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NUMERICAL EVALUATION OF THE BEAM COUPLING IMPEDANCES OF THE DAΦNE CAVITY UP TO 1 GHz

P. Arcioni, L. Perregrini*, B. Spataro*

*Dept. of Electronics of the University of Pavia
Via Abbiategrasso 209, PAVIA, Italy

1 - INTRODUCTION

This report is devoted to the presentation of the results of the investigation of the performances of the DAΦNE main ring accelerating cavity. The cavity, to be operated at a frequency of 368.25 MHz, was designed to fulfill the primary requirement of yielding optimum coupling impedances, suited to manage the high intensity beam planned for the DAΦNE Φ-Factory operation. The main concern was to minimize the excitation of higher order modes (HOM) when the beam crosses the cavity, since these modes may induce bunch-to-bunch instabilities that constitute one of the limits on the maximum beam current. For this reason a bell-shaped cavity was chosen, having two rather long conical sections that connect the body of the cavity with the beam tube. As a result, the longitudinal impedance is sufficiently high, so that the acceleration efficiency if good, whereas HOM impedances are lowered by the transit time effect [1,2].

Some preliminary simulations, performed using two-dimensional codes able to find resonant frequencies and coupling impedances in the case of axisymmetric cavities, allowed an optimization of the cavity shape, but showed that HOM impedances were still to high to fulfill the design specifications. For this reason the cavity was provided with HOM dampers, that should bring the Q-factors of the HOM to such low values that they do not induce instabilities. Wide-band dampers were used, consisting of waveguides (dimensioned so that they are below cutoff for the accelerating mode only) that connect the main body of the cavity to dissipative terminations. Three waveguides, placed 120˚ apart on the periphery of the cavity, were considered, according to the disposition originally proposed in [3] and successively analyzed in [4]. These papers discuss in detail the theoretical background and the practical considerations concerning this technique for the reduction of HOM coupling impedances.

The insertion of the waveguides destroys the azimuthal symmetry of the cavity, and therefore two-dimensional codes are no more suited for simulation. Moreover, unless we are interested in the first modes only, the dissipative terminations make it difficult to apply the experimental techniques based on the Slater perturbative theory, that is commonly used to measure the coupling impedances in low-loss cavities. In fact, it is possible that the Q-factors of the damped modes are too low to be consistent with the assumptions underlying that theory. To have a quantitative estimate of the effectiveness of the waveguide HOM dampers on the DAΦNE cavity we carried out a number of computer simulation using the code MORESCA (MOdes of RESonant CAvities), suited for the modal analysis of 3-D cavities. Data from MORESCA where used in the code POPBCI (POst Processor for Beam Coupling Impedances), to compute the longitudinal and transverse impedances. Both codes have been developed by the Electromagnetic Group of the Department of Electronics of Pavia; the code MORESCA is based on the algorithm reported in [5,6], whereas the code POPBCI is described in [4,7], together with the underlying theory.

2 - DEFINITIONS OF THE LONGITUDINAL AND TRANSVERSE COUPLING IMPEDANCES AND CLASSIFICATION OF CAVITY MODES.

The coupling impedances describing the interaction between a z-directed beam and an accelerating structure are usually defined referring to resonant cavities having a rotational symmetry respect to the z-axis (e.g. see [8]). Since the cavity we consider is not axisymmetric, the question may arise if the standard definitions of the coupling impedances still hold. In particular the transverse impedance, that yields the momentum (in the x-y plane) gained by a particle passing the cavity off-axis, should depend, in principle, not only on the amount of the displacement, but also on its direction in the x-y plane; in other words the transverse impedance should be regarded as a tensor quantity. In [4] it is shown that in the case we are interested in, i.e. when the cavity has a 3-fold symmetry around the z-axis (beam axis) and exhibits three symmetry planes passing through the z-axis, the definitions of the coupling impedances are the same as in the case of axisymmetric cavities. In particular the transverse impedance is still a scalar quantity, independent of the direction of the displacement of the beam, and therefore it can be evaluated by considering a displacement of the beam in an arbitrary direction.

For convenience, we report in the following the definitions of the longitudinal impedance Z_p and of the transverse impedance Z_P, as given in [4]. We represent the current density of a generic beam harmonic at the frequency ω by:

$$\boldsymbol{J} = I_o \, f(x,y) \, e^{-jhz} \, \mathbf{u}_z \qquad (1)$$

where I_o and h are the amplitude and the wavenumber of the harmonic, respectively (h= ω/velocity of particles), and f(x,y) is a function of the transverse coordinates, that describes the transverse beam profile.

It is assumed that f differs from zero only near the z-axis, in the small region crossed by the particles, and that we have

$$\int_\sigma f\, dx\, dy = 1 \quad ; \quad \int_\sigma x\, f\, dx\, dy = \bar{x} \quad ; \quad \int_\sigma y\, f\, dx\, dy = \bar{y}$$

where σ is the cross-section of the beam pipe and $\bar{x}$, $\bar{y}$ are the coordinates of the beam center. It is further assumed that $\bar{x}$, $\bar{y}$ are small with respect to the transverse dimension of the accelerating structure and that f is symmetric with respect to the beam center. Indicating by $E_z\,(x,y,z\,|\,\bar{x}\,,\bar{y}\,)$ the z-component of the electric field induced by $\boldsymbol{J}$ when the beam crosses the cavity at $(\bar{x}\,,\bar{y}\,)$, and considering a centered beam or a beam off-set in the x-direction when defining Z_p or Z_P, we have:

$$Z_p = -\frac{1}{I_o}\int_\sigma\int_0^L f\;\; E_z(x,y,z\,|\,0,0)\; e^{\,jhz}\; dxdydz \qquad [\Omega] \tag{2a}$$

$$Z_P = -\frac{c}{\omega\, I_o\, \bar{x}}\int_\sigma\int_0^L f\;\; \partial_x E_z(x,0,z\,|\,\bar{x}\,,0)\; e^{\,jhz} dxdydz \qquad [\Omega/m] \tag{2b}$$

where c is the velocity of light and L is the length of the structure (it is assumed that the field amplitude in the beam region is significant only in the interval $0 < z < L$).

The calculations of coupling impedances reported in the following paragraph are based on definitions (2), in the approximation $v \approx c$, i.e. putting $h = \omega/c$.

Due to the 3-fold symmetry of the cavity, the resonant modes can be classified according to their symmetry: in fact, some of them will have the same 3-fold symmetry (symmetric modes), whereas the remaining are not symmetric (asymmetric modes). Moreover, due the symmetry planes, modes can be classified according to even (magnetic wall) or odd (electric wall) symmetry with respect to one of the symmetry planes (say, the y = 0 plane). As a result, all modes belong to one of the following classes: symmetric, even modes (SE modes); symmetric, odd modes (SO modes); asymmetric, even modes (AE modes); asymmetric, odd modes (AO modes). In [4] it is also shown that only SE modes contribute to the longitudinal impedance, since only this class of modes have a non-zero axial electric fields on the axis. Moreover, SO modes, for which both E_z and $\nabla_T E_z$ are zero, do not contribute to either the longitudinal or to the transverse impedance. Finally, since AE and AO modes occur in degenerate pair, impedance (2b) can be calculated by considering AE modes only, since only these modes have a non-zero $\partial_x E_z$ along the beam axis.

