

# DESIGN OF TRAVELING WAVE WINDOWS FOR THE PEP-II RF COUPLING NETWORK\*

N. M. Kroll<sup>†</sup>, C.-K. Ng, J. Judkins and M. Neubauer  
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

## Abstract

The waveguide windows in the PEP-II RF coupling network have to withstand high power of 500 kW. Traveling wave windows have lower power dissipation than conventional self-matched windows, thus rendering the possibility of less stringent mechanical design. The traveling wave behavior is achieved by providing a reflecting iris on each side of the window, and depending on the configuration of the irises, traveling wave windows are characterized as inductive or capacitive types. A numerical design procedure using MAFIA has been developed for traveling wave windows. The relative advantages of inductive and capacitive windows are discussed. Furthermore, the issues of bandwidth and multipactoring are also addressed.

## I. INTRODUCTION

The window in the coupling network of the PEP-II RF cavity must transmit up to 500 kW of CW RF power at 476 MHz to the cavity and must also handle considerable reflected power due to sudden beam-loss conditions [1]. The waveguide window used in PEP-II is a ceramic disk mounted on an iris connected to rectangular waveguides [2]. The conventional design of self-matched windows inherently sets up a large standing wave with electric field maximum within the window. Because of the large power requirements of PEP-II, this leads to a large heating load and a requirement for a prestressed mechanical mounting to deal with the resultant thermal stress. Traveling wave (TW) windows, on the other hand, can reduce the heat deposition sufficiently to allow conventional mounting. This is achieved by introducing a reflecting iris at each side of the window in such a way that the reflection at the reflecting iris cancels that at the window-waveguide interface. TW windows can be divided into inductive and capacitive types, depending on the structure of the irises, and the choice affects their positioning in the waveguides. A capacitive TW window, due to its compactness, has been incorporated into the layout of the coupling network of the PEP-II RF cavity as an alternative to the self-matched window.

## II. GENERAL CONSIDERATIONS

For qualitative insight, we assume only one mode (circular TE<sub>11</sub>, for our case) propagating in the window with power flowing to the right. The electric field can be written as:

\*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

<sup>†</sup>Also UCSD, Department of Energy Grant DE-FG03-93ER40759

$$\vec{E} = \vec{e} \sqrt{\frac{2ZP}{1-R^2}} \{ \cos(\omega t - k_z z) + R \cos(\omega t + k_z z) \}, \quad (1)$$

where  $\int e^2 da = 1$  ( $a$  is the cross sectional area of the window),  $Z$  is the impedance of the waveguide with the window cross section, and  $P$  is the average transmitted power.  $R$  is the ratio of the wave amplitudes (left going/right going) within the window and is equal to the magnitude of  $S_{11}$  looking to the right. For a matched window it is also equal to the same quantity looking to the left. We have taken the origin of the  $z$  coordinate in Eq. 1 to lie at the maximum of the standing wave pattern and note that for typical self-matched windows (certainly ours) it lies within the window. In general  $0 \lesssim R \lesssim 1$ , and  $R = 0$  for the pure travelling wave case. By averaging  $E^2$  over the window cross section, it can be shown that the enhancement factor  $P_r$  in power deposition of a symmetric self-matched window to that of a pure TW window is given by:

$$P_r = \frac{1+R}{1-R}. \quad (2)$$

## III. DESIGN PROCEDURE

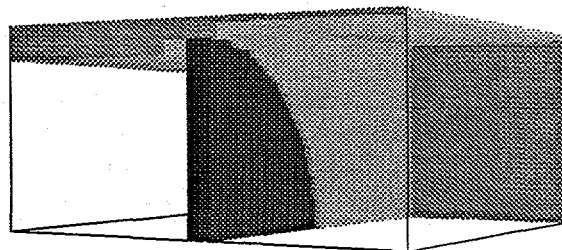


Figure 1. 1/4 MAFIA model of the self-matched window.

For a specified configuration of a mounting iris and waveguides, the matching of a self-matched window is achieved by adjusting its thickness and its position at the mounting iris. For TW windows, we have used MAFIA as a calculation tool for developing a systematic design procedure. To simplify the window development program, our designs have been based upon the self-matched configuration adopted for PEP-II. The self-matched window shown in Fig. 1 is mounted on a frame with a thickness of 1.5" for the purpose of accommodating cooling channels. The air side waveguide is a WR2100, and on the vacuum side a 16"x9" waveguide is connected to the aperture coupler of the RF cavity. The window, a ceramic disk with dielectric constant 9.5 and loss tangent 0.00015, has a diameter of 9.75" and a thickness of 0.7". The procedure for designing a TW window is described as follows.

(1) Determine the  $S$ -matrix of the window-waveguide junction.

This is determined by the geometry shown in Fig. 2, in which the window is represented by a circular waveguide filled with ceramic. The  $S$ -parameters are determined by driving the  $TE_{11}$  mode at the input end of the circular waveguide.

