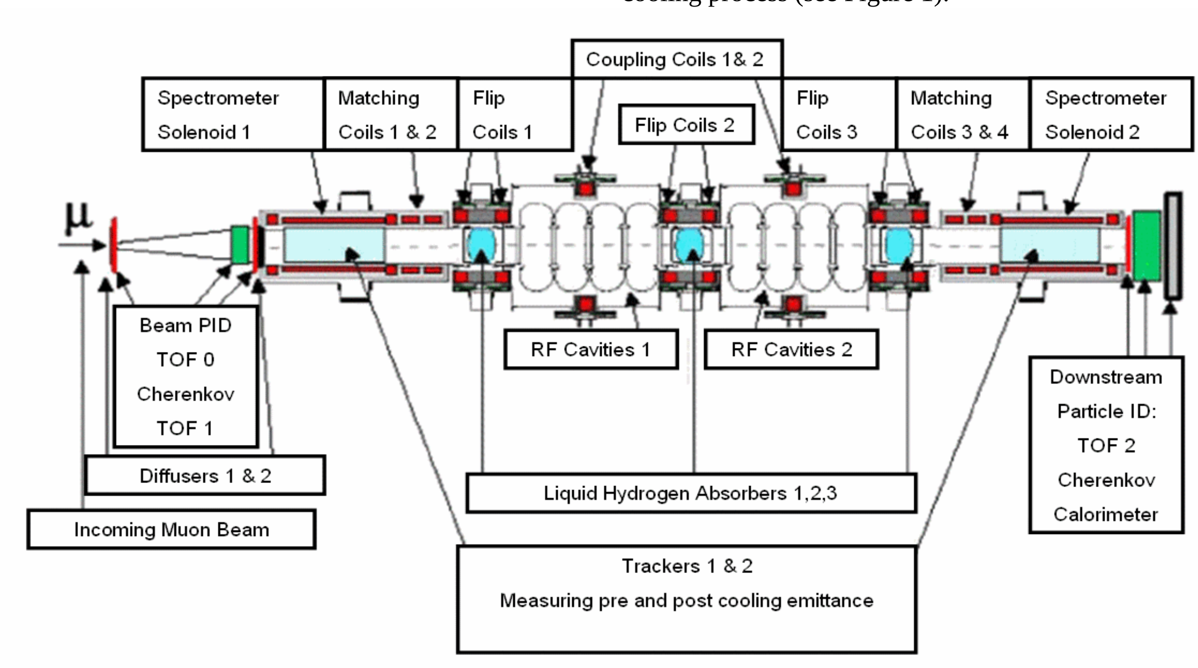

Figure 1: MICE Cooling Channel

MICE RF REQUIREMENTS

MICE will operate at 201 MHz, 1ms pulse width at 1 Hz and require RF power levels of ~ 1 MW per cavity to produce a measurable amount of cooling. Peak power levels of this magnitude, in this frequency band require conventional high power vacuum tube technology, triodes and tetrodes. Four chains of three amplifiers will each produce a final stage RF pulse power level of ~ 2.5 MW. This will be split using a 3 dB hybrid or coaxial matched Tee to deliver ~ 1 MW of RF power to each cavity. Figure 2 shows the following RF amplifier stages that will be used;

Pre amp: A Dressler 4 kW, solid state amplifier will be operated at ~ 2.5 kW nominal output power,
Drive amp: A Burle 4616 tetrode, will be operated at ~ 250 kW nominal output power.
Main amp: A Thales TH116 triode, will be operated at ~ 2.5 MW nominal output power

