PEP-II B-Factory Prototype Higher Order Mode Load Design*

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ABSTRACT

To reduce the impedance of the cavity higher order modes, (HOM's), a compact broad-band, low-reflection, waveguide load is required with a VSWR less than 2:1 in the frequency range 714 MHz to 2500 MHz. The load must also work in the high vacuum of the cavity, and be capable of dissipating up to 10 kW of power which is generated by the the interaction of the beam with the cavity HOM's and which is directed to each load assembly. A prototype load assembly is being fabricated which uses the lossy ceramic Al-N with 7% by weight glassy carbon to absorb the microwave power.

1. INTRODUCTION

Each RF cavity [1,2] in the PEP-II B-factory will have three HOM waveguide load assemblies, one of which is depicted in figure 1. The assembly consists of the vacuum flange which bolts to the cavity, a section of uniform waveguide 25cm x 2.54cm (f_c=600 Mhz) which seperates the lossy material from the exponentially decaying field of the fundamental mode at 476 Mhz, and the lossy ceramic tapers at the end of the waveguide which absorb the power from the HOM's. The lossy ceramic Al-N with glassy carbon [3] is used to dissipate the power. Computer simulations were used to design the footprint of the ceramics, which are arranged in two triangular wedges and are brazed onto one side of the waveguide at the end of the curved waveguide assembly [4]. Custom made ceramic tiles ready for brazing into the prototype were procured from industry [5]. The design was verified electrically by measuring the reflection from a cold test model of the lossy ceramic section of the HOM load assembly. In addition the complex dielectric constant was measured on both the ceramic used for the prototype, and on previous samples of this type of ceramic, and the data are presented. A schematic of the planned high power test is presented at the end.

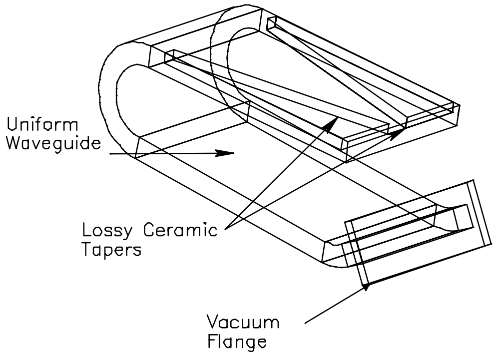

Figure 1. Higher order mode load assembly. The assembly is curved to fit in the available space.

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2. LOSSY CERAMIC LAYOUT

The Al-N ceramic tiles, nominally 2cm x 2cm x 1.9cm, are arranged into two tapers which flare out from the sidewall of the 25cm x 2.54cm waveguide. The detailed footprint of the individual ceramic tiles that will be used in the prototype HOM load assembly is shown in figure 2. The individual rectangular ceramics are angled with respect to the centerline of the waveguide so that the smoothest interface is presented to the oncoming RF wave which minimizes reflections. Non-rectangular tiles are employed on the sidewalls and the backside of the ceramic taper to smoothly fill in the space which also reduces reflections caused by changes in the propagation constant. Figure 3 shows the composite heating pattern of the load for the nominal operating conditions.

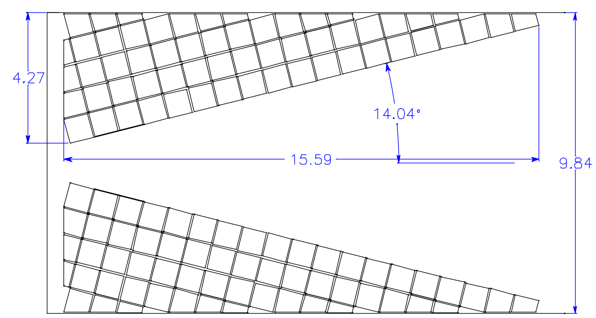

Figure 2. View of ceramic footprint looking down on the broadwall of the HOM waveguide. The square tiles are 2cm x 2cm. Spacing between tiles is roughly 1mm.

