The 800 MHz higher harmonic system for HL-HLC

Toon Roggen
BE-RF-BR, CERN, Geneva, Switzerland

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ABSTRACT:

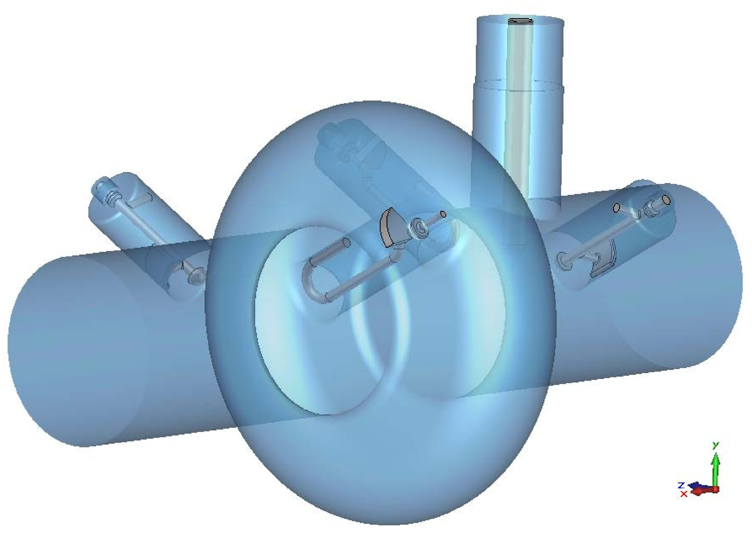
A higher harmonic cavity system in the LHC; can provide more flexibility to change the longitudinal bunch profile and/or change the synchrotron frequency distribution. It is therefore considered as a possible option for the HL-LHC upgrade. For this purpose an 800 MHz RF system is designed. Aspects related to cavity design, narrow and broad band HOM couplers and input power requirements are discussed.

INTRODUCTION:

For the future HL-LHC upgrade a harmonic system is considered to account for instabilities excited by unexpected machine impedances and to allow for additional control of the longitudinal beam parameters (flat bunches, bunch lengthening, bunch shortening…). The system can improve Landau damping and increase the instability threshold [1].

One of the possible candidates for such a system is the superconducting 800 MHz higher harmonic system described hereunder. The system consists of 8 to 10 cavities grouped in two cryostats, each cavity with its own power coupler and a set of narrow band and broad band HOM couplers, located at both sides of the cavity.

Challenges include the RF power requirements (300 kW) for the, relatively small, system, precise phase control with respect to the 400 MHz system as well as the high power extraction for the higher order modes, while maintaining optimal decoupling from the fundamental mode.

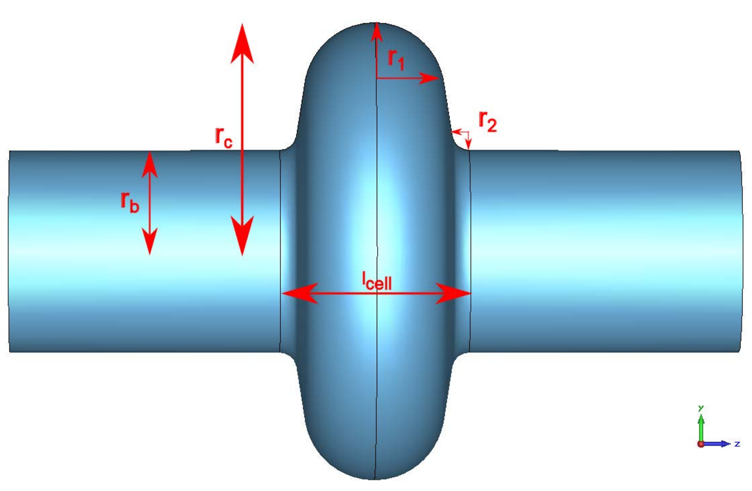


Exemplary model of a single 800 MHZ cavity equipped with a power coupler and two sets of narrow band and broad band HOM couplers.