3 - THE MODEL USED FOR THE SIMULATIONS

The code MORESCA is based on a Boundary Integral Method and thus it requires that only the boundary of the cavity is discretized. The surface mesh used in the simulations of the DAΦNE cavity [2] is shown in Fig. 1a; it consists of 1113 triangular patches (only half of the actual cavity is modelled, exploiting its symmetry). It was prepared using a code for mechanical CAD (PATRAN) suitably interfaced with MORESCA. Particular care was paid in an accurate modelling of the intersections between the waveguides and the cavity body, where some small elements were considered (see the close-up view in Fig. 1b). In fact the calculation of the coupling between the cavity and the waveguides depends critically on the good evaluation of the rapidly varying fields that occur thereat.

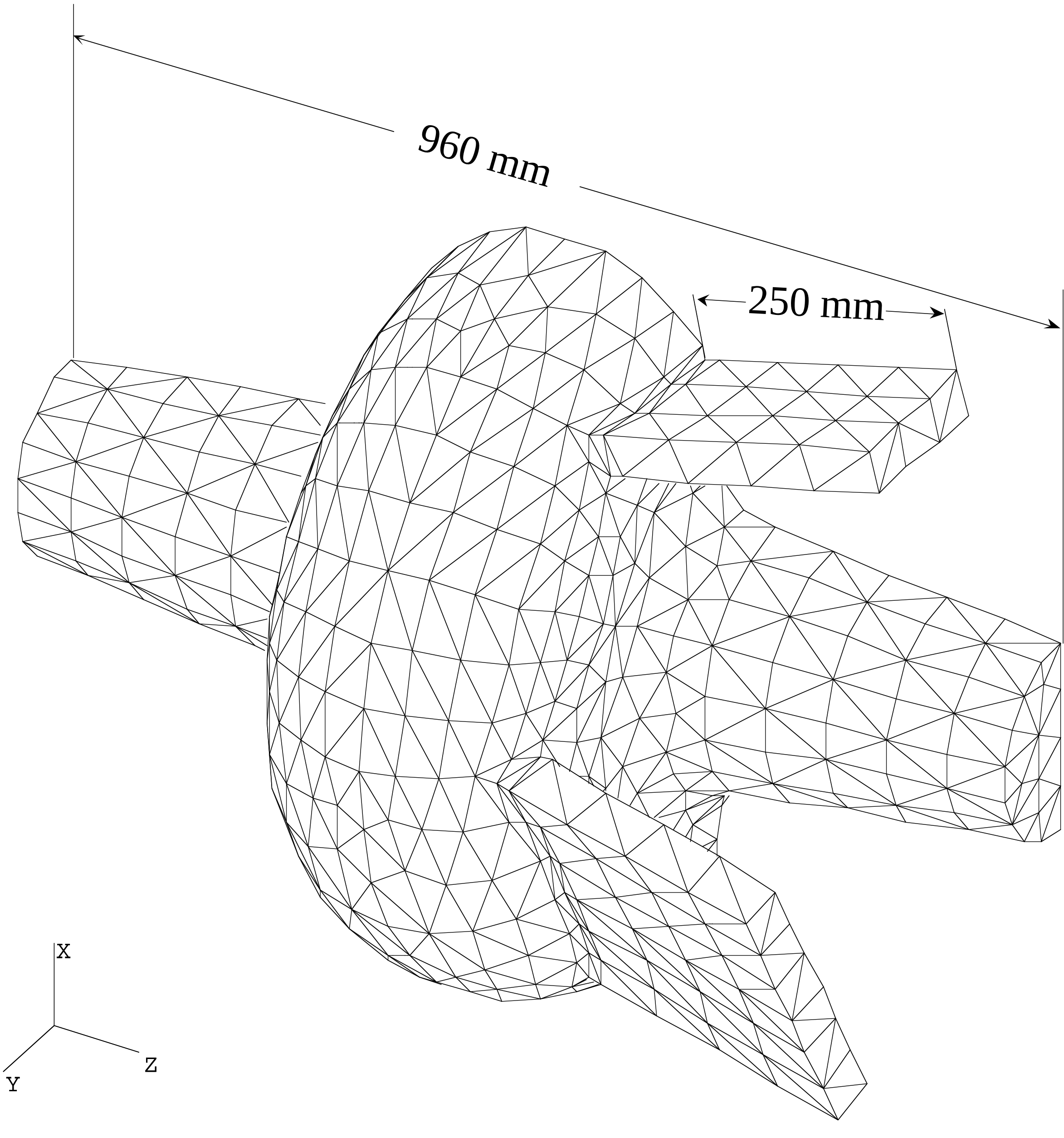


Fig. 1a - The mesh used in the simulations of the DAΦNE cavity.

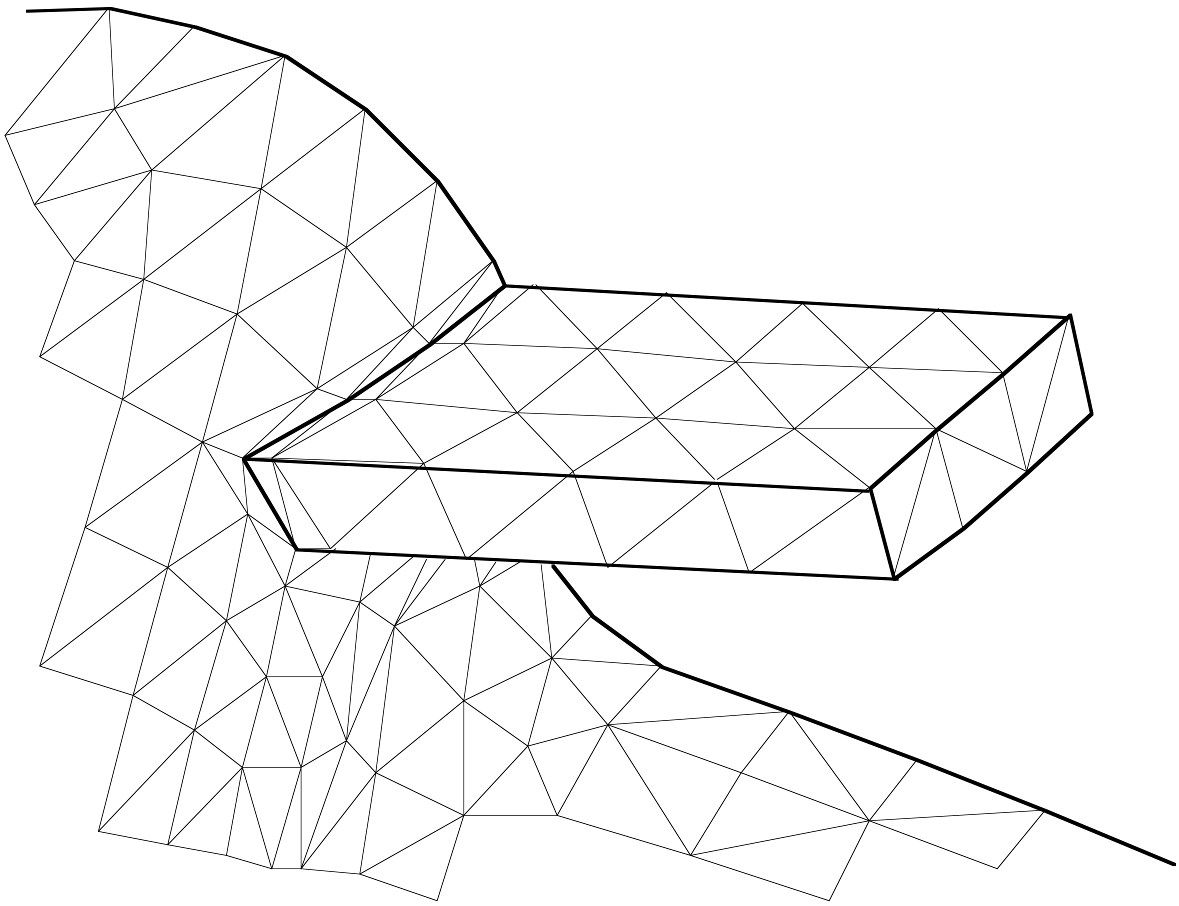


Fig. 1b - Close-up view of the mesh of Fig. 1a, showing the detail of the mesh near the waveguide openings.

