Report on RF system layout and requirements

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Background

This document sets out to discuss key design areas of the high power RF system for the MICE experiment at RAL. A design review will take place of the actual RF transmission components between the amplifiers and the MICE cavities, before procurement of the coax system can take place. Coax components at 200MHz are large, space in the MICE hall is at a premium and so careful consideration needs to be made as to what is needed for the experiment to run reliably and efficiently while still providing the required flexibility.

Amplifier systems

The amplifier system for MICE consists of a 4kW solid state amplifier, a Burle 4616 tetrode amplifier capable of delivering 250kW and TH116 amplifier system capable of delivering 2MW at 201 MHz. In some cases the amplifiers are in need of considerable refurbishment, the first set of amplifiers and power supplies are currently on test at Daresbury Laboratory (DL) and a power level of 1MW has been reached using old tubes. The plan is to refurbish each amplifier, test it in the system at DL, build up more power supplies and prove them at DL before the systems are transferred to the MICE hall at Rutherford Appleton Laboratory.

Figure 1: 116 amplifier operating at 1MW, no x-rays or microwave radiation detected

High power Coax components
The mice cavities need to be powered by couplers mounted horizontally on either side of the each cavity to a level of 1MW, each amplifier will power two cavities, therefore a power split is required. Hybrid splitters will be used as they provide greater isolation over the simpler 3dB splitter that could be used; the hybrid will provide the best possible isolation for the driving amplifier and the cavity couplers themselves. The expected coax layout for the Berkeley amplifier is shown in Figure 2.

**Figure 2:** general arrangement of Berkeley amplifier and high power distribution system

The arrangement for the CERN amplifiers (Figure 3) is similar; however as a power split is provided by the amplifier itself, one hybrid can be omitted. High power loads are used on the reject port of the hybrid to partially absorb reflected power, however in phase reflected power from the cavity (during RF filling for example) will be passed back towards the driving amplifier, this is not expected to be a problem as triode valves are very tolerant of such conditions.

Direction couplers will be included in coax to measure forward and reflected power throughout the distribution system, these will be interlocked to the RF control system to provide warnings and ultimately remove power from the system if it becomes necessary.

**Figure 3:** General arrangement of CERN amplifier and its distribution system
**Coax power**

The aim of the RF system is to provide up to 1MW of power in each of the 8 cavities. The coax system has been carefully designed to minimise the number of components that cause loss in the system. No flexible coax has been included in the design, likewise the number of 90 degree bends has been minimised to reduce as far as possible bad match conditions throughout the guide. However this will still require the amplifier to produce in excess of 2MW at its output. An identical CERN amplifier has been tested at 88MHz and has shown that the amplifier is capable of up to 2.6MW of output power; however this is limited by arcing in the amplifier tank and in the 6 inch output coax. See CERN report CERN-AB-2006-025.

The output from the Berkeley amplifier is via a capacitor through 9 inch coax. The will be reduced to 6 inch coax and a gas pressure window will be used to pressurise the guide system with 2 Bar of nitrogen. This will allow am increased voltage standoff capability of 1. The CERN amplifier has two output taps that connect to 6 inch coax, again gas windows will be used to fill the coax with nitrogen to promote a higher peak voltage standoff. When the power is split for each cavity, the coax size will be reduced to 4 inch as a maximum power of 500kW per guide is required, and this will aid physical installation in the very tight confines of the MICE hall, the 4 inch coax will be pressurized all the way to the cavity including the cavity couplers with nitrogen. SF6 will be considered at a later date if the MICE experiment is required to operate at higher peak RF power; however this will require a substantial reworking of the coax system, and should be considered as a separate project.

CAD drawings have been produced; see Figures 4, 5, 6 to optimise the layout within the MICE hall. During this process the lengths of each cavity coax system have been constructed so that power will add inside the cavity, this is to say that the incoming coupler power from each side of the cavity will add in voltage inside the cavity. A small phase optimisation will be possible to take up any installation errors using coax phase shifters (see next section).
Fig 5. Coax distribution to the MICE cavities

Fig 6. Coax distribution to cavity couplers
Cavity Phase Control

Simulations of time of flight through MICE cavity system for 140-240 MeV/c have been calculated and checked by MICE physicists. Results can be seen below Fig 7. Cavity phase relationship needs to change to maintain acceleration. This will be achieved using combinations of the low level RF control (LLRF) (green boxes in figure 8) which can adjust phase before each amplifier system, and for the second cavity on each amplifier (cavity 2, 4, 6 and 8) we need to move the phase in the high power coax. Local motorised phase shifters will be used to meet this requirement (blue boxes in figure 8); these are shown in the current design as U bend bellows devices that are regularly used in RF transmitter distribution to alter phase length at modest regularity. However alternative ferrite devices could be used to provide greater flexibility in terms of phase range and number of operations per day if required. Fig 8.

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t-0 for particle with p=240 MeV/c
t-1 for particle with p=140 MeV/c

Fig 7. Calculations of time of flight and phase change through the RF cavities

Fig 8. Phase adjustment of the amplifier and coax distribution system for different momenta of muon beam
Conclusion
The design of the MICE high power coax system has been shown. Most of the components have been identified and drawn using standard catalogue parts in the CAD package, with only the RF loads and high power phase shifters as potential special items. The phase length of each coax run has been optimised and care taken to reduce losses in the system so that the maximum power can be transferred from the amplifier system to the muon beam. Cavity phasing with respect to the muon beam has been calculated and understood, the resulting high power coax system is flexible enough to take up any small phase errors during the installation process.

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