

# Broad-Band, Multi-Kilowatt, Vacuum, HOM Waveguide Loads for the PEP-II RF Cavity \*

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## Abstract

For the HOM damping waveguides in the PEP-II RF cavity to work effectively as high-pass filters a broad-band, low-reflection, load is required with a VSWR less than 2:1 in the frequency range 700 MHz to 2500 Mhz. Additional design constraints are vacuum operation, thus eliminating an RF window and a potential source of reflections, and the capability of dissipating up to 10 kW of HOM power. A compact baseline design using a lossy dielectric is proposed which fulfills these requirements based on results from numerical simulations. We present the electrical properties of such a load, discuss its thermal properties under high power conditions, and detail a fabrication technique for brazing the lossy dielectric onto the copper walls of the HOM waveguide. Finally, simulation results of an alternative design utilizing ferrites are presented.

## 1. INTRODUCTION

The dedicated HOM dampers in the PEP-II RF cavity are designed to lower the impedances of the cavity HOM's below the level at which the feedback system can damp the beam oscillations while preserving the shunt impedance of the accelerating mode. In practice, this can only be achieved if the coupling waveguides are terminated in broadband, low-reflection loads; high reflections degrade the effectiveness of the HOM damping scheme since they can increase the  $Q_{ext}$  of the cavity HOMs. The loads will be designed to dissipate up to 10 kW of power spread out across the frequency range

generated above the beampipe cutoff (2500-5000 MHz) by additional cavity HOMs and the broadband impedance of the ring. Furthermore, the load must be compact due to the limited space available for the cavity installation. The HOM load is in rectangular waveguide with dimensions 9.843" by 1" (25 cm by 2.54 cm,  $f_c=600$  MHz), which is connected to the PEP-II cavity [1,2].

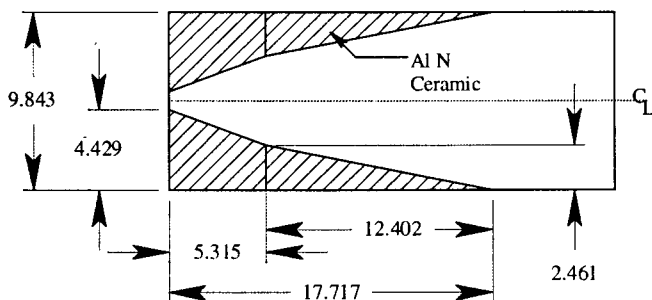
## 2. BASELINE DESIGN

### 2.1 Baseline Design Description

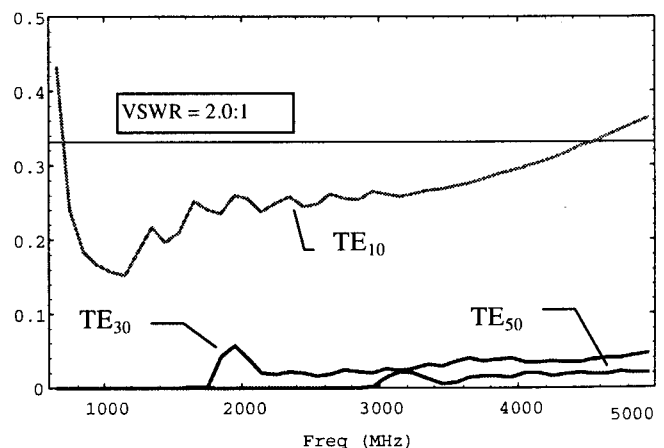
The baseline design consists of a 17.717" (45 cm) long two-stage taper using AlN with 7% by weight glassy carbon [3] which extends the full height of the waveguide. The two stage taper increases the useful frequency range of the load as compared to a single taper for a given load length. The longitudinal taper shape is shown in figure 1. Simulations of the electrical performance of this load indicate that it will meet our specifications figure 2. Note there is little mode conversion from the incident  $TE_{10}$  to the other odd TE modes.

Figure 3 shows the power density in the ceramic for the cavity generated power. This composite density was created by adding together the contributions of the modes below 2500 Mhz produced by a beam current of 3 A. The peak power density is  $5.5 \text{ W}\cdot\text{cm}^3$ .

### 2.2. RF measurement of test load.

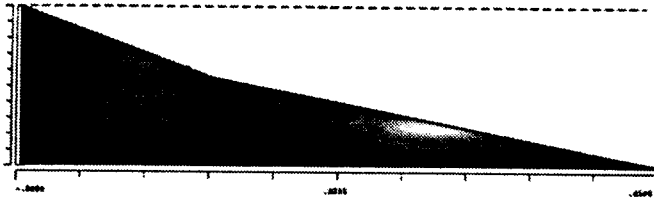


**Figure 1. Lossy ceramic layout looking down on the broadwall of the waveguide. Dimensions in inches. of 700-5000 Mhz. Part of this power comes from the cavity HOMs in the 700-2500 MHz range, while the rest is**