The mesh size is suited for analyzing the structure up to about 1000 MHz, since the mean length of the edges of the mesh is about 5 cm (the longest edge is about 8 cm), and we found that fairly good results are to be expected from the code up to a frequency where the largest dimension of the triangles is about 1/4 of the wavelength. Of course, a finer mesh would allow to analyze the cavity up to higher frequencies, but it was not possible to consider a refined model, since we were close to the maximum number of elements that, at present, can be considered in the code without running out of memory. For the same reason both the rectangular waveguides and the conical tapers have been included in the model only up to a certain distance from the central body of the cavity. The waveguides are short-circuited at a distance of 25 cm from the cavity, and the conical sections, which have the same taper angle as in the actual cavity, are such that the total length L of the model is 96 cm. Considering short-circuited waveguides is no problem, since post-processing of the data by POPBCI can account for longer waveguides and for the dissipative loads.

The truncation of the tapers probably affects in some way the simulations, but we were forced to consider such a solution, since longer tapers would require a larger number of patches. In any case, after running the code, we checked that the fields of the modes calculated by MORESCA have very small amplitudes at the far end of the tapers, and therefore considering a short circuit thereat, in place of an impedance condition as it would be theoretically required, only gives a small error on the determination of the resonant frequencies.

This fact is confirmed by some preliminary simulations performed on a cavity model without waveguides by comparing the results from simulations of cavities with full-size tapers and with shortened tapers. In this case we could take advantage from the symmetry of the cavity with respect to the three coordinate planes and thus we could consider a mesh covering only one eighth of the cavity wall (Fig. 2a,b show the two meshes used in the simulations).

Table 1a,b report the resonant frequencies, the Q-factors and the geometrical parameters R_p/Q and R_P/Q calculated in the two cases (Q-factors were calculated assuming a copper cavity with conductivity $\sigma = 58.0\times 10^6$ S/m). The modes are classified according to the even or odd symmetry with respect to the coordinate planes (even symmetry = magnetic wall; odd symmetry = electric wall). It is easy to identify in the table monopole modes ($R_p/Q \neq 0$; $R_P/Q = 0$) and dipole modes ($R_p/Q = 0$; $R_P/Q \neq 0$) from quadrupole modes (or modes with higher azimuthal variations), that are those with $R_p/Q = 0$; $R_P/Q = 0$.

It can be noted that, as expected, only the modes at the high end of the considered band are affected by the shortening of the taper sections. In particular, the transverse impedance of modes no. 23 and 24 is rather smaller in the full-sized cavity due to the transit time effect; moreover, the two deflecting degenerate modes resonating at 951.7 MHz in the full-sized cavity (mode no. 25 and 26 in Tab. 1a) are shifted in frequency by the shortening of the conical sections to 970.8 MHz (mode no. 29 and 30 in Tab. 1b), but their transverse impedances do not change much. For all other modes the results do not differ by more than a few percent in the full-sized and the shortened models.

On the basis of these observations we conclude that also the results obtained by using the model of Fig. 1 are a meaningful approximation of the real behavior of the real, full-sized cavity.

As far as the accuracy of the resonant frequencies is concerned, we note that the fundamental-mode frequency calculated by MORESCA is slightly laarger than that obtained by 2-D codes, the relative difference being about 1%. It can be observed that the error is comparable to that of other 3-D codes, since it is mainly due to the mesh size, in all cases coarser than that used in 2-D simulations.

