

MICE High Power RF Design

This document sets out to discuss the design of the high power RF components for the MICE experiment at RAL.

The amplifiers are already chosen and in some cases ready for testing. A design review needs to take place of the actual RF transmission components between the amplifiers and the Mice cavities.

Coax components at 200MHz are large, space in the MICE hall is at a premium, so careful consideration needs to be done as to what is needed for the experiment to run reliably and efficiently.

Certain types of RF tubes, klystrons for example, can not operated with even modest reflected powers at their output windows, so devices that can soak up the reflected power are used in the output line of these devices, eg isolators and circulators, these devices offer very high isolation between the tube and the load. At 201Mhz however these devices become very large, in the case of the MICE hall, too large. However after research of other laboratories, reflected power seems not to be to such a problem for gridded tubes

Having sort the advice of people who use this type of triode amplifier, two differing views on how it can and should be connected to accelerating structures are found. Laboratories that use triodes to power LINAC structures, generally mount the tube amplifier close to the linac structure, a high power phase sifter is used to set the actual phase of each tank. Significantly, no attempt is made to limit the reflected power back to the tube, the coax section simple terminates at the input to the linac tank. It is generally accepted in this part of the community that the triode amplifier is very tolerant of reflected power and no methods are used to remove or protect the tube from this effect.

Experience at the MTA, where the prototype MICE cavity has already been tested, is that a hybrid should be used to split the power to the two arms of the MICE cavity. Also a high power phase shifter is put in the incoming line before the hybrid, to move the loading of the amplifier with respect to the reflected power from the cavity. This approach is backed up by experience at Brookhaven, they suggest this approach for MICE.

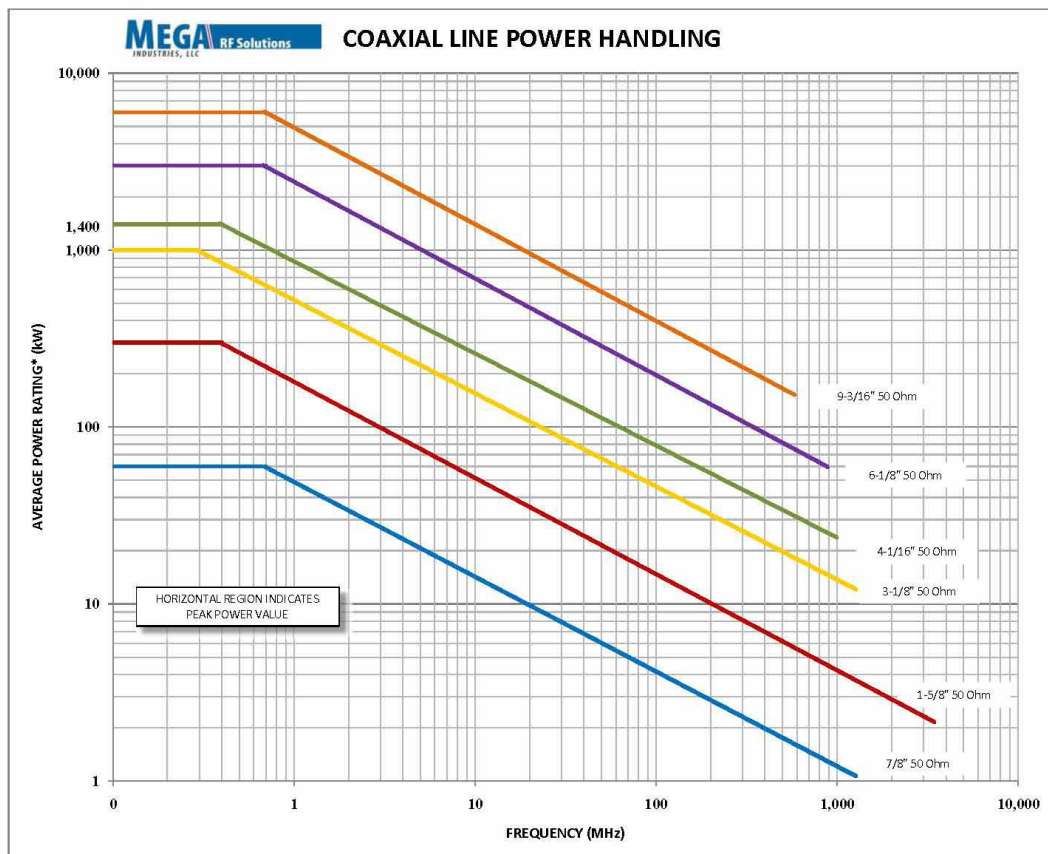
The question of reflected power affecting the driving tube plate currents and tube voltages needs to be understood... how will the design of the power supply combat this?

