DESIGN OF A NEARLY-CONFOCAL RESONATOR PICK-UP IN UPPSALA

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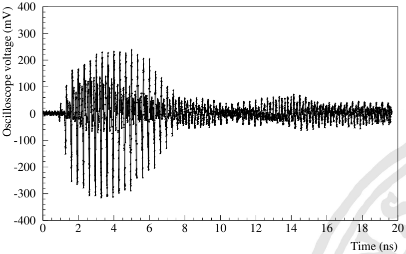
Motivations

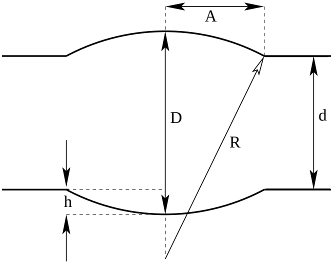
Beam diagnostic devices can be perturbed by microwave fields generated by the beam, that propagate in the wake of the bunches.



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



The solution of the wave equation between the spherical 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 → number of nodes between the spherical mirrors
- m, n → coefficients of associated Laguerre functions

Design of a nearly confocal resonator

Losses and quality factors:

- Diffraction losses depend on the Fresnel number $N_F = A^2/D\lambda \times \sqrt{(2D/R) - (D/R)^2}$ and (m, n).

$$Q_d = \frac{2\pi D}{\alpha_d \lambda} \text{ with } \alpha_d = \frac{2\pi\,(8\pi N_F)^{1+m+2n}\,e^{-4\pi N_F}}{(m+n)!n!}.$$

- Resistive losses on the spherical mirrors depend only on the geometry and the material.

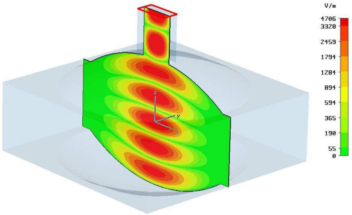
$$Q_r = \frac{G}{R_s} \text{ with } G = Z_0 \times \frac{\pi}{2} \times \frac{D}{\lambda}.$$

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 12 GHz ($m = n = 0$ and $q = 4$):

$Q_d = 3.6 \times 10^6 \gg Q_r = 4.1 \times 10^4$.

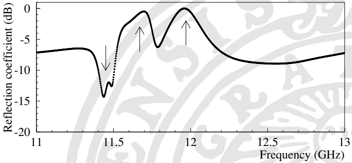
Search for NCR eigen-modes

The CST Microwave Studio simulation package was used to study the electromagnetic properties of the NCR cavity, connected to a waveguide (1.905 cm $\times$ 0.953 cm) through the upper mirror.



Electromagnetic field in the NCR cavity at 12 GHz for the $m = n = 0$ and $q = 4$ mode.

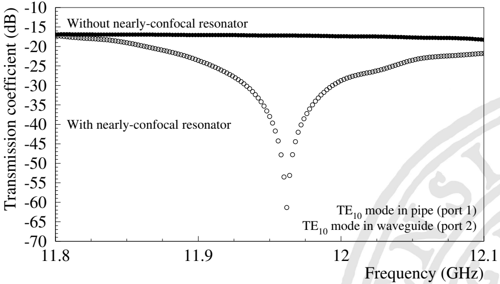
Eigen-modes are identified in the S_{11} spectrum at the waveguide port.



Resonances with a large Q_d translate into a peak close to 0 dB.

Transmission coefficient of incoming modes

The NCR is inserted into a 11 cm × 3.7 cm rectangular pipe. Below a cut-off frequency of 12.1 GHz, 38 modes can propagate through the pipe.



CST simulations show a clear rejection of the TE_{10} mode of the pipe around the resonant frequency of the NCR.

A similar behaviour is observed for all other incoming TE and TM modes.

Experimental prototype

NCR prototype on a pipe:

The horn antenna allows to inject TE and TM modes into the rectangular pipe.

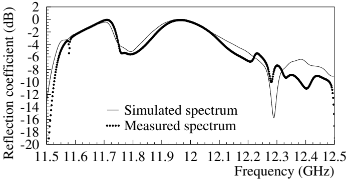
Measurement of reflection and transmission coefficients with a network analyzer in Uppsala.

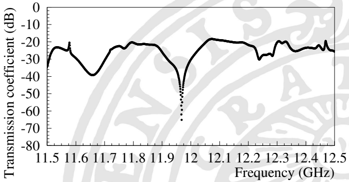
Results with the NCR prototype

Experimental tests confirmed our simulations and provided a clear proof-of-principle for the NCR.

A good agreement between the simulated and measured S_{11} spectrum.

A clear rejection of incoming modes at the NCR resonant frequency.





