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The prevention of unwanted RF loops in the ACOL cooling systems

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Introduction

A brief summary of the needs for (and the present methods of) prevention of unwanted RF loops in the AA cooling systems is presented, followed by a résumé of the measurements made so far with materials which may be used in so-called "passive dampers" of kicker-to-pick-up communication via the ACOL vacuum chamber.

Present methods of preventing RF loops

The coupling between the K output and PU input levels, due to RF leakage out of and into the beam chamber, was found to cause problems in the original 1-2 GHz AA stack-core cooling system[(1)], many of which disappeared with the introduction of the concrete shielding blocks, acting as absorbers and scatterers of microwave radiation. Attempts to prevent actual machine leakage, such as the installation of "egg-boxes" in ion and sublimation pump manifolds, also reduced the amount of stray RF power.

The most obvious route for microwaves to form an undesirable positive feedback loop, (that is, via the beam chamber itself) did not cause a problem in the AA, probably due to the placement of a cut-off screen, of internal square 69mm (giving a low frequency cut-off f_c of 2.17 GHz), in the zero dispersion region in section 12. Since the highest cooling frequency was originally 2 GHz, this screen prevented the propagation of any waveguide mode via the shorter PU-to-K path. It is believed that in the longer path the absorbent ferrite tiles lining the pre- and stack-tail- cooling and the injection/ejection kicker tanks in the longer path may have provided sufficient damping of propagated RF. It remains to be seen whether they can continue to prevent the problem once the HF systems are operating above the screen cut-off (ie 2-8 GHz). One additional possibility is to use a screen which moves in with the kicker electrodes as the beam emittance is reduced. (At 5pi mm.mrad aperture, the 4-8 GHz kicker has an f_c = 8.33 GHz.)

Unfortunately, the use of cut-off screens is not so profitable in ACOL, since the minimum betatron amplitude of about 50mm[(2)] gives a maximum possible cut-off frequency of only 1.5 GHz, which does little to cover the 1-3 GHz cooling band. Hence to be perfectly safe, one has to achieve 148 dB of broad-band attenuation by absorbent structures which will upset neither the beam nor the magnetic field profiles.

Attenuation in a ferrite-loaded waveguide; implications for ACOL

By placing high-loss ferrite tiles of characteristic impedance close to that of free space on the walls of à waveguide, such as a beam vacuum chamber, one can prevent the propagation of non-TEM modes through the guide, a technique applied in the AA low frequency cooling tanks. With sufficient tiles placed on the vacuum chamber walls one could thus hope to attain the necessary RF attenuation.

Much of the work on the amount of attenuation achievable for a given length of ferrite-covered wall was performed by Mark Robinson[3] with 60x60x3 mm "ZN" tiles. Making transmission measurements using a network analyser, he found that with the tiles placed 8 mm off the chamber walls (an optimum established in earlier work)[4], a waveguide of section 100 mm square and length 1.5 m (figure 1) gave the following approximate attenuations:

Frequency / GHz	Attenuation / dB/m
2.00	67
2.60	78
3.25	97
3.95	101

These figures were obtained by comparing the transmission characteristics of different numbers of 4-tile layers, each providing 60 mm of ferrite covering.