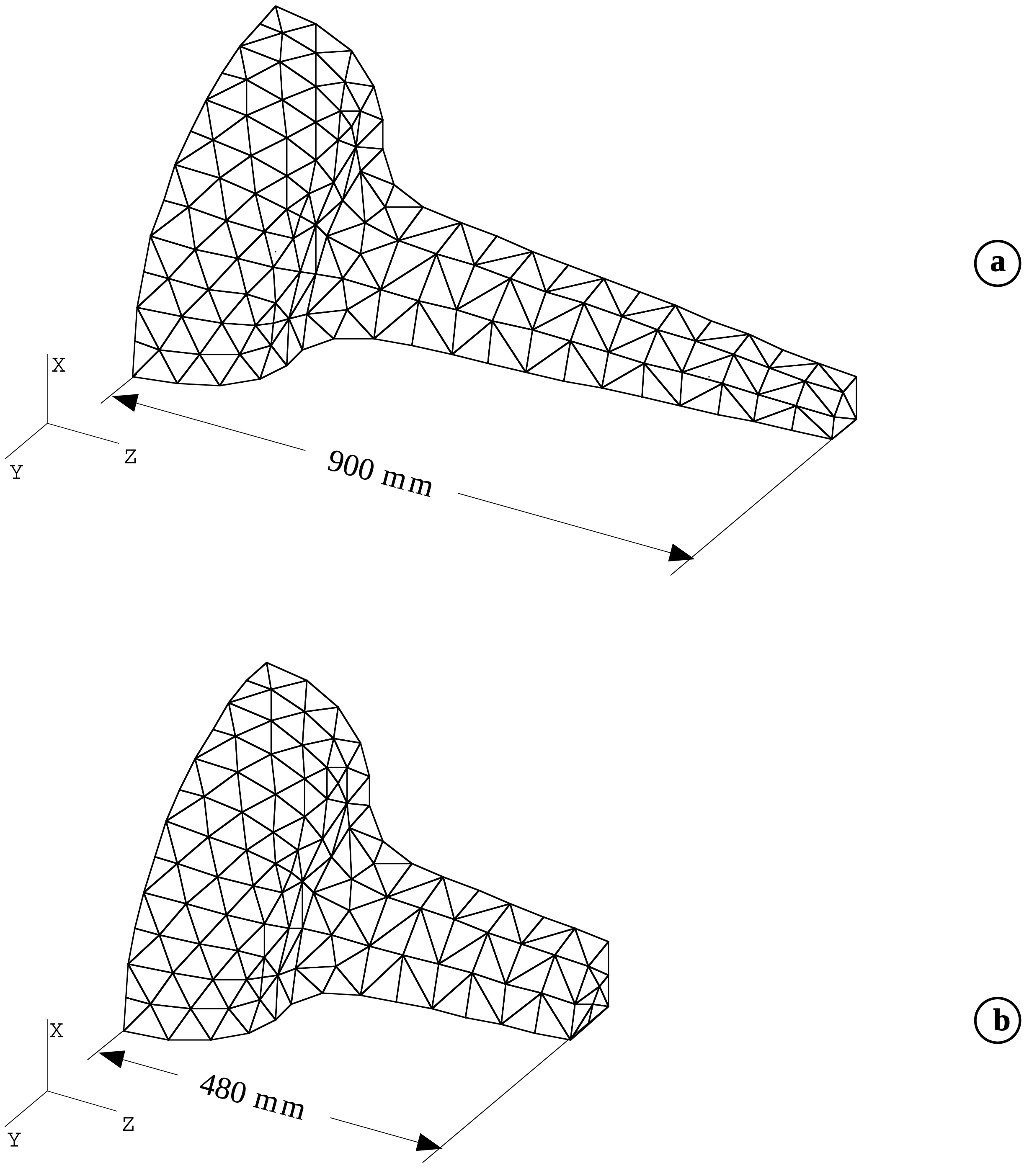


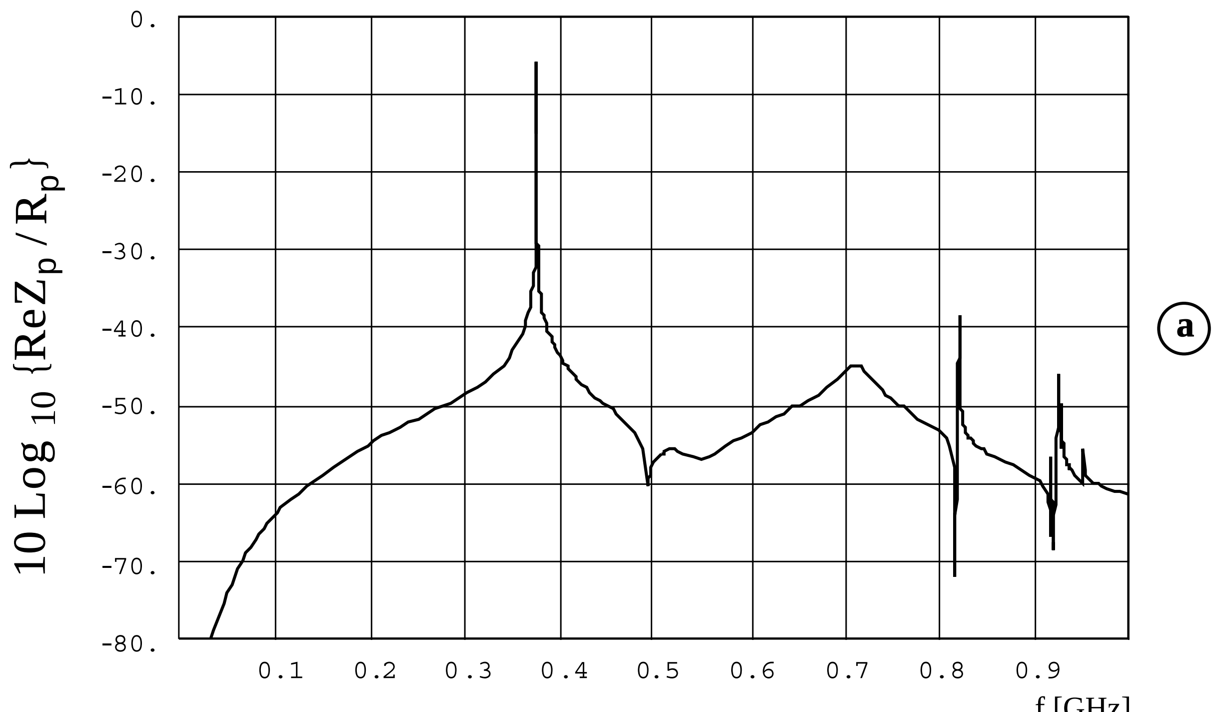
Fig. 2 - The meshes of the two model of the plain DAΦNE cavity used to calculate the modes of Table 1a,b; a) full-sized cavity (see Table 1a); b) reduced length cavity (see Table 1b).

Table 1a - Results of the simulation of the full-sized DAΦNE cavity without the waveguides (modes up to 1000 MHz)

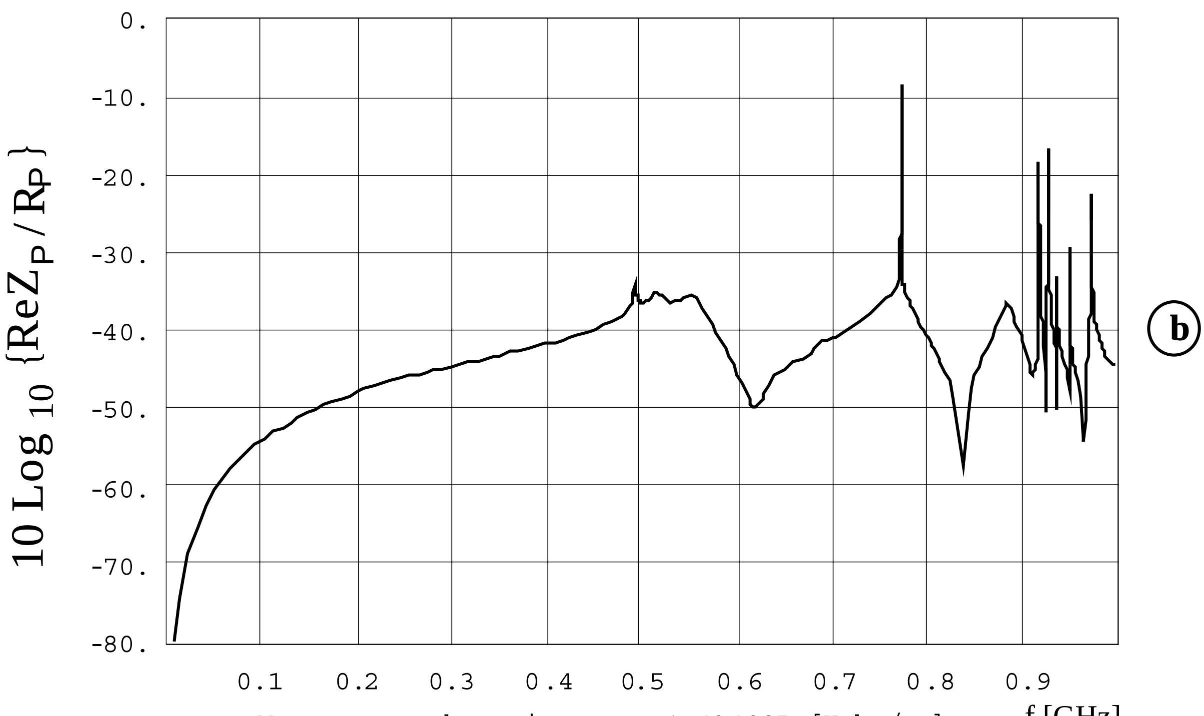
Mode no.	Symmetry respect to plane: x = 0	y = 0	z = 0	Freq. [MHz]	Q	R_p/Q [Ω]	R_p/Q [Ω/m]
1	even	even	odd	381.7	52600	58.4	0.0
2	odd	even	even	509.1	51650	0.0	57.4
3	even	odd	even	509.2	51650	0.0	57.4
4	odd	even	odd	548.7	52800	0.0	126.4
5	even	odd	odd	548.8	52800	0.0	126.4
6	even	even	even	682.4	60600	0.0	0.0
7	odd	odd	even	682.5	60600	0.0	0.0
8	even	even	even	706.4	49800	18.55	0.0
9	even	even	odd	741.7	62750	0.0	0.0
10	odd	odd	odd	741.7	62750	0.0	0.0
11	odd	odd	even	741.9	95100	0.0	0.0
12	odd	even	odd	769.9	50450	0.0	36.3
13	even	odd	odd	770.0	50450	0.0	36.3
14	odd	even	even	771.2	44375	0.0	63.4
15	even	odd	even	771.3	44375	0.0	63.4
16	even	even	odd	817.6	85700	0.19	0.0
17	odd	even	even	822.7	65770	0.0	0.0
18	even	odd	even	822.7	65770	0.0	0.0
19	odd	even	even	882.8	55500	0.0	31.5
20	even	odd	even	882.8	55500	0.0	31.5
21	odd	even	odd	923.2	72770	0.0	0.0
22	even	odd	odd	923.2	72770	0.0	0.0
23	odd	even	even	925.2	67560	0.0	0.16
24	even	odd	even	925.2	67560	0.0	0.16
25	odd	even	odd	951.7	44850	0.0	5.22
26	even	odd	odd	951.7	44850	0.0	5.22
27	even	even	even	953.1	50100	0.0	0.0
28	odd	odd	even	953.2	50100	0.0	0.0
29	even	even	even	961.8	57620	0.0	0.0
30	odd	odd	even	961.8	57620	0.0	0.0