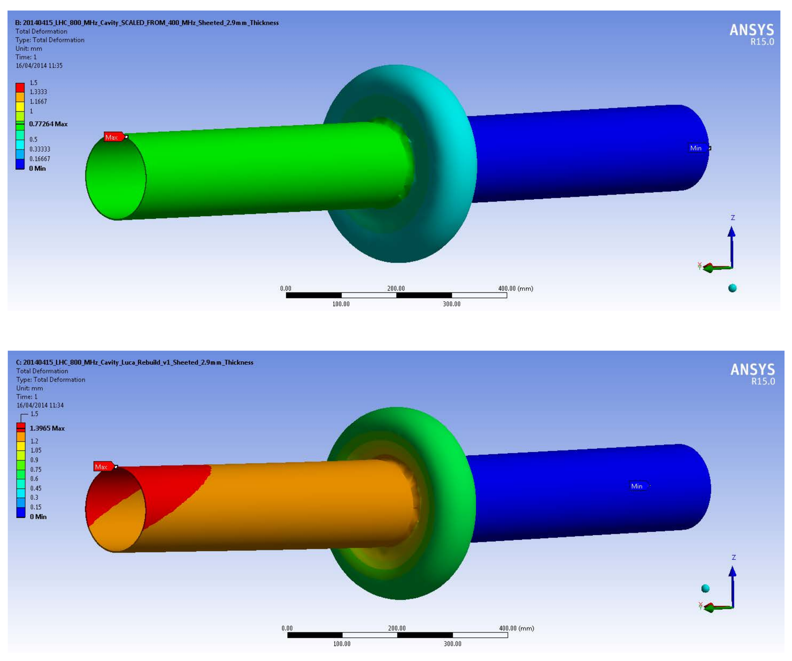
CAVITY DESIGN:

A cavity design study was initially performed in [3], based on the 400 MHz LHC accelerating cavity [2]:

→ scale ½ (f)
→ parametric study (R/Q optimisation)
→ wall inclination (Stiffness)
→ optimize r_c for f
= 800 MHz harmonic cavity



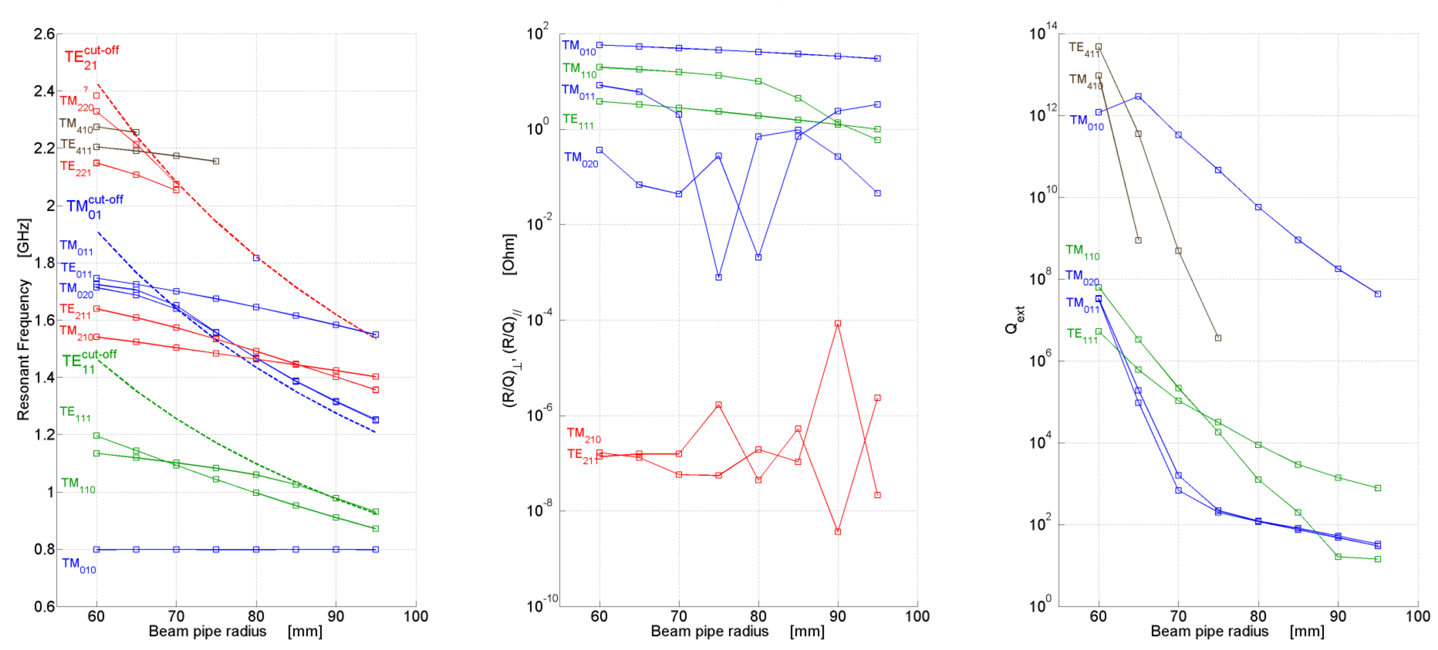
800 MHZ cavity parameters.