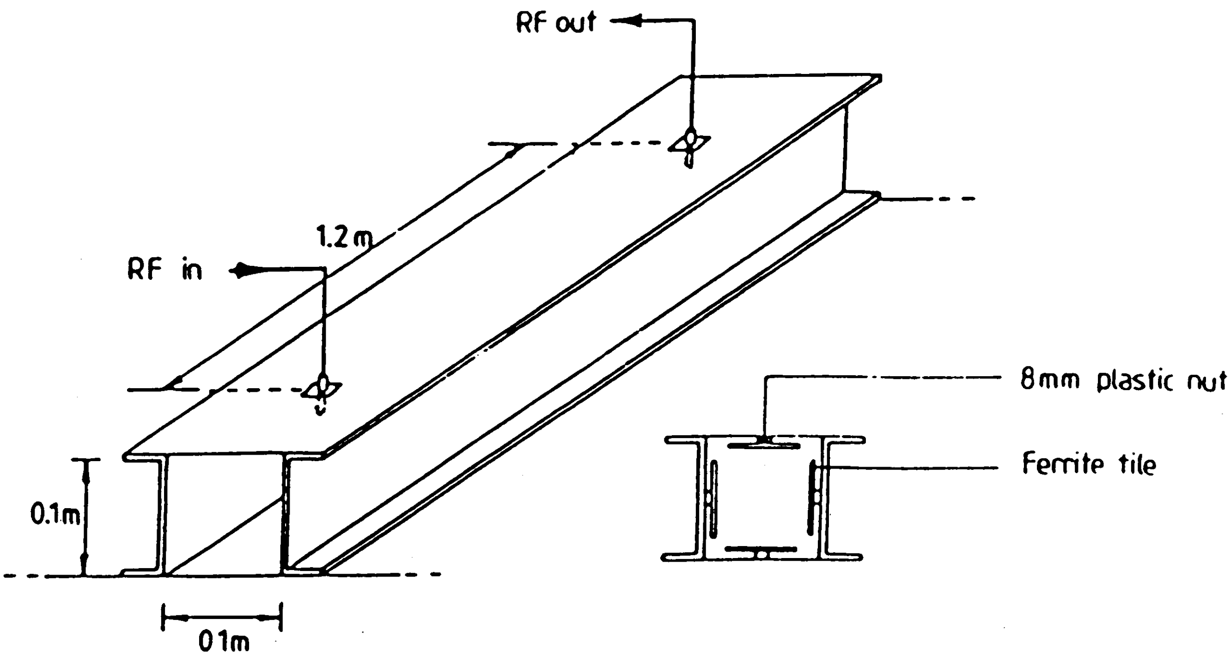

Figure 1. Experimental set-up used to measure the attenuation of ZN ferrite tiles.

In similar measurements made with a waveguide of section 330x130 mm (more closely representing that of ACOL), with ferrites again covering the inner walls, Mark found attenuations of 46 dB/m over 1-2 GHz and 41 dB/m over 2-3 GHz. Thus he concluded that the critical factor is the cross-sectional area of the chamber. His measurements have since been repeated and suggest, for a typical ACOL chamber, one can achieve 40-50 dB broad-band attenuation per metre of "ZN" ferrite covering. This means that to prevent K-to-PU feedback one needs up to 4 m of ZN-covered wall per possible route between them, or its equivalent. The obvious problem here is that since ferrites are magnetic, a passive damper using them cannot be placed in a magnet chamber, and must occupy some of the precious straight-section space. There will be, however, a considerable amount of ferrite, inherent to the design of various elements, inside the ACOL vacuum chamber. The twelve stochastic cooling tanks will all contain "NZ" ferrites, and the injection and ejection kicker tanks Philips "91C" ferrites; the probable damping effects caused by the presence of these materials are studied in the next section.

Inherent RF damping in the existing ACOL design

Figure 2 shows the position of the ACOL stochastic cooling systems; all three bands have a nominal gain of 148 dB, which is therefore the minimum damping required in each possible K-to-PU path around the machine. Also shown are the positions of the injection and ejection kickers. These are to be of similar design to the AA structures[5], and will thus contain ferrites seen by the beam, which can act as attenuators of RF radiation.

Each stochastic cooling element will contain ferrite tiles covering something like 15% of its surface. These tiles, of the NZ51 type, have properties comparable to those of the ZN's. Hence, taking 40 dB/m for a fully-covered chamber, one could hope to obtain roughly 10 dB per 2 metre tank. Since both routes between any given kicker and its pick-up contains 5 such tanks, we may assume (choosing 160 dB/path as a completely safe figure) that we need to find a further 110 dB for each possible path.

Now, the total effective length of the injection & ejection kickers in "quadrant" Q of figure 2 is 4.56 m[2], which would give the further required 110 dB if we could assume a modest 25 dB/m for the attenuation of "C" ferrites. (The attenuation measurements performed using these C ferrites have been limited, but they indicate that equal volumes of ZN and C give very nearly the same loss for the frequencies and chamber sections tested. Thus it seems reasonable to expect the quoted 25 dB/m to be a conservative estimate of the damping achievable in these kickers.)