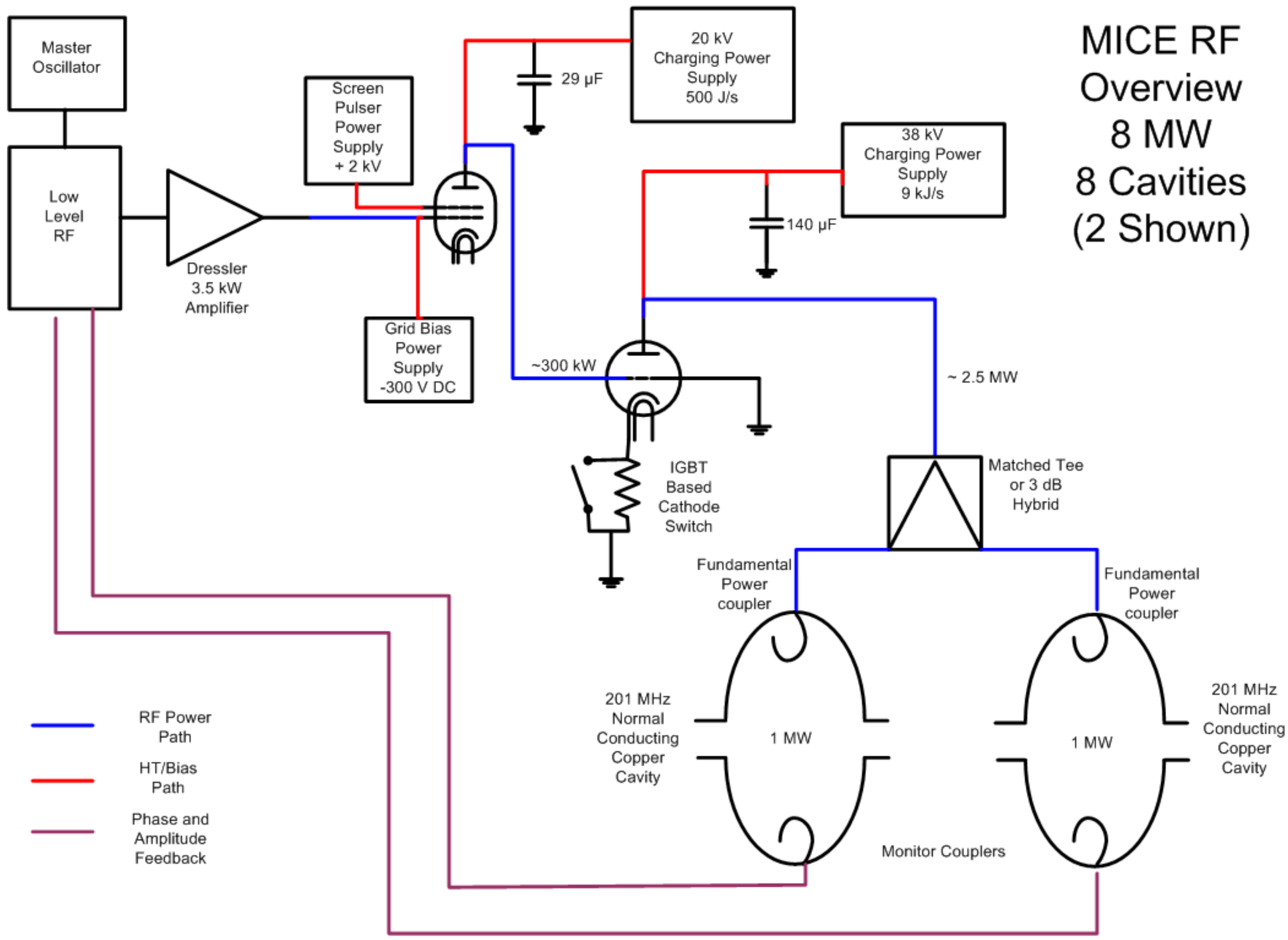

Figure 2: MICE RF System (2 Cavities Shown).

Three Burle 4616 intermediate power RF circuits and two high power Thales TH116 circuits have been donated by Lawrence Berkeley National Laboratory (LBNL) for refurbishment at Daresbury Laboratory (DL) (see Figure 3).

Figure 3: LBNL 4616 and TH116 RF Circuits

CERN are presently refurbishing two more TH116 circuits which should be delivered to DL in July 2008.

Burle 4616 Circuit

The Burle 4616 is a high power vacuum tube which operates in pulse mode at frequencies of 195-600 MHz. The 4616 RF circuit comprises tuneable input and output RF cavities and is operated at 20 kV anode voltage, 201 MHz, 1 ms pulse width at 1 Hz pulse repetition frequency (PRF). To operate this tube in pulse mode the grid is held at a DC voltage of 250 V negative with respect to (wrt) the cathode. This, in effect, biases off the tube. Pulsing the screen grid 2 kV positive wrt the cathode brings the tube into conduction for the duration of the pulse.

The first 4616 circuit has now been refurbished at DL and a high voltage power supply (HVPS) has been built by the DL Power Supplies Group. The HVPS consists of a 20 kV charging power supply feeding a 29 μF capacitor. Due to the relatively low duty factor a modest charging power 500 Js^{-1} can be used. However a considerable amount of capacitance is required (29 μF) to reduce HT droop across the pulse. This capacitance has a stored energy of 5.8 kJ and to protect the tube an ignitron based Crowbar has been incorporated into the HVPS (see Figure 4). A 2 kV pulsed power supply has also been built to pulse the tube using the screen grid and a -300V supply to bias the control grid.

