# A Power Prototype Design of an Accelerating Cavity with Broadband H.O.M. Suppressor.

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*Abstract*

A prototype of a radiofrequency cavity with a heavily damped HOM spectrum is under design at "Sincrotrone Trieste" for the ELETTRA Synchrotron Light Source. The tests on the prototype will be performed under full RF power conditions. The design is based on a low power prototype, which has shown very satisfactory HOM damping behaviour on a wide frequency band. The HOM power is coupled out to an external load by means of two square waveguides. One of the more critical items of the design, the HOM power absorbing system, is discussed here.

## 1. INTRODUCTION

In the last years, during the construction, installation and commissioning of the four RF cavities for the Synchrotron Light Source ELETTRA at Trieste, an alternative accelerating cavity has been studied [1], [2], [3].

The main feature of this new design is the high damping of the Higher Order Mode (HOM) resonances. The power induced in the HOM is extracted via two large apertures on the cavity walls; two waveguides (WG) convey it to a broadband load where it is dissipated.

The load, which is expected to dissipate a few kilowatts, is the critical item in this design, since either it operates in UHV environment or the power is fed through a ceramic window to a conventional device in air. Many solutions have been proposed in other laboratories where similar projects are under study [4], [5], [6].

Nevertheless our case requires a particular study, since our goal is a nearly monochromatic cavity. Thus the apertures on the cavity walls are rather large, consequently the WG is large, having a 250x250 mm square section.

An intensive analysis has then been started, based mainly on computations with the HP 85180A High-Frequency Structure Simulator (HFSS), a software package which calculates the S-parameters of passive high frequency structures. The feature of the package of main interest to us is that materials characterized by complex permittivity and permeability ($\varepsilon^*$, $\mu^*$) can be simulated as well.

## 2. THE CAVITY

The pill-box shape, without nose-cones, has been found to be the preferred one for our design, since it allows the easiest mechanical coupling of the waveguides to the external cavity surface. Furthermore the large apertures on the cavity walls affect the fundamental mode less than for a bell-shaped structure, the cavity being still good for acceleration [7], [8].

The first studies carried out on this kind of damping method showed that the $TE_{111}$ and the $TM_{011}$ modes of the pill-box cavity have a preferred coupling to the $TE_{11}$ and $TM_{11}$ waveguide modes [2]. Thus to minimize the cut-off frequency, $f_c$, for these modes the waveguide shape was chosen square (@ a = 250 mm, $f_{cTE10}$ = 600 MHz, $f_{cTE11} = f_{cTM11}$ = 850 MHz). In this way, along with an optimization of the load (pyramid plus wedges in the WG corners), an important improvement of the damping efficiency has been obtained. The Q value of the $TE_{111}$-like mode, at 980 MHz, could be lowered to 20 while that of the $TM_{011}$-like mode, at 1047 MHz, could be reduced to 70. These measures have been taken on a low power prototype, with a conventional load. The Qs of the other modes are lower than 100 [8].

With a further optimization of the coupling aperture shape and of the absorbing device, a stronger damping of the Q-values can be expected , particularly for the $TE_{111}$-like mode and for the $TM_{011}$-like mode, which usually are those with the highest probability to drive multibunch instabilities, transverse and longitudinal respectively.

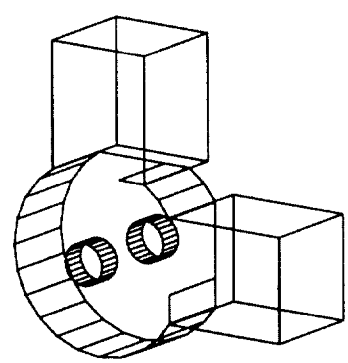

Figure 1. The Pill-Box cavity simulated with HFSS.

We have analyzed the performance of the HFSS package with resonating structures. The package cannot study narrow band devices like high Q-resonators, since the simulation would require a high number of frequency points for the analysis of the resonating peak, reaching probably the limits of the computing system (In our case an HP 9000-715 workstation, 128M RAM, 1G memory). This is not the case when working with low Q resonances, as for a damped mode, where covering a 1+2 MHz frequency span with points every 50+100 KHz is sufficient to characterize the resonance.