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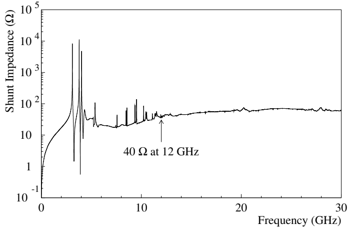
GdfidL simulations of the NCR pick-up (1)

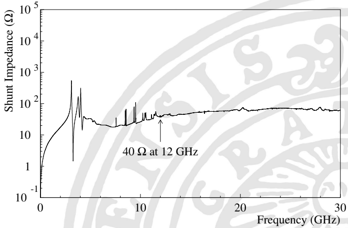
To study the signal induced by the CTF3 beam in the NCR pick-up, simulations are performed with GdfidL.

Shunt impedance as a function of frequency:

Only the NCR pick-up:



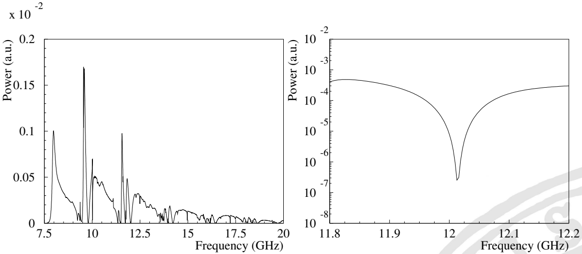
With SiC damping bricks:



Low-frequency modes couple best to the beam and they can be damped with absorbing material in the beam pipe walls (SiC here).

GdfidL simulations of the NCR pick-up (2)

The signal induced by one bunch ($q = 3$ nC, $\sigma = 2$ mm) in the NCR extraction waveguide is $\mathrm{FFT}(E) \times \mathrm{FFT}(H)$:



Minimum at 12 GHz: small transit time factor for the mode with $m = n = 0$ and $q = 4$, which has $E_z(s) \propto e^{-s^2/2w_0^2}$:

$$\Delta E = \int E_z(s) \cos\left(\frac{2\pi f}{\beta c} s\right) ds = \exp\left(-\frac{\pi^2 w_0^2}{\lambda^2}\right) \int E_z(s) ds.$$

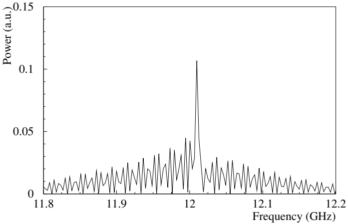
The analytical and computed transit time factors are 0.0048 and 0.0035.

Power spectrum computation (1)

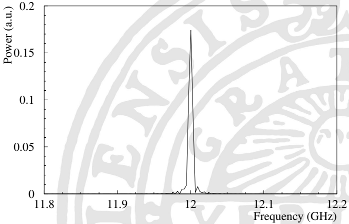
The power induced by N_b bunches (in the right unit) is:

$$P_{bunch}(f) \times \left[\left(\sum_{i=1}^{N_b} cos\,(2\pi f \tau_i) \right)^2 + \left(\sum_{i=1}^{N_b} sin\,(2\pi f \tau_i) \right)^2 \right].$$

With the NCR pick-up after summing up 420 bunches:



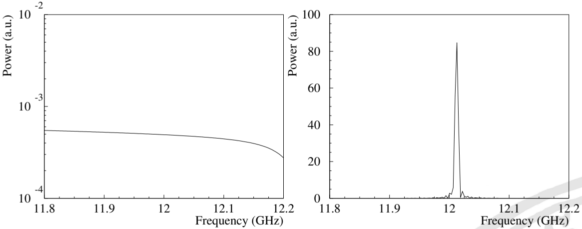
With a 140 ns long unitary sine function at 12 GHz:



With a bandwidth of 50/300 MHz, the power coming from the NCR during the passage of a bunch train is 1.0/3.5 W.

Power spectrum computation (2)

For a pick-up with no NCR cavity:



For a bandwidth larger than 50 MHz, the output power during the passage of a bunch train is 500 W.

The two spherical mirrors in the beam pipe:

- reduce the available signal in the NCR waveguide,
- do not allow a significant improvement of the signal-to-noise ratio.

Summary

- Simulations and experimental tests of a new NCR pick-up showed a clear rejection of external parasitic modes at the resonant frequency (12 GHz).
- GdfidL simulations show that there is a very weak coupling of the beam to the NCR mode of interest and thereby not a significant improvement of the signal-to-noise ratio.

* Several publications on the NCR project: EUROTeV-Reports 2006-024, 2006-081, 2007-061, 2007-063, 2007-073.

* Many thanks to Magnus Johnson, Shi Cheng, Gabriel Gourie for their collaboration!