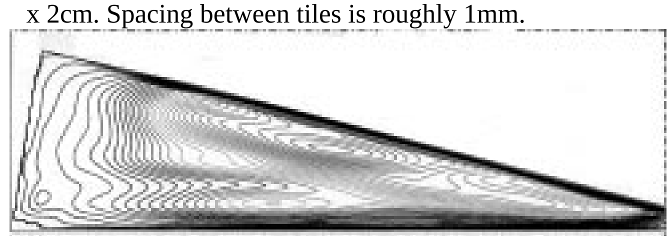

Figure 3. Time-averaged power density in ceramics for the HOM power generated in the cavity from 714 Mhz - 2500 Mhz with 3A of beam current. Only one side of the load is shown. The peak power density is 3.2 W cm^{-3}.

3. PROTOTYPE LOW POWER RF MEASUREMENTS

A low power test model of the microwave absorbing load portion of the prototype assembly was created by assemblying the tiles into the triangular pattern of figure 2 and inserting the tiles into a piece of uniform waveguide. The reflection coefficient, S_{11}, of this test model was measured. The RF measurements were made with an HP-8510 network analyzer and three sets of waveguide taper and coaxial transitions which, in combination, covered the frequency range of 650 Mhz to 4200 Mhz. A TRL calibration was performed with each set of tapers and transitions and then the test model was measured. The combined data measured over the normal operating ranges of the transitions is shown in figure 4.

The ceramics used in the test model are shorter than the design value due to a manufacturing error; the ceramics are only 0.714” tall whereas the design height is 0.75”. With these short ceramics the load meets the specification of VSWR = 2.0:1, but exhibits little margin at 714 Mhz. MAFIA Simulations indicate there is about a 7 dB increase in S_{11} because of the reduced ceramic height, thus the load with the full size 0.75” tall ceramics should have more margin at 714 Mhz.

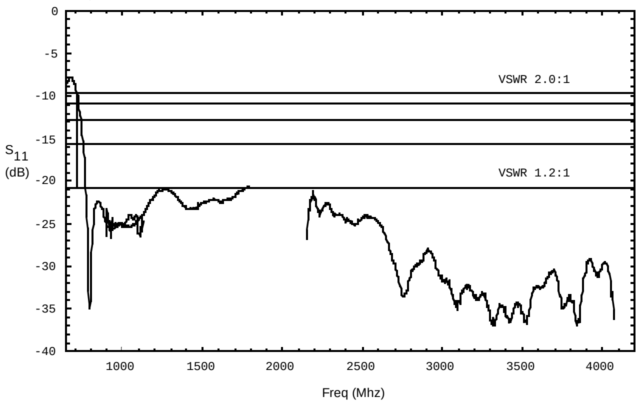

Figure 4. Reflection, S_{11}, of prototype load ceramics arranged in footprint of figure 2. The ceramics are 0.714” tall. The gap from ~1800 to 2100 Mhz is between waveguide bands and is covered in more detail later.

The dip in reflected power at ~800 Mhz is due to the partial cancellation of the reflections from the short at the end of the load, and the reflection which occurs at the modal transition plane. The modal transition plane is defined as the region where the propagating mode switches rapidly from the normal TE_{10} mode, with most of the power in the center of the waveguide, to the mode which carries energy in the ceramics along the edge of the waveguide. To test this we measured the response of the load while varying the distance at the end of the load to the short; a longer distance should move the dip lower in frequency. The results are shown in figure 5.