Table 1b - Results of the simulation of the reduced-length DAΦNE cavity without the waveguides (modes up to 1000 MHz)

Mode no.	Symmetry respect to plane: x = 0	y = 0	z = 0	Freq. [MHz]	Q	R_p/Q [Ω]	R_P/Q [Ω/m]
1	even	even	odd	381.8	52650	58.3	0.0
2	odd	even	even	509.2	52780	0.0	58.1
3	even	odd	even	509.2	52780	0.0	58.1
4	odd	even	odd	548.7	52850	0.0	123.0
5	even	odd	odd	548.8	52850	0.0	123.0
6	even	even	even	682.2	60920	0.0	0.0
7	odd	odd	even	682.2	60920	0.0	0.0
8	even	even	even	706.1	52850	17.4	0.0
9	odd	odd	even	741.6	95400	0.0	0.0
10	even	even	odd	741.8	65300	0.0	0.0
11	odd	odd	odd	741.8	65300	0.0	0.0
12	odd	even	odd	770.6	51000	0.0	38.0
13	even	odd	odd	770.8	51000	0.0	38.0
14	odd	even	even	771.7	48600	0.0	66.8
15	even	odd	even	771.8	48600	0.0	66.8
16	even	even	odd	817.7	83450	0.22	0.0
17	odd	even	even	823.0	57700	0.0	0.0
18	even	odd	even	823.0	57700	0.0	0.0
19	odd	even	even	885.7	62100	0.0	32.76
20	even	odd	even	885.7	62100	0.0	32.76
21	odd	even	odd	922.6	67500	0.0	0.0
22	even	odd	odd	922.6	67500	0.0	0.0
23	odd	even	even	931.7	75500	0.0	2.17
24	even	odd	even	931.7	75500	0.0	2.17
25	even	even	even	952.7	46000	0.0	0.0
26	odd	odd	even	952.8	46000	0.0	0.0
27	even	even	even	960.4	63900	0.0	0.0
28	odd	odd	even	960.4	63900	0.0	0.0
29	odd	even	odd	970.8	55150	0.0	4.28
30	even	odd	odd	970.8	55150	0.0	4.28

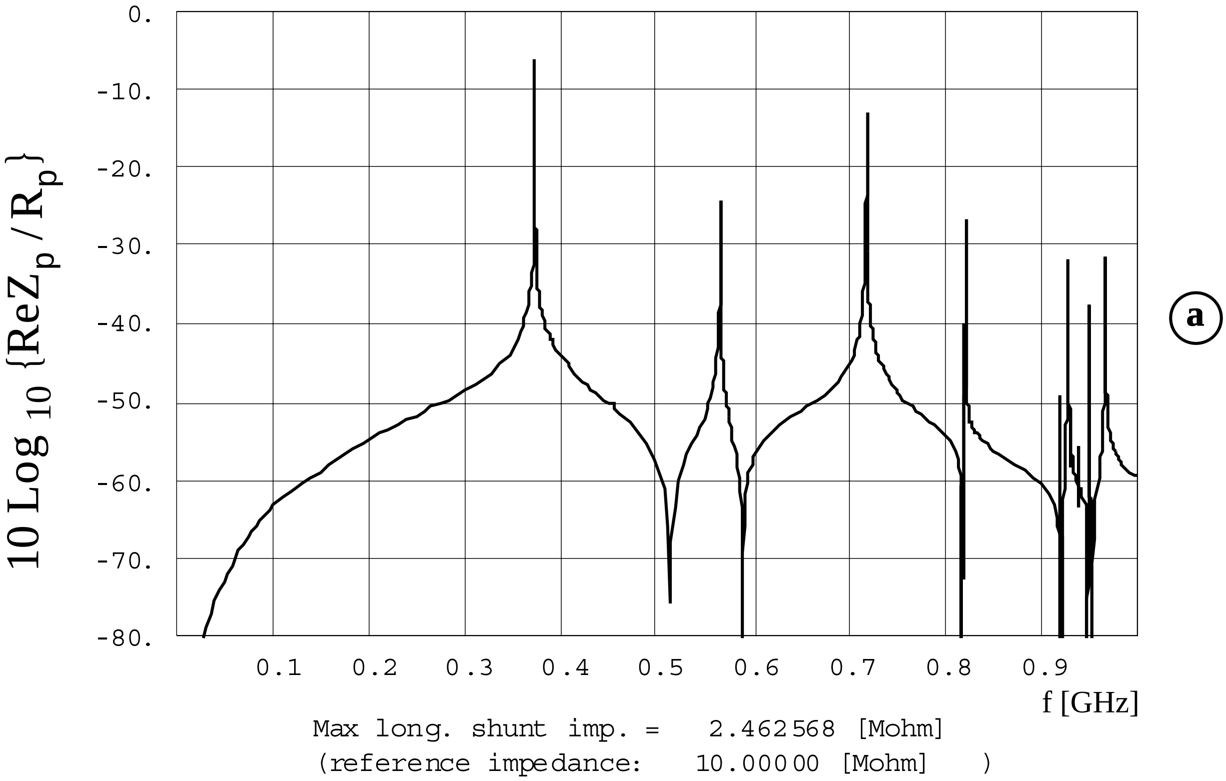


Max long. shunt imp. = 2.461388 [Mohm]
(reference impedance: 10.00000 [Mohm])



Max trans. shunt imp. = 1.494025 [Kohm/mm]
(reference impedance: 10.00000 [Kohm/mm])

Fig. 3 - Longitudinal and transverse coupling impedances of the DAΦNE cavity in the 0 - 1000 MHz frequency band (waveguides terminated with perfectly matched loads)