Mechanical deformation of the 800 MHZ cavity with a 20º wall inclination (top) and a 10º wall inclination (bottom), exposed to a load of 20kN. The top cavity is 35 % stiffer than the original 400 MHz cavity. The bottom cavity is 25% less stiff.

	ACS	Harmonic system		ACS	Harmonic system
f [MHz]	400.8	801.4	r_1 [mm]	104.3	52
$(R/Q)_{circuit}$ [Ω]	45	45.3	r_2 [mm]	25	12.5
V [MV]	2	0.8-1.6	**l_{cell} [mm]**	**320**	**140**
Q_L	20k - 60k	11k - 100k	Wall thickness [mm]	2.9	2.9
r_b [mm]	150	75	**Wall inclination [º]**	**20**	**10**
r_c [mm]	**344**	**169.3**			

400 MHz and 800 MHZ cavity characteristics [3].



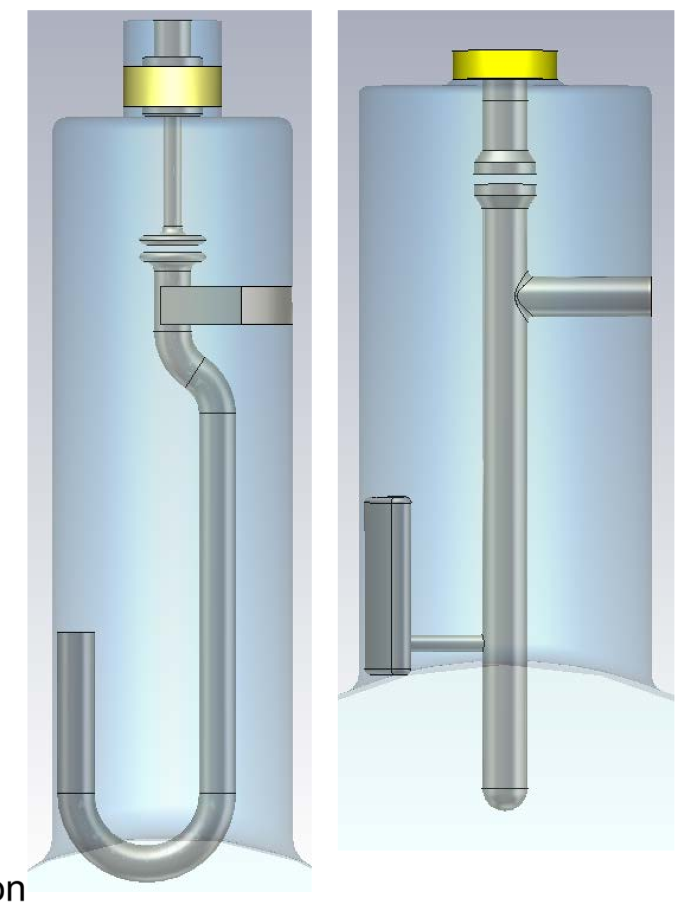
Sensitivity of the HOM frequencies, R/Q and Q_{ext} for different radii of the beam pipe [3].