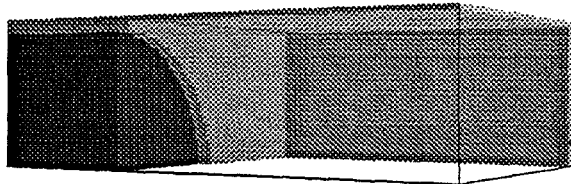


Figure 2. 1/4 MAFIA model of a ceramic-waveguide junction.

(2) Determine the size and position of the matching element.

The condition which must be satisfied by the matching element (ME) on the RHS of the window is

$$S_{11}(\text{ME}) = S_{22}^*, \quad (3)$$

where  $S_{22}$  refers to the configuration of Fig. 2, and the reference plane on the LHS of the ME is taken to coincide with that on the RHS of the Fig. 2 configuration. An analogous condition applies to the ME on the LHS of the window. Trial dimensions for the ME's were obtained from analytic formulas, and MAFIA was used to trim the dimensions so that Eq. 3 holds for the absolute values. From the phases of the MAFIA computed elements of  $S(\text{ME})$  one can use standard formulas to determine the position required to satisfy Eq. 3 with respect to phase. The procedure is checked by appending the ME on the RHS of the Fig. 2 configuration and confirming the absence of reflection of the right going wave in the window. If evanescent waves generated near the ceramic overlap the ME or vice versa (as is the case for the capacitive ME), some additional trimming may be required. The analogous procedure is followed for the ME on the LHS of the window. Finally the entire assembly is checked for match using MAFIA. Because the window is thin, some overlap of higher order modes generated on the two sides of the window is expected and further trimming is required to secure a match. The field distribution in the entire assembly is then checked to, for example, compute the power dissipation ratio. In practice some of the steps described above are skipped as the "bottom line" is simply to obtain a matched window assembly with an improvement in power dissipation of the order of that obtained from Eq. 2.

#### IV. SIMULATION RESULTS

##### (a) Inductive traveling wave windows

The inductive TW window is made by providing vertical bars along the heights of the waveguides as shown in Fig. 3. The thickness of the matching irises is chosen to be 0.25". The distances of the irises from the window in the WR2100 and 16"x9" waveguides are found to be 13.3"

and 18.9" respectively. This additional space poses stringent conditions for the coupler network layout, in particular when the detuned-short position is preferably within the window. The required iris gaps are 8.4" and 8.8" for the two waveguides.

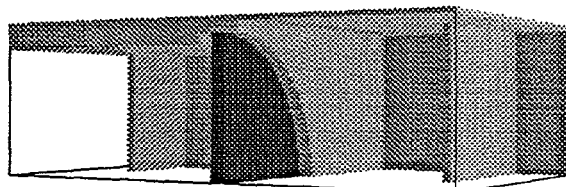


Figure 3. 1/4 MAFIA model of an inductive TW window.

The electric field pattern in the structure is shown in Fig. 4. The minimum of the field is at the window, while field maxima are located in the waveguides between the matching irises and the window, indicating the set-up of standing waves in these regions. The power distribution in the window is shown in Fig. 5. The power dissipation is large in the center and is reminiscent of the  $TE_{11}$  mode distribution. Thus higher-order mode effects in the window are small. The power is about 7.6 times smaller than that of the self-matched window, where field maximum is found at the window. The self-matched window has a  $S_{11} \sim 0.77$  at the window-waveguide junction, and from Eq. 2,  $P_r = 7.7$  which is in very good agreement with MAFIA calculation. The dielectric loss in the self-matched window is 157 W, and hence the loss is 20 W for the TW window.

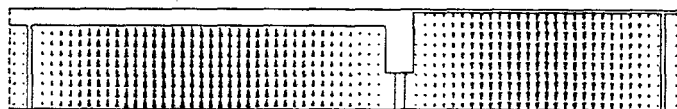


Figure 4. Electric field pattern in the inductive TW window. The plane is chosen such that the matching irises are shown.

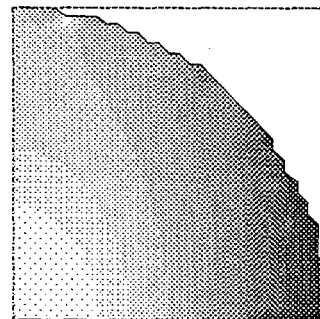


Figure 5. Power distribution in the inductive TW window.

The PEP-II RF feedback system requires a bandwidth of 5 MHz for 3 db transmission and a group delay of  $\leq 350$  ns. In Fig. 6, we show the variation of  $S_{11}$  of the window assembly as a function of frequency. The bandwidth satisfies our requirement. In Fig. 7, we show  $\phi_{21}$  as a function of frequency. Within the relevant bandwidth, the phase variation is linear. Subtracting the group delays of the waveguides in the window assembly from the slope calculated from Fig. 7, the additional time delay due to the window assembly is 14.3 ns, which is relatively small compared with the total allowed group delay.