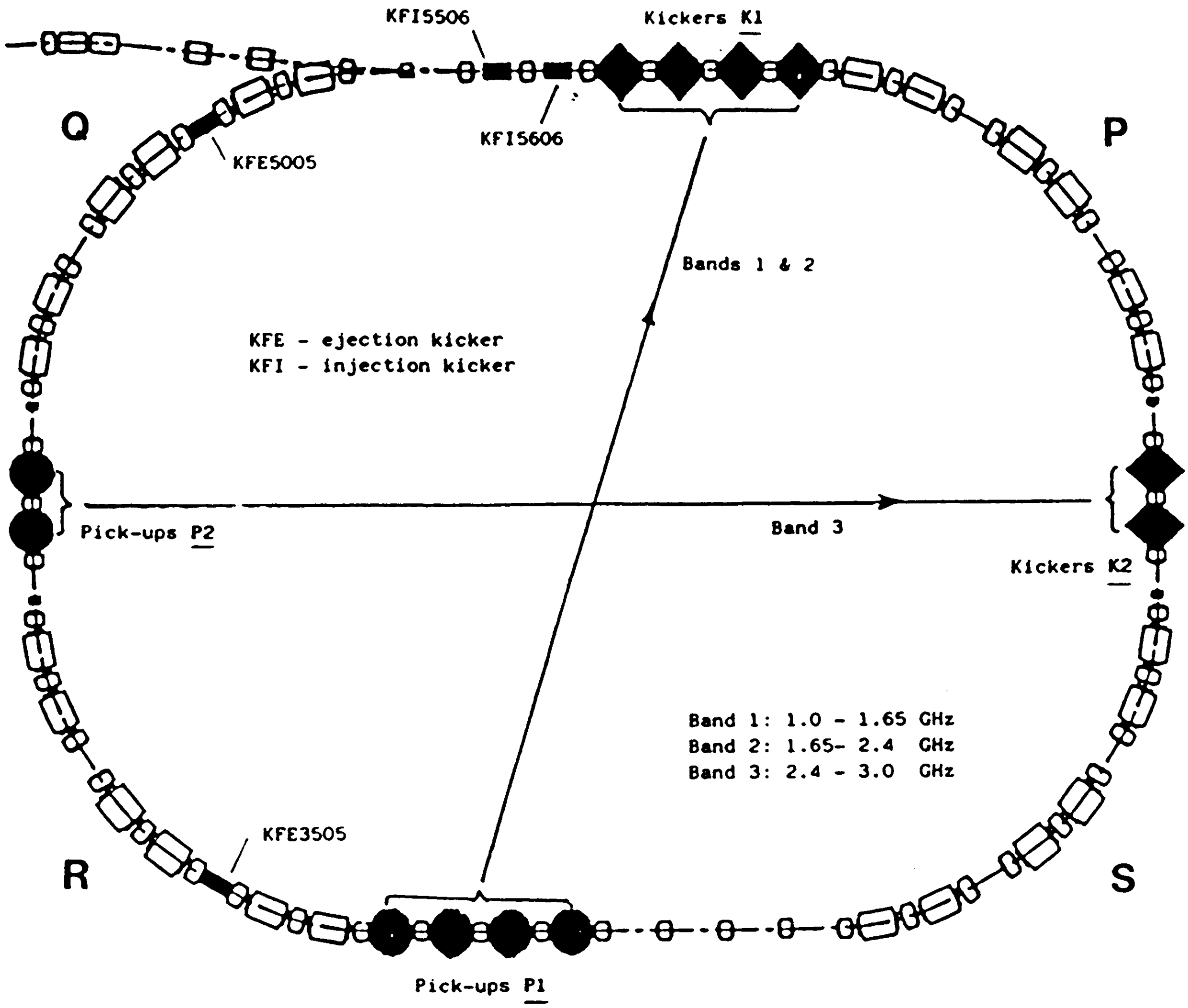

Figure 2. ACOL layout showing the positions of the stochastic cooling and the injection/ejection kicker tanks.

The presence of this 160 dB in quadrant Q means that the paths K1 to P1 via Q and R, and K2 to P2 via P and Q are completely blocked, leaving only the routes K1-P1 via P and S and K2-P2 via S and R as the ones which could cause feedback problems. The latter route does contain, however, the ejection kicker KFE3505, worth (at 25 dB/m) just under 30 dB. Thus to be sure of averting our problem, we need 110 dB attenuation in the P,S path and 80 dB in the S,R path. Placing a lumped attenuation of 110 dB in quadrant S would obviously prevent having to apply damping to all three vulnerable quadrants.

Possible sources of the required attenuation

Although it is unlikely that straight-section space will be found for a passive damping chamber, it would seem, after experiment with other materials, that ferrites still offer the easiest method of achieving the required blockage of K-to-PU paths, particularly if a high attenuation region can be incorporated into quadrant S. To that end, Peter Bramham has proposed a ferrite-lined elliptical tank (figure 3) which hugs the beam as much as possible between two quadrupoles. With 12 tiles per layer, and a wall-tile spacing of 8 mm, simulations of this structure suggest it would provide between 40 and 50 dB attenuation per metre, over all three cooling bands.

