Status Report on the Nearly Confocal Resonator (NCR) Pick-up

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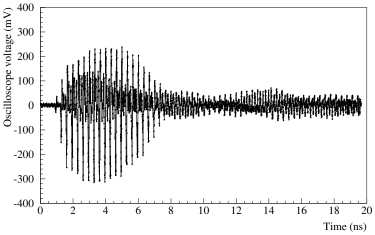
Motivations

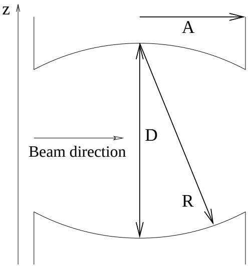
Beam diagnostic devices are often perturbed by microwave fields generated by the beam, that propagate in the wake of the bunches.



An open resonator pick-up with spherical mirrors can have a high quality factor for the diffraction losses. Reciprocity then suggests that it couples weakly to external TE or TM fields, while keeping anyway a significant coupling to the beam.

Open resonator with spherical mirrors

In cylindrical coordinates, the paraxial solution of the wave equation between the round mirrors is described by Gaussian beams modulated with associated Laguerre polynomials.



$$f = \frac{c}{2D}\left[q + 1 + \frac{1}{\pi}(1 + m + 2n)\arccos\left(1 - \frac{D}{R}\right)\right]$$

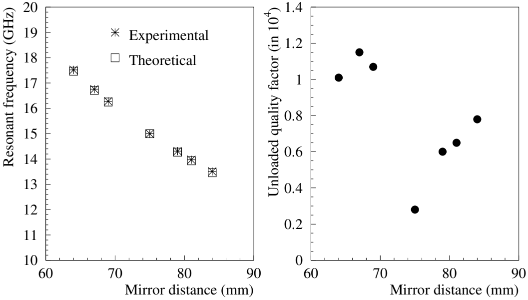
- $q \longrightarrow$ number of nodes between the spherical mirrors
- $m, n \longrightarrow$ coefficients of associated Laguerre functions

Losses and quality factors

- Diffraction losses strongly depend on the Fresnel number $N_F = A^2/D\lambda \times \sqrt{(2D/R) - (D/R)^2}$ and the eigen-mode.
- Resistive losses on the spherical mirrors depend only on the geometry and the material.
- If there is a small coupling hole in one mirror, it acts as a single magnetic dipole and it induces two types of losses:
    - Coupling losses for the (small) fraction of power that escapes through the hole to microwave equipment downstream.
    - Scattering losses for the rest of the power radiated by the magnetic dipole, directly or after reflection by the small hole.

Limitations of the confocal resonator

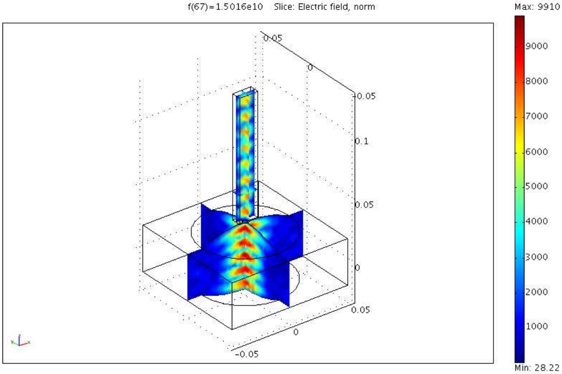
In 2005, we studied the electromagnetic properties of a purely confocal resonator ($D = R = 75$ mm). However, there are 28 modes at 15 GHz, with very different quality factors... Such a configuration was thus found to be highly unstable.



This warrants investigation of nearly confocal configurations.

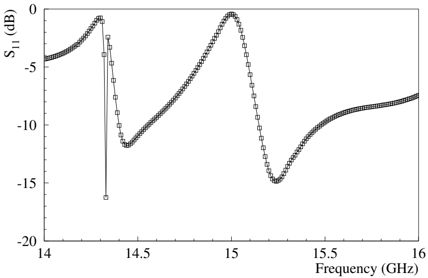
Design of a nearly confocal resonator

We use a mirror distance $D = 5.345$ cm and a curvature radius $R = 8.908$ cm. This ensures that there is only one eigen-mode at 15 GHz, with small diffraction losses ($Q_d = 3.3 \times 10^5$, while $Q_r = 4.0 \times 10^4$).



Simulation results (over-coupled configuration)

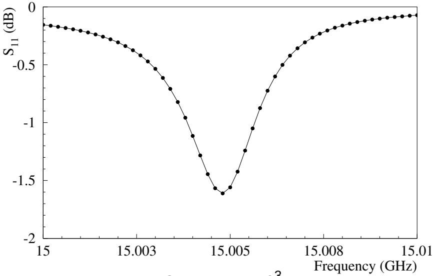
Here, a WR62 waveguide is coupled directly to the upper mirror (i.e. there is no iris).



At the resonance, the power injected through the waveguide is trapped inside the nearly confocal resonator, which has small diffraction losses. So, most of the power oscillating between the mirrors couples back to the waveguide, and S_{11} is close to 0 dB.

Simulation results (under-coupled configuration)

In order to derive the quality factors, one should have a small coupling iris in the upper mirror. If $\ell_h = 2$ mm and $d_h = 5$ mm, we expect $Q_c = 1.5 \times 10^5$ and $Q_s = 5.6 \times 10^3$.