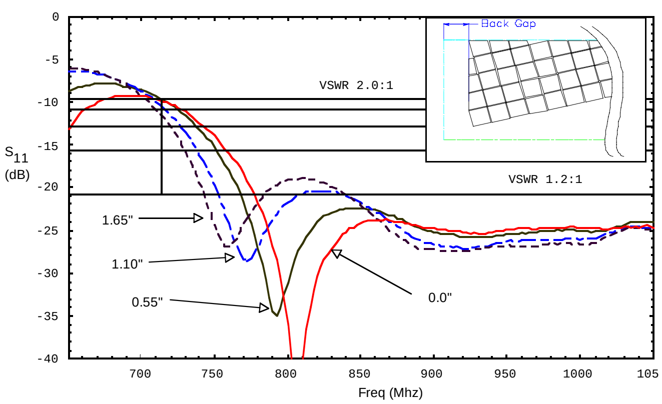

Figure 5. Prototype load response with different distances between the end of the ceramic tiles and the short at the end of the load (”Back Gap”). With increasing distance the dip in reflected power decreases in frequency.

There is a region from 1800 Mhz to 2100 Mhz which is not covered by the experimental set-ups when used over their designed operating ranges. However, a measurement can be made in this region using the WR-650 tapers and transitions. We calibrate the tapers and transitions as we normally do but over the frequency range of 1600 to 2200 Mhz. The calibration procedure is unable to remove the affects of the larger reflections in this frequency band, which is outside the designed range of the tapers and transitions; however, there do exist regions in between the large reflections where the calibration procedure is able to accomodate the remaining reflections. Figure 6 shows the measurement of the test model and the measurement of the two waveguide tapers alone used in the calibration. The spikes in the measurement of the two tapers alone are frequency regions in which the large reflections could not be calibrated out; however, in between these spikes are regions in which the measured reflection from the load is believed reliable. Note that at 1600 Mhz and at 2200 Mhz this measurement of the test model agrees with the previous measurements made with components operating within their designed frequency range.

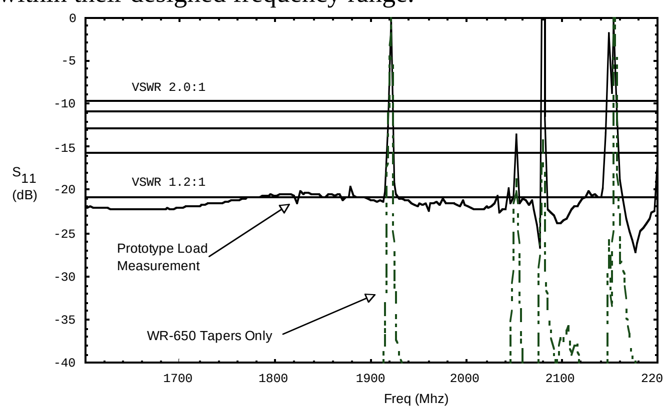

Figure 6. Reflection, S_{11}, of prototype load ceramics measured using the WR-650 set-up above TE_{20} cutoff. The dashed line is a measurement of the waveguide tapers alone. In between the spikes of the taper response the data for the load is believed reliable.

4. Dielectric Measurements of Ceramic

4.1. Ceramic for the Prototype

The electrical properties of the Al-N ceramic which will be used for the prototype were measured using a coaxial probe, HP 85070B, attached to a network analyzer. Figure 6 shows the results of eight measurements on one 8” x 8” billet. The spread in dielectric constant is slightly larger than the precision of the measurement and indicates some slight variability in dielectric constant within the billet.

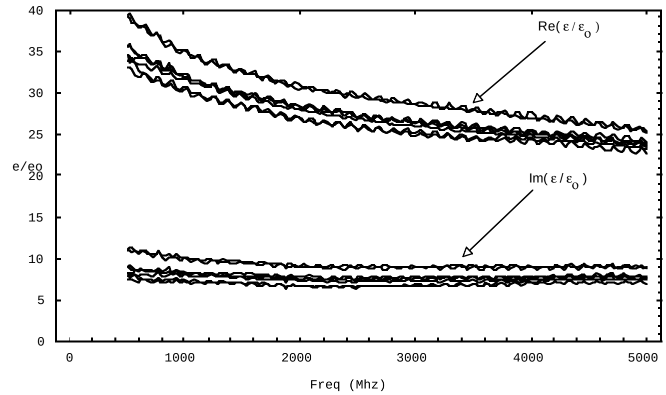

Figure 7. Measured dielectric constant of ceramic used in prototype. The 8 measurements are from one 8” x 8” billet.