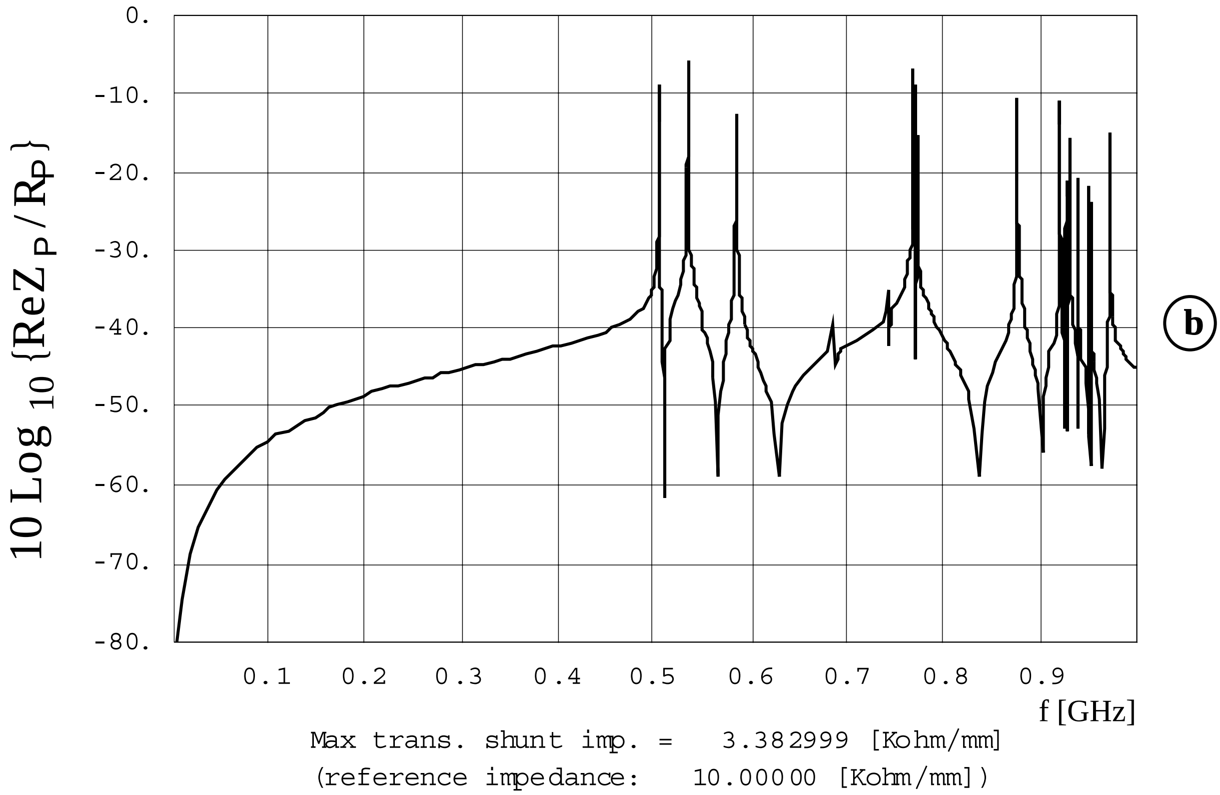


Fig. 4 - Longitudinal and transverse coupling impedances of the DAΦNE cavity in the 0 - 1000 MHz frequency band (waveguides short-circuited)

4 - COUPLING IMPEDANCES OF THE DAΦNE CAVITY WITH WAVEGUIDES

After the model of Fig. 1 has been analyzed by MORESCA, the resonant frequencies and the modal fields have been used as inputs to the post-processor POPBCI to evaluate the coupling impedances. As reported in [4], POPBCI can calculate the real part of Z_p and Z_P as a function of ω, thus allowing to estimate the coupling at a generic beam harmonic. The plots of Re{Z_p} and Re{Z_P} in the case of waveguides closed on perfectly matched loads are reported in Fig. 3a,b. For reference, Fig. 4a,b shows the same quantities when the loads are replaced with short circuits. The impedances are plotted in a logarithmic scale and are normalized to reference impedances $R_p = 10$ MΩ and $Z_P = 10$ MΩ/m respectively. The accelerating mode is found to resonate at 374.0 MHz, very close to the value of 372.8 MHz found by an other kind of 3-D simulation [9]. Due to the waveguide apertures the resonance is 7.7 MHz below the vaalue calculated by MORESCA for the cavity without waveguides, and also this frequency shift compares well with those from 3-D simulations and with experimental results [9].

Comparing Fig. 4a to Fig. 3a we note that the waveguide dampers are very effective in smoothing the longitudinal impedance peaks other than the fundamental accelerating mode. In particular the damping introduced for the mode at 717.0 MHz (that corresponds to mode no. 8 in Table 1a) and at 567.7 MHz (a mode existing only in the cavity equipped with waveguides) is really good, whereas the effect on the resonance at 821.3 MHz (corresponding to mode no. 16 in Table 1a) is a bit weaker, though the impedance level at that frequency exceeds 1 KΩ only by a small amount. It can be also observed that at the fundamental-mode frequency the waveguide dampers reduce by 20% the longitudinal impedance with respect to the value obtainable from the plain cavity of Fig. 2a (from Table 1a we deduced R_p = 3.13 MΩ for the fundamental mode). This reduction is mainly due to the decrease of the Q-factor caused by the insertion of the waveguides, that perturb the current flow on the cavity wall (we recall that the waveguides are well below cut-off at this frequency, and thus the decrease of the Q-factor cannot be ascribed to the power dissipated inside the terminations).

The effectiveness of the waveguides in damping dipole modes is also good, as evidenced in Fig. 3b, apart from the peak surviving at 772.5 MHz. At this frequency the transverse impedance has a value of about 1.5 MΩ/m, to be compared with that of the corresponding mode in the plain cavity (mode no. 12 or 13 in Table 1a), that is R_P = 1.83 MΩ/m. It is alear that, in this case, the damping effect is rather poor. An examination of the modal field of the mode resonating at 772.5 MHz and of the corresponding one in the plain cavity reveals that this mode has a field structure close to the one of the TM_{112} of the cylindrical cavity, strongly perturbed by the conical sections. This fact is evidenced in Fig. 5, that shows a cut of the cavity along the y = 0 plane, namely along the symmetry plane of the structure (see Fig. 1a), together with the contour plot of the y-component of the magnetic field for the mode at 772.5 MHz. It can be noted that this component is very weak at the waveguide aperture, that is placed near a null of H_y. On the other hand coupling with the TE_{10} mode in the waveguide (the only mode above cutoff at 772.5 MHz) is mainly through this component, and therefore the mode remains trapped in the cavity body, since it is very weakly coupled to the waveguides.

In order to verify the sensitivity to the positioning of the waveguides of the amount of damping of the mode that remains trapped we carried out some simulations with a slightly different cavity shape, where the waveguides are moved from their original position in order to allow a better coupling. We found that a radial displacement of 3 cm and an additional tilt of 5° lowers the transverse impedance of the trapped mode almost by a factor 2, giving rise to a value of about 0.8 MΩ/m, without affecting noticeably the values of both impedances at other frequencies. A further displacement may produce a slightly better damping, but probably a narrow-band damper designed "ad hoc" for that mode would be necessary if the impedance of the mode at 772.5 MHz is to be lowered by a substantial amount. Other simulations, concerning a cavity equipped with three extra waveguides (placed so as to obtain a structure symmetric with respect to the z-axis), showed that this potentially dangerous mode is no more trapped, its impedance being lowered by a factor 100, at the expense of a lowering by an additional 15% the impedance of the fundamental mode.

