The design of a coaxial high power loop coupler for use on a 500 MHz superconducting (SC) accelerating cavity of "spherical" shape is described. Non-superconducting construction materials (copper and copper plated stainless steel) are used. Cooling is obtained by cold helium gas in counter flow. The coupling loop is located at the cavity equator and a choke provides an uncritical RF joint at a minimum current flow position. For the coupling required ($Q_{ext} = 10^{-10}$) the loop does not protrude into the cavity. Test experiments up to 70 kW incident RF power with a matched copper cavity and up to 17.5 kW with a superconducting cavity (corresponding to an acceleration field $E_{acc} = 3.6$ MV/m) are described. Design and measurements with two types of compact higher order mode ( horn) couplers, coupling to the magnetic and electric field respectively are described. Both couplers are manufactured from Nb and are low Q resonant devices with their centre-frequency matched to the relevant part of the cavities' higher order mode spectrum. All couplers have been operated with a SC cavity up to the design field level.

**Introduction**

At CERN a five cell, 500 MHz SC accelerating cavity has been constructed and is at present installed in the PETRA storage ring at DESY. During operation, a high power coupler and higher order mode (hom) couplers, for damping beam excited cavity modes are needed. In the following we describe briefly the design, construction and performance results obtained with these couplers. More details can be found in refs 2 and 3.

The couplers have been developed in view of LEP applications and a design accelerating field of 3 MV/m has been assumed. For application in PETRA with the same accelerating gradient and with an assumed beam current of $4 \times 5$ mA the main coupler should be operated at a power level of $\approx 60$ kW. Under these PETRA conditions the hom damping may turn out somewhat insufficient for some modes if one asks for all excited higher order modes to decay in between subsequent bunch passages.

**The high power loop coupler**

The large size of waveguides at 500 MHz is hardly compatible with an economic cryostat design. Therefore a coaxial line geometry has been used. In fig. 1(a) a sketch of the coupling region is given in order to illustrate some design principles. In fig. 1(b) the present layout of the coupler is shown. The coupler can be subdivided into three sections: nearest to the cavity, power is transported by a balanced, parallel conductor line of 100 $\Omega$ impedance and terminated by the loop simply formed by a short bar joining the two conductors. This line geometry ensures efficient mode conversion to the $TE_{11}$ fields leaking from the cavity into the coupling port.

![Fig. 1 Main coupler.](image)
Transition to the following 100 $\Omega$ coaxial line section is made by a 1/4 choke whose main function is to provide a very high impedance gap between outer coaxial conductor and coupling port. Hence a joint or flange placed there is practically free of current flow. The combined length of these first line sections is made slightly shorter than $1/2$ compensation in this way the loop's selfinductance. The following third section is a standard 50 $\Omega$ coaxial line of 3 1/8" diameter leading up to the vacuum window situated already outside the cryostat since its losses of approximately 30 W cannot be tolerated at He temperatures. The RF window has been placed at a location where the electric field strength does change only slightly with the different matching conditions to be expected in storage ring operation (e.g. beam on-off, cavity detuned). This window, a simple A1$_2$O$_3$ disk, is compensated by a second equivalent one in 1/4 electrical distance. To avoid condensation of moisture under all operating conditions window cooling circuits using 40 $\Omega$ warm water are employed. The coaxial line is fabricated from standard thin walled Cu-tubes and the loop from flattened Cu tube. The coupling port is made from Nb and for the RF choke Cu-plated stainless steel has been chosen. Together with the choke gap this provides a good thermal insulation between the He-temperature region and the coaxial line. Cold He gas counterflows are used for the inner and outer conductor cooling. With a He flow of 0.05 g/s in each cooling circuit the temperature of the loop remains below 50 K at full RF power and the heat input to the LHe bath lies well below 1 Watt. All parts of the coupler have been assembled by brazing.

The coupler has been tested in a twofold way before the final mounting on the 5-cell cavity. A first test was performed with a Cu-cavity. The coupler was matched to the cavity and air cooling for the inner and outer conductor was used. This reduces heat exchange with respect to LHe by about a factor 10. Therefore we had to work with a duty cycle of $\sim$ 10% with 0.2 sec RF pulse durations. We believe that multipactor and glow discharge phenomena would have shown up with this pulse duration as with CW operation. It was possible to operate at a peak RF-power of 70 kW over many hours. The power level was not increased further because the brazing region of the RF windows started to show glowing spots. In a second test the coupler was mounted with the design value of $Q_{ext}$ ($\sim 5\times$) on a single cell Nb-cavity with a coupling port layout identical to the one of the 5-cell cavity. Using a double stub for resonance transformation a field of 3.6 MV/m was reached which corresponds to 17.5 kW of incident power in the coupler. The field was limited by a quench in the coupler. After a processing of about 1 h no signs of multipactor or glow discharges were observed. Before mounting on the 5-cell cavity the coupler was rinsed with distilled dustfree water. The maximum accelerating field of the cavity was reached which corresponds to 17.5 kW of incident power in the coupler. The field was limited by a quench in the coupler. After a processing of about 1 h no signs of multipactor or glow discharges were observed. Before mounting on the 5-cell cavity the coupler was rinsed with distilled dustfree water.