The low Q resonance can be obtained also for an undamped resonator, scaling the conductivity by a certain factor. Doing that for the $TM_{011}$ mode in our undamped pill-box cavity, we found a frequency of 975.2 MHz and a Q of 4500 ($\sigma$ scaled by a factor ~7) which agree fairly well with the prediction of OSCAR2D (973.7 MHz and Q of 4000). Connecting one waveguide to the cavity surface, we find a frequency of 940.5 MHz for the $TM_{011}$ mode while on the prototype the frequency was measured equal to 942.0 MHz.

Observing the plots of the field excited in the WG by the $TM_{011}$ mode, it was clearly shown that it is the $TM_{11}$ WG mode, thus confirming our experimental observation. This stresses again the need to design the absorbing system also for the $TM_{11}$ WG mode. The conclusion of these tests is that we can proceed in the optimization of the whole damped cavity using HFSS, including the lossy damping material.

## 3. Analysis of the HOM Power Absorber

### *3.1 Ceramic Window*

The straightforward solution for the HOM power absorber would be the separation of cavity vacuum and load environment by means of a ceramic window. This solution could make use of a conventional absorber, requiring only a particular design of the load's shape.

Tests made on our low power prototype cavity with a dielectric window ($\varepsilon_r$~6.0) inserted into the WG have shown that, to maintain a satisfactory damping behaviour between 700 and 1000 MHz, the minimum size should be circular, Ø 200 mm [7]. Simulations with HFSS confirmed a good $|S_{11}|$ (0.1÷0.3, on the same frequency interval) for the structure with this dielectric, but afterwards, inserting an alumina window ($\varepsilon_r$~10.0) of this diameter, the $|S_{11}|$ at the WG input port deteriorates to 0.5÷0.8 , depending on the thickness of the alumina (5÷10 mm). Hence, considering also the problems that could arise from the vacuum point of view if the ceramic window suffered from a breakdown, this solution has been definitively rejected.

### *3.2 UHV Microwave Absorbing Material Load.*

Along with the studies on WG HOM couplers, particularly at CEBAF [6], [9], an intensive R&D has been developed on Microwave Absorbing Materials for the construction of the HOMs' dissipating loads.

Even if up to now good results have been obtained in this field, it seems to be not suitable for our needs, mainly for the huge dimensions that such a load would require in our case. In fact, our test low power loads are pyramids of 250x250x1140 mm, and corresponding wedges for the corners. Also after an optimization of the shape and even if the absorbing characteristic are definitively better, allowing a smaller design, we expect still a rather large object. Apart from the costs that should be taken into account, the outgassing problems seems to exclude in our case this solution too.

### *3.3 Ferrite Load*

The DAΦNE group at Frascati is dealing with a similar project for the Φ-factory RF cavities [4], [10]. The first solution they proposed for the load is to use *Trans Tech TT2 11R* ferrite tiles which they have found to behave satisfactorily under UHV and to match nicely the vacuum characteristic impedance. Thus we have taken the values for ε* and μ* shown in [10] and designed with HFSS a load for our needs.

The simulated load is a sheet of ferrite material put on the bottom of the WG; thicknesses of 5, 10, 15 mm have been considered, finding the best behaviour, for all considered modes, with 10 mm. The results, shown in figure 2, are satisfactory for the $TE_{10}$ mode ( $|S_{11}|\leq 0.1$), encouraging for the $TE_{11}$ mode ($|S_{11}|\leq 0.2$, if f>900 MHz), not so good for the $TM_{11}$ mode where our specification of having $|S_{11}|$ better than 0.2 is not met on more than half of the considered bandwith. The same happens with the $TE_{20}$ mode.