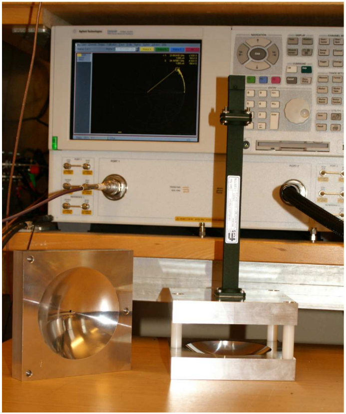


$Q_u = 4.7 \times 10^3$

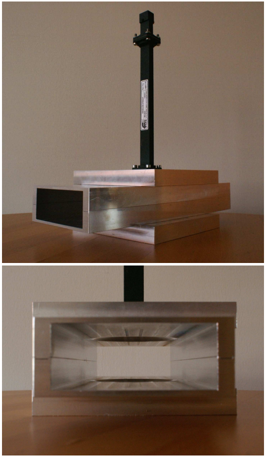
One should not take for granted the quality factor derived with FEMLAB. For instance, it is very sensitive to the mesh. Also, the low-reflecting boundaries used in FEMLAB do not strictly behave as open boundaries.

Experimental prototypes

Open NCR prototype

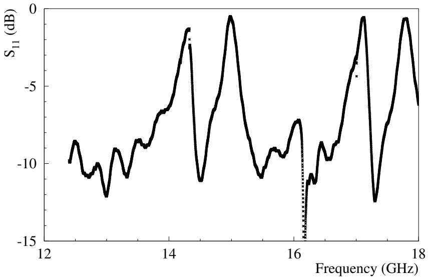


NCR prototype on Aluminium pipe



Results with the open NCR prototype (1)

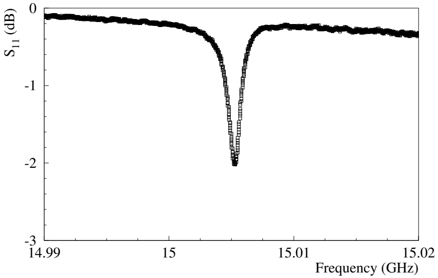
Over-coupled configuration: the WR62 waveguide is connected directly to the upper mirror (i.e. there is no iris).



All expected resonances, with small diffraction losses and a non-zero field at the centre of the upper mirror, are observed experimentally.

Results with the open NCR prototype (2)

Under-coupled configuration: a clean resonance is observed and the unloaded quality factor is 1.2×10^4.



Q_u is larger than expected, because a fraction of the scattered power does not leave the resonator and oscillates between the mirrors (not considered in the theoretical estimation of Q_s).
If the mirrors are further apart, this effect becomes smaller: the expected and measured Q_u-values agree.

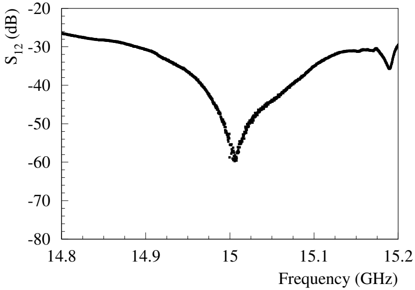
Results with the NCR prototype on an Al pipe (1)

- S_{11} measurements (under-coupled configuration): the unloaded quality factor is about 20% larger than for the open resonator prototype. Because of the surrounding pipe, a larger fraction of the power scattered by the iris stays inside the resonator.

- S_{12} measurements were also performed by sending microwave signals into the pipe with a horn at one of its ends and by measuring the signal in the waveguide.

Results with the NCR prototype on an Al pipe (2)

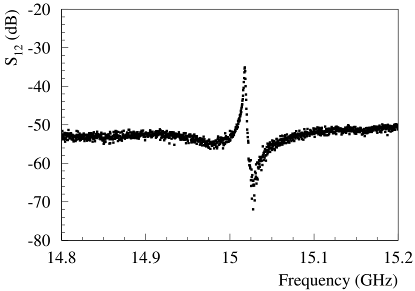
Over-coupled configuration: the WR62 waveguide is connected directly to the upper mirror (i.e. there is no iris).



The rejection of parasitic external fields by the nearly confocal resonator prototype is clearly visible.

Results with the NCR prototype on an Al pipe (3)

Under-coupled configuration: a worse rejection efficiency is obtained, presumably due to the presence of the coupling iris.



S_{11} measurements suggest that the iris scatters power out of the resonator. By reciprocity, external fields may couple to the iris: around 15 GHz, a fraction of the radiated power is trapped in the resonator and transmitted into the waveguide, leading to the observed pattern for S_{12}.

Summary

- We have studied the properties of a nearly confocal resonator with a large quality factor for the diffraction losses, which weakly couples to external fields.
- Two prototypes were constructed and we demonstrated the proof of principle for the NCR pick-up: the rejection of waveguide modes at the resonant frequency.
- One major limitation was identified: when the resonator is under-critically coupled to a waveguide, the quality factor is dominated by the scattering losses at the iris, which also couples to external fields, leading to a worse rejection.

More details in A. Ferrari, M. Johnson, V. Ziemann, E. Öjefors, *Limitations of the confocal resonator pick-up and investigations of nearly confocal configurations*, EUROTeV-Report-2006-081.

Outlooks

Before building a final prototype and testing it with beam in CTF3, more simulation studies are needed in 2007:

- Simulations with HFSS and/or CST Microwave Studio to estimate the S_{12} spectrum for all incoming modes in the pipe, and better understand the results obtained with the NCR prototype on an Al pipe.
- Simulations of the coupling between a passing (bunched) beam and the NCR pick-up.
- More open questions: over- or under-critical coupling between the resonator and the extraction waveguide, absorbing material around the resonator to get rid of unwanted modes, tolerances?