The higher order mode (hom) couplers

In superconducting cavities damping of hom produced by particle bunches is of crucial importance. We have tried to reach for the most important hom dampings comparable to the ones achieved in Cu-cavities (Table 1). Amongst the possible approaches $2,3,4$ we have again excluded waveguides despite their inherent high pass characteristics which is very attractive for hom couplers. It was tried to keep the couplers very compact and to use a geometry favourable for the hom-cooling. Two types of hom couplers have been constructed, an electric (antenna) type, and a magnetic (loop) type. They are positioned at the equator of the cells where the different modes have either a vanishing magnetic or electric field. This simplifies considerably coupler design.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (MHz)</th>
<th>Type of coupler</th>
<th>$Q_0$ (Cu)</th>
<th>$Q_{ext}$</th>
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<tbody>
<tr>
<td>$TM_{11}$</td>
<td>693</td>
<td>$E$ at 32°</td>
<td>40 000</td>
<td>55 000</td>
</tr>
<tr>
<td>$TM_{12}$</td>
<td>737</td>
<td>$H$ at 32°</td>
<td>33 000</td>
<td>16 000</td>
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<td>917</td>
<td>$E$</td>
<td>34 000</td>
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<td>500</td>
<td>$E,H$</td>
<td>40 000</td>
<td>$&gt; 10^5$</td>
</tr>
</tbody>
</table>

TABLE 1

RF characteristics of hom couplers as measured in a single cell Cu cavity

Antenna coupler

Because of the E-field zero crossing at the equator, coupling of the fundamental mode to a E-field coupler situated there is strongly reduced, allowing the choice of a simple geometry without integrated filter. This is particularly welcome since this coupler has to deal with the TM$_{11}$ mode which having the highest hom coupling impedance produces the dominant part of the external hom power flow.

The antenna coupler is shown in fig. 2(a). Details of the design considerations can be found in ref. 3. The probe is a capacitively loaded and hence reduced length 1/4 resonator. A large field pick-up surface (C) forms with the shaft inductance (L) and the parallel combination of vacuum window capacitance and 20 a load a low $Q$ resonator ($Q = 2$) and tuned to the TM$_{11}$ mode frequency of 920 MHz.

All metal parts of the coupler are from Nb formed by spinning or turning on a lathe and assembled by electron beam welding, only the window being brazed. The coupler is designed for a power flow of $\sim$ 1 kW. Vacuum tightness and RF contact to the Nb coupling port is obtained by a flat lead ring. The central antenna is filled with LHe and communicates with the external LHe bath via holes in the inner and outer conductor of the coaxial line (fig. 2). In table 1 the measured $Q_{ext}$ for different modes are given. These values have been obtained for the antenna position shown in fig. 2(a).

Loop coupler

In contrast to the antenna a loop at the equator couples strongly to the fundamental mode and some means to suppress fundamental mode power flow to the load has to be found$^2$.

Here a 500 MHz stop filter in series with loop and load has been employed. In placing it in direct topological neighbourhood to the loop one can make use of its capacitive reactance above 500 MHz to
compensate the loop inductance. The so formed series
resonator with low Q (Q = 2) has been tuned to
the TM111 mode frequency of 740 MHz.

As shown in fig. 2(b) the filter is realised as
a capacitively loaded 1/4 resonator (Cp and Lp)
surrounding coaxially the line leading from the loop
towards the load.

Fig. 2 Layout of higher order mode couplers:

(a) Antenna coupler. A: coupling port (Nb), C,L: capacitively loaded 1/4

(b) Loop coupler. A: coupling port (Nb),
B: coupling loop, C: vacuum tight RF window, D: Nb-joint, E: LHe-inlet,
Lp, Cp: notch filter tuned to fundamental mode.

All coupler parts are fabricated from thin Nb
sheet and joined by electron beam welding. Surfaces
carrying RF currents are cooled by LHe with all parts
shaped to avoid gas pockets. The geometry of the
coupling port and of the RF-joint is identical to the
one for the antenna coupler. In table 1 the measured
Qext for the most important horn and for the
geometry of fig. 2(b) are given (with the coupler
positioned as in fig. 2(b).

Test results
Up to now three antenna couplers and two loop
couplers have been tested after a careful chemical
polishing and after rinsing with dust free water.
With a single cell Nb cavity fields could be raised
up to an accelerating gradient of 3.6 MV/m, with a
quench of the cavity itself in no relation to the
coupler, as limit. The couplers' Qext for the
fundamental mode exceeded in all cases 10^6. Three
antenna couplers and two loop couplers were mounted
on the 5-cell cavity and were supporting the maximum
field levels without problems. The Q_{ext} for a few
horns obtained in the 5-cell cavity are given in
ref. 1).

Acknowledgements

I would like to thank all technicians of our
group and of the SB workshops involved in this works
and my colleagues for their help.

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