HOM COUPLERS:

- Narrow band: Hook type
  → 801.4 MHz notch
  → TE_{111} and TM_{110} transmission
- Broad band: Probe type
  → 801.4 MHz notch
  → Transmission for f ≥ 1488 MHz

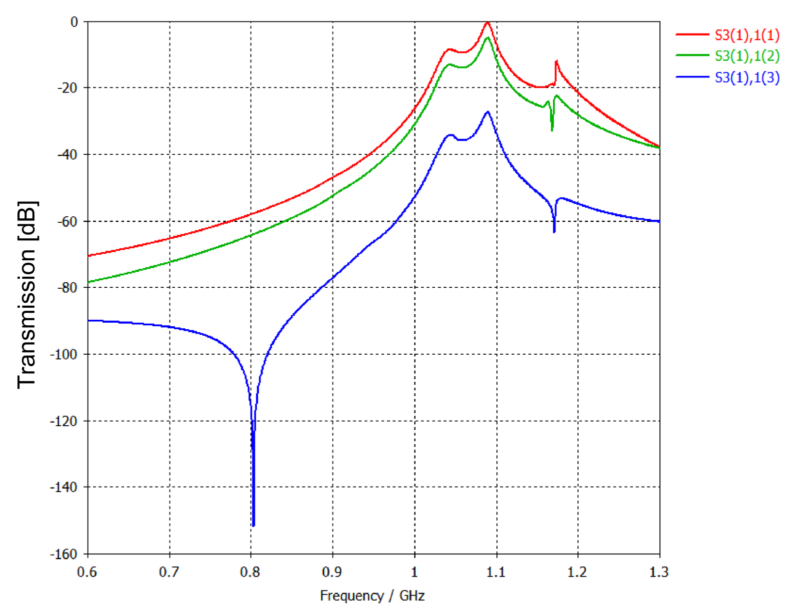
Frequency [MHz]	TE/TM	Couples to	$(R/Q)_{max}$ [Ω]
801.4	TM_{010}	TM_{01}	45.3
1039/1044	TE_{111}	TE_{11}	2
1087/1089	TM_{110}	TE_{11}	12.5
1488	TM_{210}	TE_{21}	< 0.1
1541	TE_{211}	TE_{21}	< 0.1
1616	TM_{020}	TM_{01}	3
…	…	…	…

800 MHZ cavity: Fundamental and higher order modes.

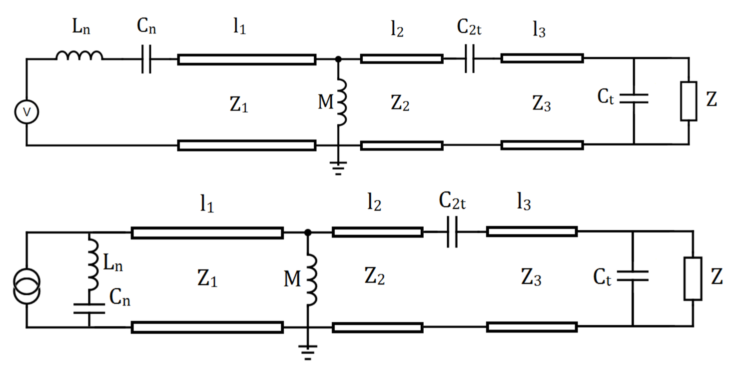


HOM Couplers: Narrow band coupler (left) and broad band coupler (right).