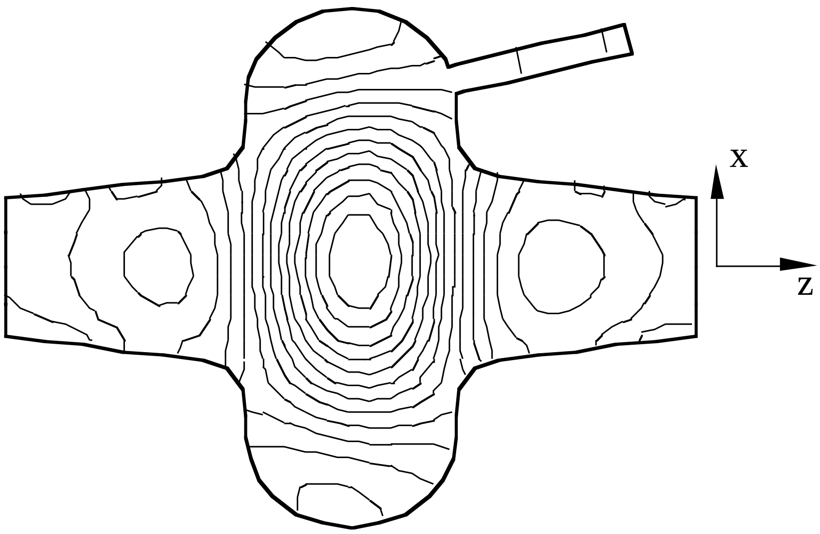
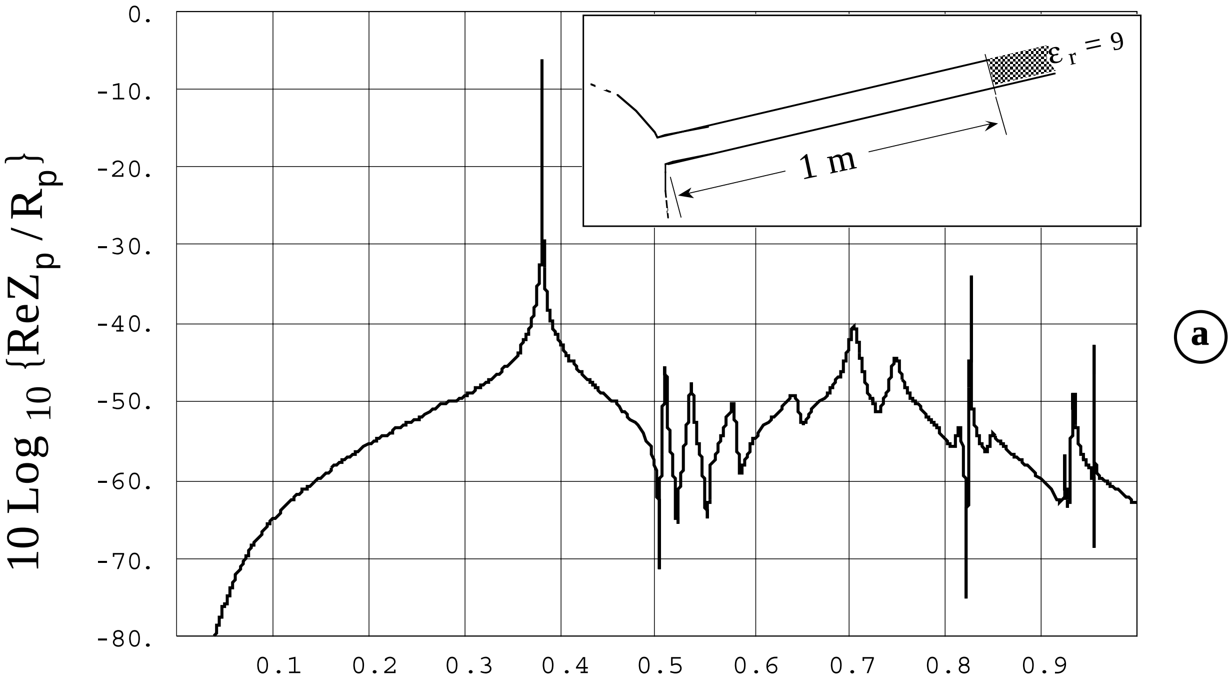
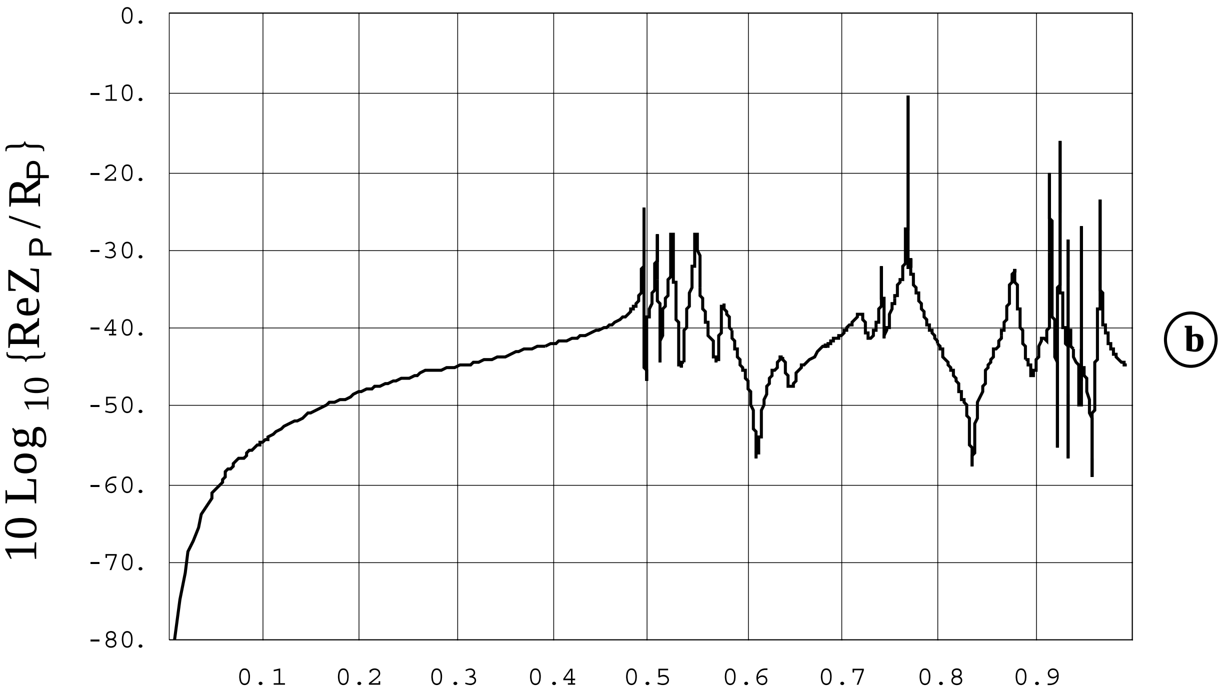


Fig. 5 - Contour plot showing the amplitude of the y-component of the magnetic field of the mode resonating at 772.5 MHz.

Other simulations have been carried out to check the influence of a mismatch of the waveguide terminations on the HOM damping: we simulated a termination consisting of waveguides filled with a dielectric of relative permittivity $\varepsilon_r = 9$, beginning at a distance of 1m from the cavity ports (see insert in Fig. 6). The resulting VSWR is rather high, being larger than 3 throughout the considered frequency band. The coupling impedances calculated in this case are plotted in Fig. 6a,b. It is found that the mismatch does not change considerably the HOM damping, since it only gives rise to a ripple in the plots.



Max long. shunt imp. = 2.461236 [Mohm]
(reference impedance: 10.000000 [Mohm])



Max trans. shunt imp. = 1.071317 [Kohm/mm]
(reference impedance: 10.000000 [Kohm/mm])

Fig. 6 - *Longitudinal and transverse coupling impedances of the DAΦNE cavity in the 0 - 1000 MHz frequency band (reflecting terminations)*

5 - EFFECT OF THE WAVEGUIDE DAMPERS ON THE POWER DISSIPATION OF THE ACCELERATING MODE

As mentioned before, the waveguides connected to the cavity body, though well below cutoff at the resonant frequency of the accelerating mode, decrease the Q-factor of that mode due the perturbation of the wall currents. It is found that the Q-factor reduces from 52600 (Table 1a) to 41000.

The increased current density near the waveguide openings increases the power dissipated thereat by an amount that should be taken into account in the thermal design of the cavity. To quantify this effect we calculated the power dissipated on each triangular patch of the model in Fig. 1, assuming that the cavity walls are made of copper ($\sigma = 58.0\times 10^6$ S/m) and that the total energy stored in the cavity is 1 mJ.