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

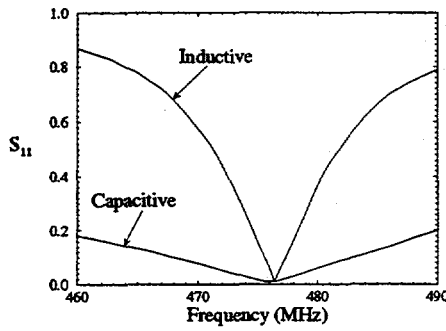


Figure 6.  $S_{11}$  as a function of frequency for the inductive and capacitive TW windows.

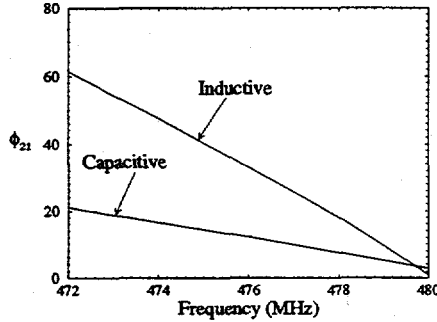


Figure 7.  $\phi_{21}$  as a function of frequency for the inductive and capacitive TW windows.

#### (b) Capacitive traveling wave windows

The capacitive TW window is made by providing horizontal bars along the widths of the waveguides. Since the waveguide  $TE_{10}$  mode has its electric field in the vertical direction, the small gap width between the bars introduces high field gradient. The gap width can be increased by using thicker matching irises. Furthermore, the irises are found very close to the window. For a single gap design, the power distribution highly peaks around the center of the window, making cooling difficult. Thus we introduce a double gap configuration as shown in Fig. 8. In the WR2100, the iris thickness is 3", the gap width is 1.6", and the distance of the irises from the window is 0.94". In the 16"x9" waveguide, the iris thickness is 4", the gap width is 1.3", and the distance of the irises from the window is 0.91".

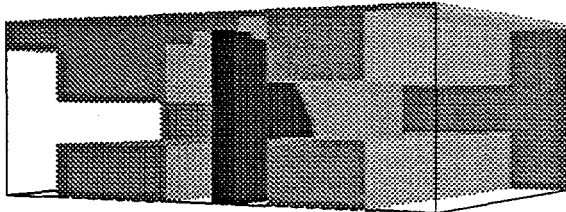


Figure 8. 1/4 MAFIA model of a capacitive TW window.

The electric field pattern in the structure is shown in Fig. 9. The field is small at the window, while field maxima appear in the gaps of the matching irises. For 500 kW average power, the peak fields are 0.54 kV/cm and 0.35 kV/cm in the 16"x9" and WR2100 waveguides, respectively. It is anticipated that rounding and coating of the irises will be required to avoid multipactoring at the vacuum side and arcing at the air side. The power distribution in the win-

dow is shown in Fig. 10. The distribution is more uniform than that of the inductive case, peaks at a distance away from the center, and is not purely  $TE_{11}$ -like, presumably because of the closeness of the matching irises to the window. The total dielectric loss is about 6.6 times smaller than that of the self-matched window. This corresponds to 24 W loss for 500 kW average power from the klystron.

Form Figs. 6 and 7, the bandwidth is broader than that of the inductive TW window and the additional group delay of the window assembly is 3.3 ns, which are within the PEP-II requirements.

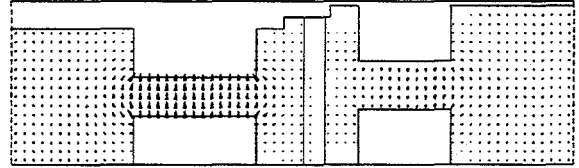


Figure 9. Electric field pattern in the capacitive TW window.

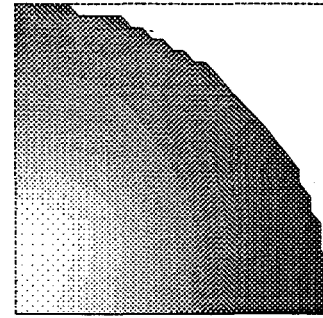


Figure 10. Power distribution in the capacitive TW window.

## V. SUMMARY

The relative advantages of the TW windows compared with the self-matched window are summarized in Table 1. The capacitive TW window is a superior design in terms of its compactness, broad bandwidth, small group delay and almost 7 times less dielectric loss than the self-matched window. Despite its complexity compared with the self-matched window, it is an attractive alternative for handling high power throughput of the PEP-II B-Factory.

Window type	Relative power loss	Bandwidth (MHz)	Group delay (ns)
Self-matched	1	acceptable	small
Inductive TW	0.13	acceptable	14.3
Capacitive TW	0.15	acceptable	3.3

Table 1. Comparison of the self-matched, inductive TW and capacitive TW windows.

## Acknowledgements

We would like to thank P. Corredoura, K. Ko, R. Rimmer and H. Schwarz for useful discussions.

## References

- [1] An Asymmetric B Factory, Conceptual Design Report, LBL-PUB-5379, SLAC-418, CALT-68-1896, UCRL-ID-114055 or UC-IRPA-93-01, June 1993.
- [2] M. Neubauer et. al., High-Power RF Window and Coupler Development for the PEP-II B Factory, these proceedings.

---

### **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.