Hybrids are used to split the power and will provide a 30dB isolation between the outgoing ports of the device and hence the input couplers to the cavity. However when reflected power is sent back in phase, during the cavity filling for example, the hybrid will split the reflected power equally to both the incoming port and the load port. This means that half the driven power will be reflected back to the driving tube, and half will be absorbed in the hybrid load.

In order for the amplifier to supply 2 MICE cavities with 1MW of RF power, the amplifier output must be split in two. This will be done using a hybrid also, 3 db splitters could be used here, however the greater isolation of the hybrid means it is better suited to the task. The tuning and loading of one cavity is then isolated by 30dB to the other.

The output of the Berkeley amplifier is a single 9 inch coax, this will be split using a hybrid and reduced to 6 inch coax to enable smaller components for the ~1MW lines. This can then be split once more using a hybrid and reduced to 4 inch and 500Kw. However the peak voltage handling of these coax lines particularly under reflected power situations (at the beginning of each pulse) must be taken into consideration. It will be necessary to pressurise the entire 6 and 4 inch coax systems with SF6 to push the peak voltage handling characteristics into a safe zone.

The CERN amplifier has two 6 inch coax outputs. Tests at CERN have shown that the amplifier is capable of up to 2.6MW of output power, however this is limited by arcing in the tank and coax structures. See CERN report **CERN-AB-2006-025**. The 6 inch outputs will need to be split using hybrids to 4 inch for mating to the MICE cavity couplers. Again SF6 pressurisation will be needed to cope with reflected power pulses in the entire coax system. Using SF6 will mean adding gas stop windows to various parts of the coax line.



Mega Industries coax

A possible way to avoid using SF6 is to use the LLRF system to slow fill and slow empty the cavity. Normally the RF is switch on very quickly to get the cavity up to

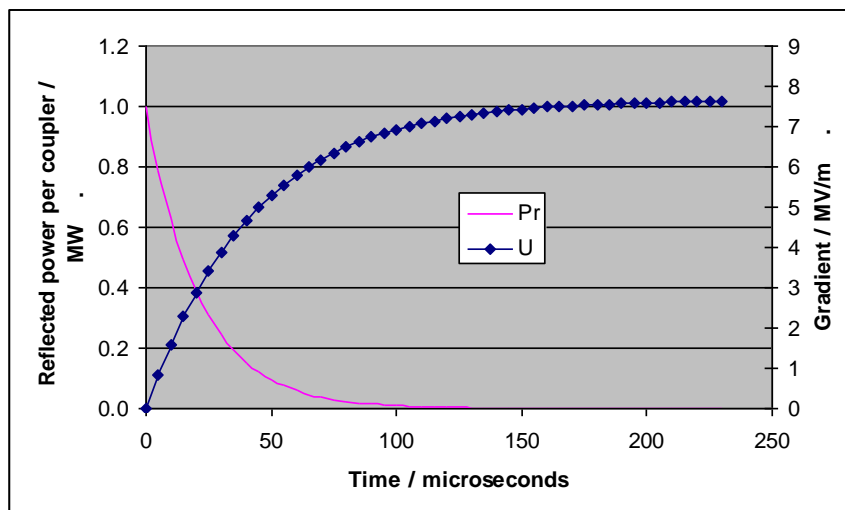
the field required as quickly as possible. It is possible to provide a more gradual switch on to get the cavity time to slow fill and avoid very high peak reflected powers. A similar possibility can be down at the end of the RF pulse, rather than simply switching off, a ramp down of the RF power could avoid high peak reflected powers. Whether this is approach is satisfactory in operation will need to be discussed. See paper TUP5A16 epac Vienna 2000

| LINE SIZE | Z _o | Production test voltage @ 20°C | RF Voltage Limit | Peak Power (watts) |
|-----------|----------------|--------------------------------|------------------|--------------------|
| 7/8' | 50 | 5825 | 1442 | 41600 |
| 1 5/8" | 50 | 10409 | 2576 | 132700 |
| 3 1/8" | 50 | 18971 | 4695 | 440900 |
| 4 1/16" | 50 | 24076 | 5959 | 710100 |
| 6 1/8" | 50 | 35411 | 8764 | 1536100 |
| 6 1/8" | 75 | 36179 | 8954 | 1069000 |
| 7 3/16" | 75 | 41788 | 10342 | 1426100 |
| 8 3/16" | 75 | 47273 | 11699 | 1825000 |
| 8 3/16" | 50 | 46460 | 11498 | 2644200 |
| 9 3/16" | 50 | 51879 | 12839 | 3296900 |
| 9 3/16" | 75 | 52730 | 13050 | 2270700 |
| 12' | 50 | 68336 | 16912 | 5720500 |

Peak power limits for coax from Myatt

Direction couplers will be used to measure forward and reflected power around the coax installation. Controls will ensure that unsafe levels of RF power are monitored, flagged and will trip the system off if dangerous levels occur.