We found that, as expected, the "hot spots" are in proximity of the insertion of the waveguides into the cavity body. A quantitative insight on this topic is obtained from Fig. 7, where the triangular elements surrounding one of the waveguides apertures are labelled with the calculated values of the dissipated power density in mW/cm^2 (the triangles are drawn to scale and they are untied due to the curvature of the cavity wall).

The largest value calculated is 56 mW/cm2 on the beginning of the lateral wall of the waveguide[1].

The values of Fig. 7 should be compared with the corresponding ones obtained in the case of the plain cavity in Fig. 2. We found that in this case the largest value of the dissipated power density is about 5 mW/cm2, i.e. a value comparable to those of Fig. 7, apart from the close proximity to the waveguide openings. This fact confirms that the extra power dissipation responsible of the Q-factors decrease occurs close to the waveguide openings, and that an accurate thermal design is necessary to keep the operating temperature below a safe limit.

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[1] We recall that the reported values are mean values of the dissipated power density inside each element, i.e. they are obtained by dividing the total power dissipated inside a triangle by its area. It is of no practical interest to give the actual power density dissipated near the waveguide apertures, since, theoretically, the magnetic field (and therefore the power density) diverges at the aperture edges.

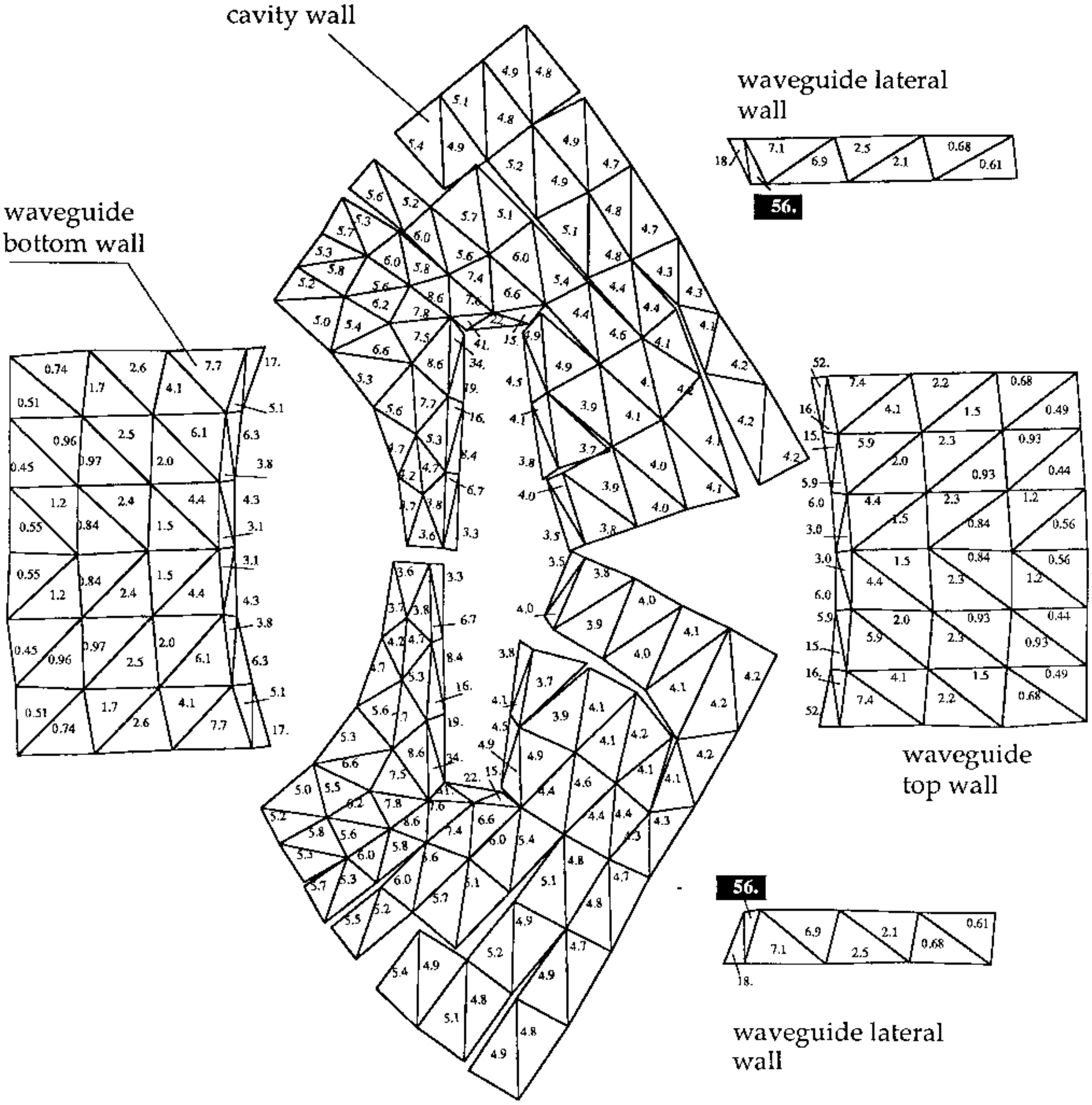

Fig. 7 - Map of the power density dissipated near the waveguide openings (assuming copper walls) when the energy stored in the fundamental mode is 1 mJ. The values inside each mesh element represent the mean value of the dissipated power density in mW/cm2.

6 - COMPARISON WITH OTHER SIMULATIONS

Some simulations have been carried out at LNF using both a 3-D code (HFSS by Hewlett-Packard) [9] and a semi-analytical method applied to the output of 2-D codes [10].

HFSS is a finite element code specialized for the e.m. analysis of microwave junctions, and is able to determine scattering parameters and E and H fields inside the junction, when a port is excited at a given frequency. Its features do not include an eigenvalue-problem solver, as it is necessary to find the resonant modes of a cavity. For these reasons its use in the simulation of the DAFNE cavity is not straightforward, since, in order to get the field distribution of any desired mode, it is necessary to consider an appropriate excitation and to perform a frequency-by-frequency analysis in a small frequency band around each resonance (whose location in the frequency spectrum should be known in advance, at least roughly). Once the resonant fields are known, it is possible to compute Q-factors and coupling impedances. Due to its features, HFSS appears to be probably the best tool to help in the design of the RF coupler and of the fundamental mode tuner. The main limitation of this code, when used in the HOM analysis of heavily damped cavities such as the DAFNE one, derives from the fact that it is not possible to define a line excitation along the cavity axis, as it would be necessary to get the correct field distributions when the cavity losses are high. In this case, in fact, it is not possible to assume that the field structure in the cavity volume is independent from the type of the excitation, as it is customary when dealing with a low-loss cavity excited at a frequency close to anyone of its resonances. When the energy lost in the dampers is a large fraction of that stored in the cavity, as it happens when a HOM is heavily damped, and when considering the field generated by the beam at a frequency where the mode spectrum becomes crowded (see Table 2a), it is necessary to take into account the contribution of many different modal fields. As a result this field, used to evaluate the coupling impedances (see Eq. 2), may be quite different from the field induced in the structure under a different excitation, i.e. that used in the simulations by HFSS.

The technique used in [10] for the evaluation of the damping effect is based on the determination of the field induced in the waveguides by suitable current sheets at the apertures that connect the cavity and the waveguides. These current sheets, in turn, are approximated with the modal magnetic fields of the unperturbed cavity, which can be deduced from 2-D codes. The approximation is valid as far as the apertures are "small", i.e. when they do not perturb the fields inside the cavity too much. For the DAFNE cavity this is the case only when dealing with the lower order modes of the cavity.

The results reported in [9-10] refer to the first monopole modes only. For those modes the comparison with the results reported here shows a reasonable agreement.

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