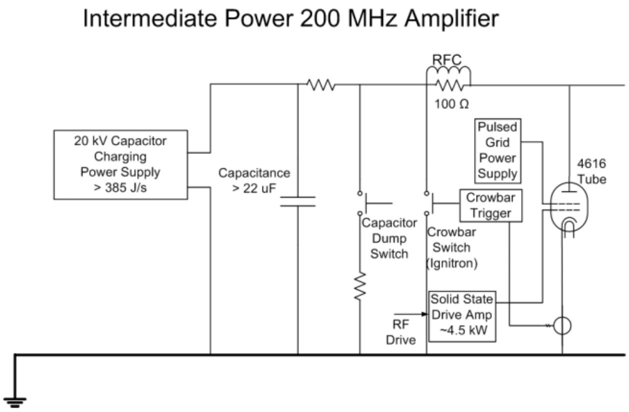

Figure 4: 4616 Power Supplies and Crowbar

Thales TH116 Circuit

The TH116 is a high power triode which operates in pulse mode with 5 MW peak power at up to 200 MHz. The operation of the tube for MICE will be similar to the 4616 tube. A 9 kJs^{-1} power supply will charge a 140 μF capacitor bank which supplies the ~ 40 kV HT to the tube. Pulsing will differ from the 4616, as the TH116 is a triode and so screen grid pulsing is not an option. When last operated at LBNL on the Bevatron the control grid was pulsed to bring the tube into conduction. However when the TH116 circuits are refurbished it is planned to replace the grid pulsing system with a simpler and more efficient cathode switch. The cathode switch is in essence a high value (15kΩ) resistor in parallel with an insulated grid bipolar transistor (IGBT) based switch. When the IGBT is open any anode current will give a volts drop across the cathode resistor and this will self bias the tube off. During the pulse the IGBT will close, giving a low resistance path and allowing the tube to fully conduct. A thyristor or thyratron based Crowbar (see Figure 5) will be used to protect the tube from the capacitor banks high stored energy (112kJ).

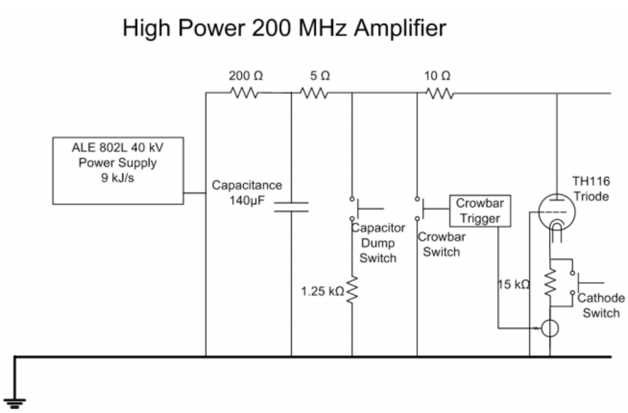

Figure 5: TH116 Power Supplies and Crowbar

MICE RF STATUS

The 4616 circuits required relatively little refurbishment, apart from replacement of ageing hoses and electrical cabling. The refurbishment of the first 4616 circuit has now been completed and its HVPS, Grid Power Supply, Screen Pulser, Crowbar and all other necessary ancillary equipment has been fabricated or procured.

The TH116 circuits were in a far more dilapidated condition;. RF surfaces were pitted, fingerstock was damaged and the cavity tuning mechanisms were seized. The first circuit has been completely stripped down and cleaned, damaged components replaced and all RF surfaces have been silver plated. The hand wheel operated tuning mechanisms have all been replaced with motors to enable remote tuning capability.

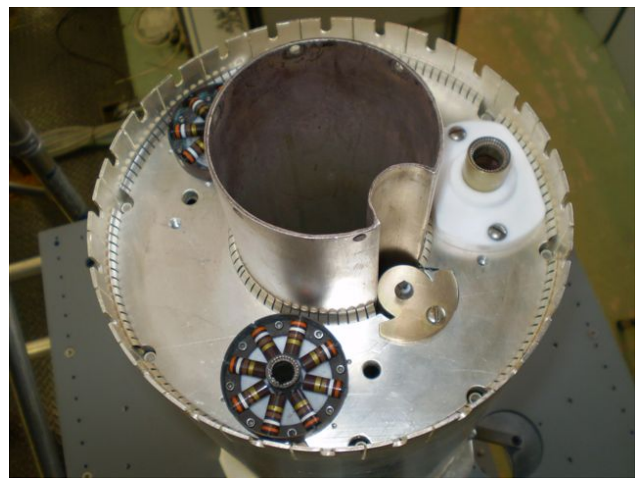

Figure 6: Input Cavity Tuning Annulus after Silver Plating and replacement of Fingerstock

Testing

The first 4616 circuit has now been successfully tested, this was carried out using the old 4616 tube which was in circuit when the equipment arrived from LBNL. This had not been in service for many years and little or no output power was expected. Surprisingly, 170 kW was eventually squeezed from the geriatric tetrode. The tube displayed a gain of up to 18 dB, unfortunately accurate efficiency measurements were impossible as the beam current monitoring was heavily corrupted by RF interference. Filtering will be used in future testing.

The first TH116 circuit is due to be rebuilt and tested later this year.

CONCLUSION

Despite severe constraints on manpower, Daresbury Laboratory is successfully achieving a cost effective solution to achieving the MICE RF requirements.