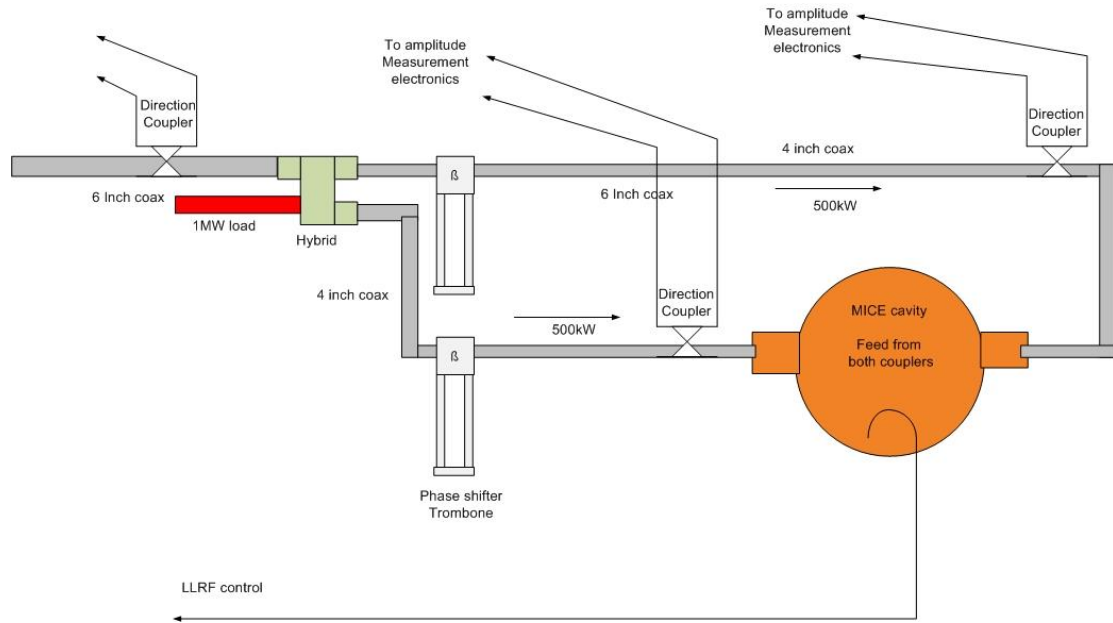
The cavity input couplers are 4 inch coax. During tests at the MTA these were pressurised with SF6. When the MICE experiment starts the forward RF power into each coupler will only be 500kW, however the peak breakdown voltage of 4 inch coax is only 700kW, therefore SF6 will still need to be used for operation under reflected power conditions as the reflected power can add and cause standing waves in the coax that are 4 times the input RF power.



MICE cavity gradient (blue) and Reflected power (pink) simulation

The RF power transmitted to the cavity must be fed in via the cavity couplers so that the RF power adds inside the cavity. To ensure this happens the coax system must be

designed so the path length as seen by the RF is an integer. To allow for some take up of errors a small range phase shifter or line stretcher should be included in every cavity coupler arm



Coax distribution to the cavity

We need to understand the relationship between the MICE cavities and the muon beam so that acceleration can be preserved inside the cooling channel.

Coax on cavity 1 will be constructed to present an equal phase angle so that power entering the cavity from the two coupler arms will added, small errors can be removed using the phase shifter in one coupler arm

The global phase angle of cavity 1 can be set via the LLRF. This will also move the global phase angle of cavity 2 at set the gradient of both RF cavities.

Coax on cavity 2 will once again be set so that RF power adds inside the cavity, small errors can be removed using either of the phase shifters in the coupler arms

The phase angle of cavity 2 needs to be set by understanding the transit time of the muon beam from cavity 1 (hence the phase angle at 201MHz) and then moving both phase shifters in the coupler arms by an equal amount to set the required phase angle of cavity 2. Cavities 3 & 4 can be set in the same way.

The phase shifters in the coupler arms will be of limited travel ~ 60 degrees, so the transit time must be understood before the coax system is finalised