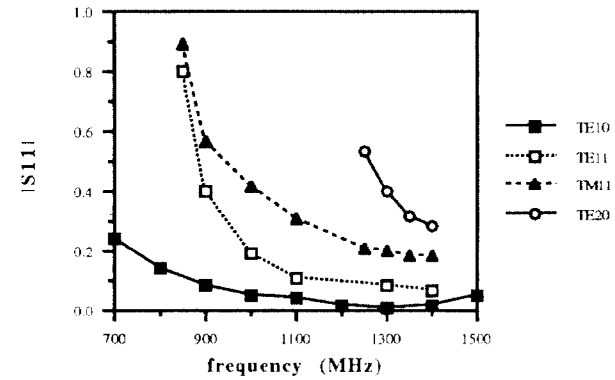


Figure 2. Results of the ferrite load for the first WG modes.

### *3.4 Waveguide to Coaxial Cable Transition*

A different solution, proposed by the DAΦNE group to overcome bonding problems that can be encountered with the ferrites described above, is to extract the HOM power from the WG via a WG to coaxial broad band transition. The ceramic window is then placed in the coaxial cable and becomes of traditional design as well as the load. [4], [11]

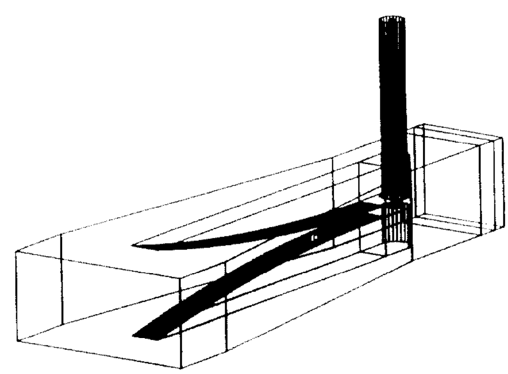

Figure 3. Broad band Transition for a rectangular waveguide.

We are taking into account a similar design. The WG to coaxial transition should be broad band, i.e. $|S_{11}|\leq 0.2$ over at least two octaves, should work on both degenerate polarizations of the fundamental mode of a square WG, $TE_{10}$ and $TE_{01}$, requiring thus two transitions 90° apart, finally should behave well with the $TE_{11}$ and particularly the $TM_{11}$ WG mode. Our work in these fields is still in progress, the first results obtained with HFSS are presented here.

The design has been divided in different steps. First a broad band transition for a rectangular WG (250x120mm) in the $TE_{10}$ mode has been analyzed. Two ridges have been inserted into the WG to match the 50 Ω cable impedance; the waveguide section has been reduced to a square section to keep the cut-off frequency well above the cavity $TM_{010}$ frequency (horn in the H-plane, see fig. 3) [12]. Adjusting the position of the short circuit plane which terminates the WG to 100 mm, the reflection coefficient $|S_{11}|$ at the WG input port was found to be below 0.2 up to 1.5 GHz.

In the next step of the project a transition for a square section WG has been studied starting from the above described structure. Two major changes have been required to obtain a good frequency response. Transforming the WG to a square section, the gap between the ridges has been further reduced to maintain the impedance matching. Along the ridges the waveguide section has been reduced also in the E-plane, like a pyramidal horn, as can be seen in fig.4.

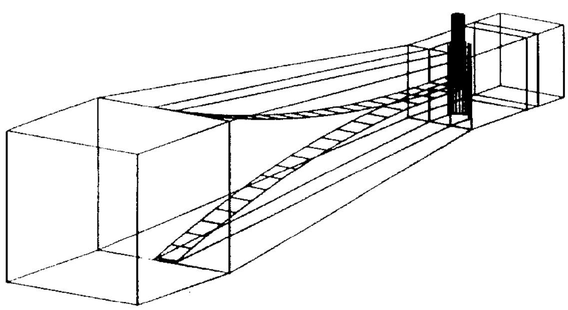

Figure 4. WG-Coaxial transition for a square section WG.