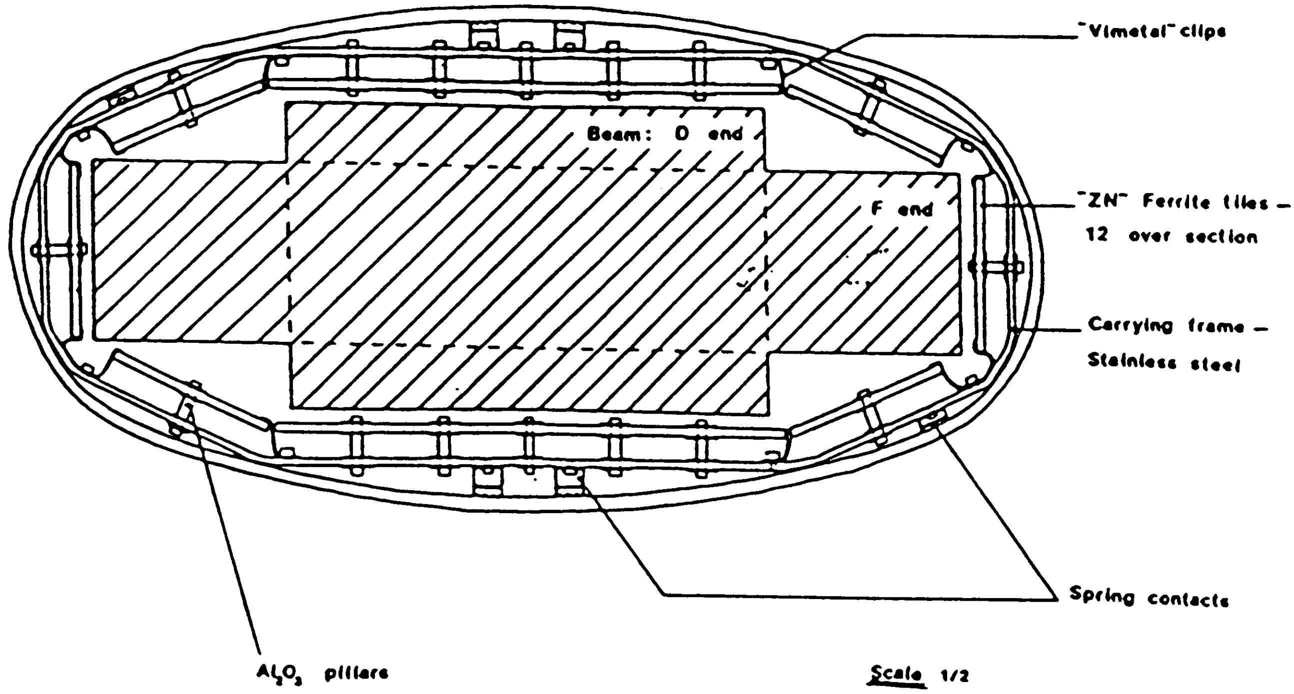

Figure 3. Elliptical design of a straight-section ZN ferrite passive damper

There are, of course, many other materials capable of reducing RF transmission around the vacuum chamber, but most of those offered for testing in the lab. were in such small quantity that their damping effects were completely swamped by those of reflections in the waveguide. For the record, however, materials such as silicon carbide may produce high attenuation per unit length.

One form of attenuator of which we have a reasonably plentiful supply, and which can be placed inside a magnetic field, is the nichrome-coated alumina resistor. We managed to aquire all the old ISR resistors, which are all nominally 100 ohm per square and 30 mm diameter. Transmission measurements have been made in a set-up similar to that of figure 1, with various resistor configurations, all of which must have the resistors close enough to the chamber walls so as not to interfere with the passage of the beam.

Unfortunately, though not surprisingly, the resistors seemed to couple almost entirely into the electric field, so that all feasible configurations, with them standing or lying on or close to the vertical walls, gave an approximate attenuation of only 0.1 to 0.2 dB per resistor, or between 6 and 12 dB/m for a chamber with both walls completely lined. Fritz Caspers suggested that resistors should be laid horizontally, three high, and shorted to the waveguide walls top and bottom, so providing a high impedance shunt. Although one metre of this structure took out roughly 40 dB at around the fundamental frequency, the broad-band attenuation was no better than before. Fritz suggested that a thicker coating of nichrome might improve this situation, but this obviously requires considerable work to achieve.

Although the attenuation per metre of the resistors is too low for them to be used in a straight-section damper, they can of course be placed in magnet chambers. Therefore use could be made of the many metres of dipole chamber in each undamped quadrant. Peter Bramham has calculated that up to 100 30 mm resistors can be placed in an ACOL dipole chamber without restricting the maximum expected beam dimensions. Thus with 0.1-0.2 dB/resistor one could hope to achieve between 60 and 120 dB per 6-dipole quadrant. The obvious drawback here is in having to attach so many resistors to the chamber walls in order to achieve reasonable attenuations. It is also doubtful whether we have sufficient resistors to furnish all the dipoles in the vulnerable regions.

Conclusions

Although the ferrite in the ACOL injection and ejection kickers and the stochastic cooling tanks should provide considerable RF damping, there is still a need of up to 110 dB attenuation, particularly in the quadrant furthest from the injection line, in order to prevent K-to-PU feedback via the vacuum chamber. A combination of a straight-section ferrite damper with nichrome coated alumina in the dipole magnet chambers would almost certainly perform this task; on its own, the nichrome solution requires rather too many resistors, the ferrite too much straight space. The use of cut-off screens, as in the AA, is not of much use in ACOL.

Acknowledgements

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