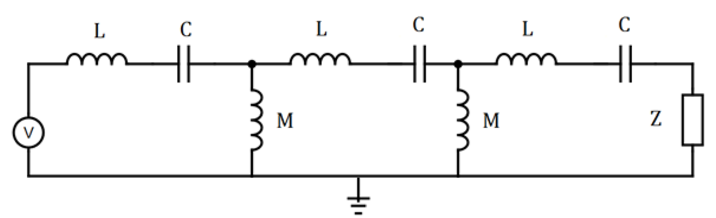
Procedure [4,5]:
- Equivalent circuit design: Component optimisation
- Conversion to transmission line circuit
- Optimisation through l_1, l_3 and C_t
- Conversion to 3D model



Tuned narrow band coupler transmission curves.



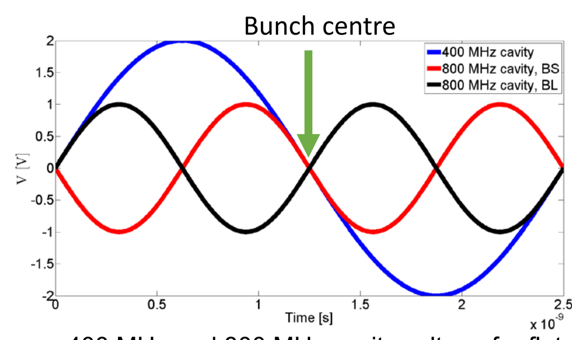
Narrow band coupler equivalent circuits for electric (top) and magnetic (bottom) coupling.



Broad band coupler equivalent circuits for electric coupling.

POWER REQUIREMENTS [6] :

- Power management 400 MHz cavities: Full detuning scheme: Fixed voltage, allow phase modulation φ(t) due to beam loading: 0.180 rad → 187 kW (≈ constant over one turn)
- bunches will follow phase modulation → unequally spaced
- 800 MHz cavities: locked to 400 MHz cavities
  → follow phase modulation: $\varphi(t) + \varphi_{offset}$.
- BS mode:
  → Large $Q_{L,800}$ → 55 kW
  → Variable coupler required
- BL mode:
  → Small $Q_{L,800}$ → 292 kW (! 300 kW upper limit)
  → Fixed coupler → BS mode: 173 kW
  → Low V_{800} : more cavities, limited installation space



400 MHz and 800 MHz cavity voltage for flat top working point.

HL-LHC bunch characteristics	
P⁺	$2.2e^{11}$
Bunch length [ns]	1
Bunch spacing [ns]	25-50
# (filled) bunch places	(2604) 3564
β	1
T_{gap} [ns]	3200

HL-LHC bunch characteristics.

	BS optimization		BL optimization	
	BS	BL	BS	BL
V_{800} [MV]	1.4	1.4	0.8	0.8
$Q_{L800, opt}$	429000	17000	41000	12000
$I_{g800, opt}$ [A]	0.05	1.30	0.31	0.72
$P_{g800, opt}$ [kW]	25	650	87	290
$Q_{L800, custom}$	100000	100000	11000	11000
$I_{g800, custom}$ [A]	0.16	0.92	0.84	0.80
$P_{g800, custom}$ [kW]	57	2000	173	292

Harmonic system power requirement study.

CONCLUSIONS:

- Cavity design:
  - Initial cavity design parameters determined
  - Based on HOM frequencies, R/Q's
  - Mechanical deformation considered
- HOM couplers:
  - Narrow band and broad band
  - Tuned to their respective frequencies using equivalent circuit models
- Power requirements
  - Fixed vs. variable power coupler
  - High vs. low power
  - High vs. low cavity voltage
  - More cavities vs. limited available space
  - Todays power coupler limits: ≈ 300 kW

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