4.2. Entire collection of ceramics

In addition to the material for the prototype we also measured some Al-N ceramic we had previously purchased earlier in the development cycle. These measurements encompass some material which was produced while the ceramic process yielded more variability in density. The current process is claimed to yield ceramics with a density of 2.95 - 2.98 gm·cm^{-3}. The ceramic used in the prototype load assembly has a density of 2.97 gm·cm^{-3}. We present this data for reference. We measured this material using a combination of the HP coaxial probe technique and also using a stripline fixture that was supplied by W. Barry at LBL[6]. Based on the limited measurements to date, we have found the dielectric constant increases with density, but also exhibits some variability for a given density. Figure 8 shows a series of measurements that encompassed materials of different densities. Measurements using the two techniques on the same material agreed within ~10%.

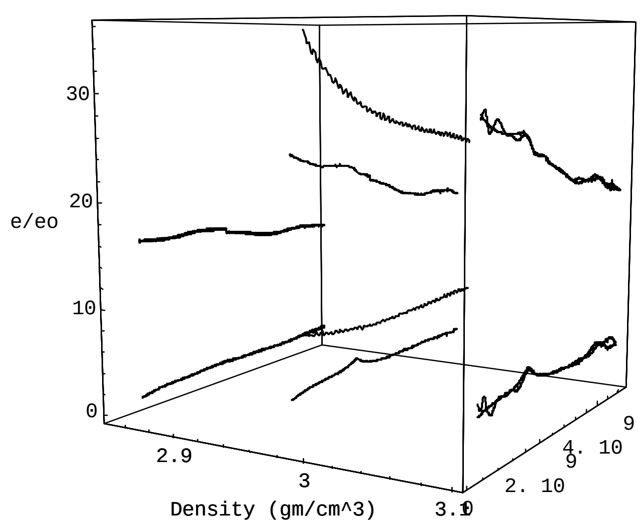

Figure 8 Real and imaginary part of dielectric constant vs. frequency and density.

4.3 Sensitivity of Load to Variations in Dielectric Constant.

The reflection from the load is most strongly affected by changes in the dielectric constant at the lower frequencies where the load is electrically shorter and some of the incident power reflects off the back wall. Simulations predict the load will meet the reflection specification for 50 > Re($\varepsilon/\varepsilon_0$) > 26 at 714 Mhz.

5. POWER TEST OF PROTOTYPE HOM ASSY.

The prototype load assembly is under construction and is scheduled for a high power vacuum test in early summer. We will test the assembly using a 714 Mhz klystron which is capable of producing much higher power densities in the load than will be seen in normal operation. A waveguide window made from MACOR® and sealed with an O-ring will form the vacuum seal. A layout of the test is shown in figure 9.

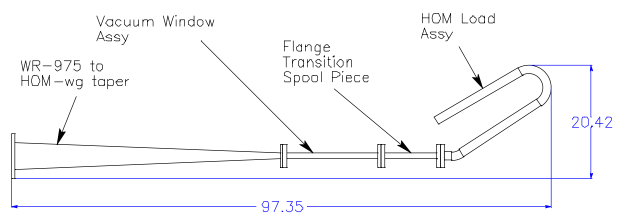

Figure 9. Layout of high power test on the load assembly.

6. ACKNOWLEDGMENTS

We would like to thank R. Campisi of CEBAF for useful discussions on the use and application of the Al-N material.

7. 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.
[3] Material is manufactured by Ceradyne corporation and was developed in collaboration with R. Campisi of CEBAF.
[4] R. Pendleton et. al., ”Broad-Band, Multi-Kilowatt, Vacuum, HOM Waveguide Loads for the PEP-II RF Cavity”, Proc EPAC, London, June 27-July 1, 1994.
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