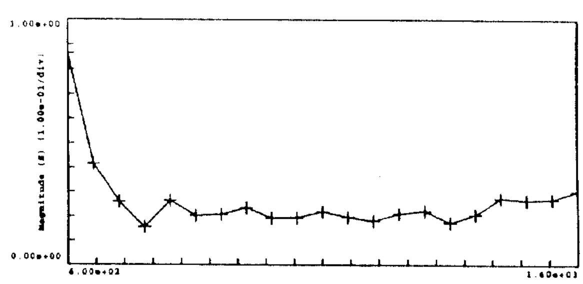


Figure 5. $|S_{11}|$ at WG input port for the transition in fig. 4.

The $|S_{11}|$ calculated by HFSS shows a nice flat behaviour, remaining below 0.3 up to 1.8 GHz. To meet our specifications we had to smooth the ridges, increasing their length to 750 mm. The final result is rather good, since $|S_{11}|$ remains within the specs up to 1.5 GHz, as shown in Fig. 5. The simulations presently deal with the third step of the design, that is the cascade of two transitions, one for the $TE_{10}$ mode, the second, 90° apart, for the $TE_{01}$ mode. It has been already verified that the first element doesn't affect the performance of the downstream one, while that of the first element has still to be improved. The future, final step of this study will deal with the $TE_{11}$ and $TM_{11}$ WG modes.

## 4. CONCLUSION

A global overview of the status of the HOM free resonator at Trieste has been presented. Many solutions for the HOM power absorbing load have been discussed. The study of a waveguide to coaxial cable transition has been detailed since it seems the more promising for our design.

## 5. ACKNOWLEDGMENTS

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## REFERENCES


[1] A. Massarotti, et al., "500 MHz Cavities for the Trieste Synchrotron Light Source ELETTRA", in *Proceedings of the 2nd EUROPEAN PART. ACC. CONF.*, Nice, France, June 1990, pp. 919-921.

[2] A. Massarotti and M. Svandrlik, "Proposal for a Broadband Higher-Order-Modes Suppressor for Radiofrequency Accelerating Cavities", in *Particle Accelerators*, 1991, Vol. 35 pp. 167-175.

[3] A. Massarotti, et al., "Further Developments of the Broad Band H.O.M. Suppressor at Trieste", in *Proceedings of the 3rd EUROPEAN PART. ACC. CONF.*, Berlin, FRG, March 1992, vol. 2, pp. 1185-1187.

[4] S. Bartalucci et al., "The RF Cavity for DAΦNE", in *Proceedings of the 1993 PART. ACC. CONF.*, Washington, USA, May 1993, pp. 778-780.

[5] H.D. Schwarz et al., "Design of a High-Power Test Model of the PEP-II RF Cavity", in *Proceedings of the 1993 PART. ACC. CONF.*, Washington, USA, May 1993, pp. 1039-1041.

[6] I.E. Campisi, "The Workshop on Microwave-Absorbing Materials for Accelerators", in *Proceedings of the 1993 PART. ACC. CONF.*, Washington, USA, May 1993, pp. 1115-1117.

[7] G. D'Auria, A. Fabris, A. Massarotti, C. Pasotti, C. Rossi, M. Svandrlik, "A nearly monochromatic cavity for high current storage rings", in *Nuclear Instruments & Methods in Physics Research*, A329 (1993), pp. 393-402.

[8] A. Massarotti, et al., "The Design of a Pill-Box Cavity with Waveguide HOM suppressors", in *Proceedings of the 1993 PART. ACC. CONF.*, Washington, USA, May 1993, pp. 953-955.

[9] I.E. Campisi et al., "the Design and Production of the Higher-Order-Mode Loads for CEBAF", in *Proceedings of the 1993 PART. ACC. CONF.*, Washington, USA, May 1993, pp. 1220-1222.

[10] R. Boni et al., "Study of Parasitic Mode Absorbers for the Frascati F-Factory RF cavities", in *Proceedings of the First Workshop on Microwave Absorbing materials for Accelerators (MAMAs)*, CEBAF, Newport News, VA. USA, February 1993. (in print)

[11] R.Boni, private communication.

[12] Ragan, Microwave Transmission Circuits, New York, McGraw-Hill, 1951, pp.358+361.