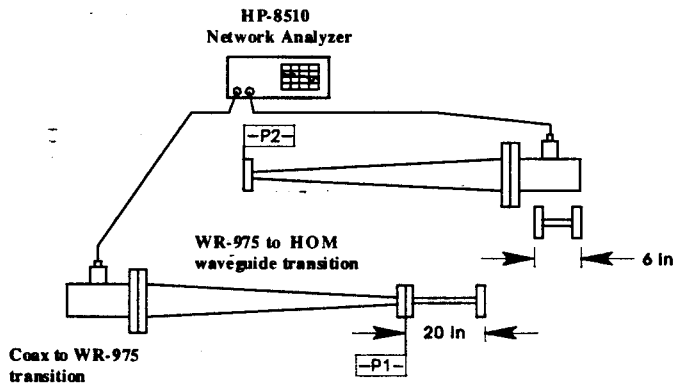
**Figure 2. Voltage reflection coefficient into  $TE_{10}$ ,  $TE_{30}$ , and  $TE_{50}$  modes with incident power in the  $TE_{10}$  mode for the baseline design.**

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**Figure 3. Composite power density of cavity generated power with a beam current of 3A. There are two regions of increased power density; the peak is  $5.5 \text{ W}\cdot\text{cm}^{-2}$ .**

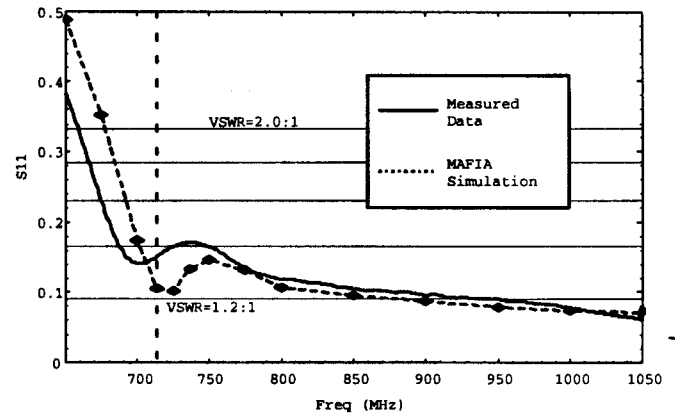
The reflection coefficient of a test load which had the longitudinal ceramic layout detailed in figure 1, but which was filled with 0.75" of lossy ceramic material was measured. The longitudinal profile shown in figure 1 was made in three sections. To achieve the overall thickness in each section, three ~0.25" thick lossy ceramic tiles of the same shape where stacked on top of each other. All these pieces were inserted into a 20" piece of uniform waveguide with a short bolted to the end to form the closed HOM load. This test load was connected to the end of a 48" waveguide down taper, which tapered in both height and width to go from WR-975 to the HOM waveguide size. The downtaper itself was connected to a WR-975 waveguide to coax transition which then fed into the network analyzer (fig. 4). A full two port TRL calibration was performed to calibrate the apparatus to the HOM ports of the downtapers ( $P_1$  and  $P_2$  in fig. 4). The bandwidth of the coaxial to waveguide transitions set the maximum frequency of measurement with this arrangement. The results of the measurement are shown in figure 5.



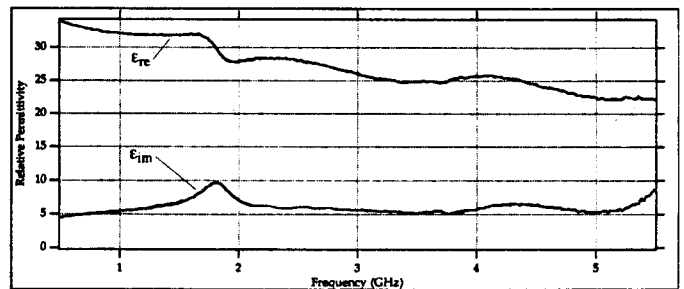
**Figure 4 Layout of test load measurement setup. The lossy ceramics were inserted into the 20" long waveguide section. The two identical RF assemblies and the 6" section were used for a TRL calibration at ports  $P_1$  and  $P_2$ .**

### 2.3. Comparison of simulations to measured data.

The comparison of MAFIA simulation results to measured data is shown in figure 5. The values of dielectric constant used in the simulations were based on measurements [4,5] on this particular batch of ceramics figure 6. These data show the dielectric constant to be anisotropic. In the simulations we used an isotropic dielectric constant with a value equal to the measured value in the direction of the electric field in the



**Figure 5. Measured  $S_{11}$  vs frequency and MAFIA simulation for 0.75" lossy ceramic with 0.25" air gap HOM load geometry. The profile of the lossy ceramics is the same as in figure 1.**



**Figure 6. Measured dielectric constant in the direction of the electric field for the ceramic used in the test load measurements.**

waveguide; figure 6 shows the variation of this component of the dielectric versus frequency. As an example: at 1 GHz the dielectric constant is  $\epsilon/\epsilon_0 = 33 + i 5.5$ .

## 3. BRAZING ASSEMBLY

It is difficult to braze large pieces of ceramic to copper because of the difference in the thermal expansion of the two materials; for copper it is  $18.5 \cdot 10^{-6} \text{ }^\circ\text{C}^{-1}$  and for the alumina nitride it is  $4.6 \cdot 10^{-6} \text{ }^\circ\text{C}^{-1}$ . The initial plan was to braze the ceramic tiles directly to copper with Ticusil™ (liquidus temperature of  $850 \text{ }^\circ\text{C}$ ); however, it was possible to braze slightly larger size tiles using Cusin-1-ABA™ (liquidus temperature of  $806 \text{ }^\circ\text{C}$ ). The braze fillet formed with the Cusin-1-ABA™ is more ductile [6]. Acoustic imaging of the bond foot print confirmed a slightly larger bond area with the Cusin braze material as compared to the Ticusil braze material. The next refinement was to score the copper to create posts upon which the ceramics were brazed. The copper posts provided a measure of strain relief and allowed even larger size tiles to be brazed, with little reduction in heat transfer area. A cross section of this joining arrangement is shown in figure 7. This technique was used to braze four 2 cm by 2 cm tiles which were held apart at braze temperature by a stainless steel fixture. This method is the planned assembly technique for a HOM load prototype.

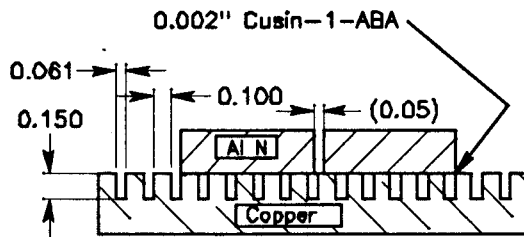


Figure 7. Cross section of ceramic tile brazing joint with saw cut copper fingers to take up some of the strain from brazing.

#### 4. POWER MANAGEMENT

The power densities in the baseline design (fig 3). are lower than those found in earlier conceptual designs and as such are not expected to present a problem. A previous design with a peak power density of  $76 \text{ W} \cdot \text{cm}^{-3}$  deposited into a 0.25" thick ceramic slab, which was attached to a 0.25" thick piece of copper and water cooled was analyzed with ANSYS. The resultant temperature and stress was  $126^\circ \text{C}$  and 8446 psi. This peak stress is lower than the rupture stress of Al-N which is 40 Kpsi. In the baseline design the ceramic tile thickness is small compared to the spatial variation in heating so we can use a 1D model of heat flow to scale the results from this earlier ANSYS model to our present design. For our present design with a peak power density of  $5.5 \text{ W} \cdot \text{cm}^{-3}$  and  $1/2$ " thickness the predicted peak temperature at the top of the ceramics is  $51^\circ \text{C}$  and the surface flux into the copper wall is  $7.0 \text{ W} \cdot \text{cm}^{-2}$ .

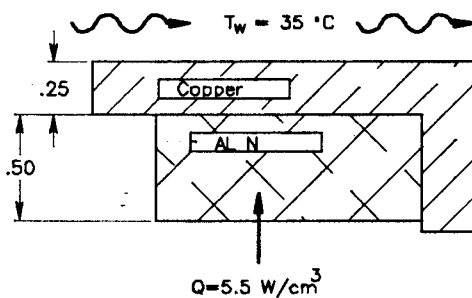


Fig. 8. End view cross section of baseline design. With a cooling scheme as indicated the estimated peak temperature is  $51^\circ \text{C}$ .

#### 5. FERRITE LOAD

The analysis of an HOM load with power absorption by ferrites instead of lossy dielectric is also being pursued. The current geometry for the ferrite load is a wedge 50 cm long, 4 mm thick and affixed to the HOM waveguide wall. The ferrite is TRANS-TECH TT2-111R. In the simulations the frequency dependent complex  $\mu$  and  $\epsilon$  are taken from measurements [5]. Figure 9 shows EMAS results for return loss which are well below our specification to beyond 4 Ghz.

Further studies will include detailed calculations for modes through 5 GHz including power dissipation and alternate ferrite geometries.

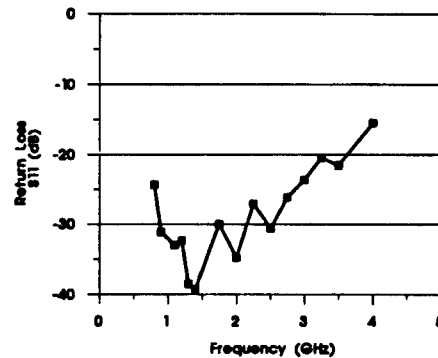


Figure 9. Return loss of 4mm ferrite wedge.

#### 6. CONCLUSIONS

A design for the HOM load which will terminate the damping waveguides of the PEP-II RF cavity and meets the electrical specifications is ready to be used for the prototype load. A technique for securing the ceramic tiles to the copper wall has been tested and will form the basis for the assembly of a prototype load.

#### 7. ACKNOWLEDGEMENTS

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#### 8. REFERENCES

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- [2] H. Schwarz et. al. "Design of a High Power Test Model of the PEP-II RF Cavity", Proc. PAC, Washington D.C., 1993, pp1039-1041
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- [4] Private communication with W. Barry, LBL.
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