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HIGH POWER S-BAND WINDOW OPTIMIZED TO MINIMIZE ELECTRIC AND MAGNETIC FIELD ON THE SURFACE*

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Abstract

RF windows are used to separate vacuum from atmosphere in high power microwave systems, such as klystrons. RF breakdowns in these megawatt power environments could damage the window. An S-band RF window was designed to have reduced electric and magnetic field in the waveguide joints and the ceramic. Specifically the electric field on the ceramic was minimized and a traveling wave was created inside the ceramic by optimizing the shape of the window and the geometry of the joint between the circular waveguide to the rectangular waveguide. A prototype of this window is being made at SLAC for high power tests.

INTRODUCTION

Ceramic RF windows are a critical component of high power (tens of MW peak power) klystrons for isolating the klystron vacuum system from the RF distribution system, for isolating various portions of the RF distribution systems and so on. Robust high power operation of such windows is important for reliability and lifetime of high power RF sources. A variety of innovations and improvements to RF windows have been offered and demonstrated for klystrons operating in S, and X band [1, 2, 3, 4] over the years. The so called Traveling Wave window is of particular interest. Such a window was designed by the authors and built and successfully tested at SLAC for the ILC prototype L-band positron source. A large number of accelerators in the world, including the SLAC two-mile linac operate at S-band. The window is typically the weakest link in the RF source system. Thus developing a high power S-band window to minimize the electric and magnetic fields on all surfaces is of particular interest to the accelerator community. We designed such a window which should operate comfortably at 65 MW peak power. Particular attention was paid to mitigate the high fields on the ceramic and the metal. Trapped and so-called ghost modes were investigated to assure that such modes are outside klystron bandwidths. This particular design was motivated by the wish to improve the reliability of the current SLAC 5045 klystrons. These klystrons are the work horse for the SLAC two-mile linac which currently powers the Linac Coherent Light Source (LCLS) and the Facility for Advanced Accelerator Experimental Tests (FACET). Currently the 5045 klystrons employ a pair of windows which could be replaced with a single window of the design presented here.

DESIGN CONSIDERATIONS

To minimize the fields on the ceramic, we chose the traveling wave window approach [1, 2]. The basic design requirements of the window and the values achieved in simulation are presented in Table 1.

Table 1: S-Band Window Design Parameters

Parameter	**Required**	**Achieved**
Frequency (MHz)	2856	2856
3 dB BW (MHz)	≥ 20	≥ 100
Reflection (S11)	< -20 dB	< -70 dB
Peak Power (MW)	65 MW	65 MW
Peak E on Ceramic (MV/m)	Minimize	1.75
Peak H on Ceramic (KA/m)	Minimize	17
Peak E (MV/m)	Minimize	11
Peak H (KA/m)	Minimize	20

The ceramic is housed in a circular waveguide to facilitate its brazing to the metal. To minimize the fields on the metal surfaces we optimized the shape of the joint between the circular and rectangular waveguide. Figure 1 shows the geometry of the window including the elliptical parameters of the joint.

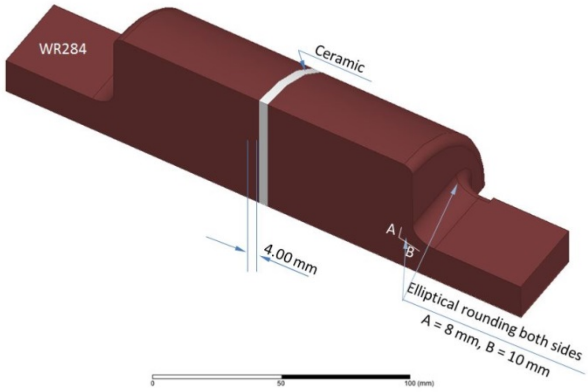

Figure 1: S-band window geometry (one quadrant)

DESIGN PROCEDURE

We chose a commonly available alumina ceramic of ε = 9.6 and 4 mm thickness considering the approximate radius of an S-band window and the mechanical robustness of the ceramic when one side is under vacuum while the other is at 1 atm. We used Cascade [5] for the initial simulations. Cascade is a commercial code that uses mode-matching for rapid S parameter analysis and optimization of 2-port passive waveguide components including windows, filters and mode converters and calculation of frequency and Q of waveguide resonators.

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To create a traveling wave in the ceramic, reflection from the ceramic and the reflection from the circular to rectangular waveguide joint should be nearly the same. To achieve this, we first simulated the reflection from the ceramic vs. circular waveguide radius, then we simulated the reflection from the circular to the WR284 rectangular waveguide joint vs. the same radius using both Cascade and HFSS [6]. We found the results from both codes to be almost identical. We chose the radius where the reflections from the ceramic and the waveguide joint were the same as our first approximation for the window radius. We then created an HFSS geometry of half the window longitudinally from the rectangular guide to the center of the ceramic. We rounded corners and then adjusted the length of the circular waveguide to minimize the total reflection. Then we built a model of the whole window and made small changes in all the parameters to minimize reflection at 2856 MHz. This exercise produced a traveling wave window with minimal fields on the ceramic.

Next we needed to minimize the electric and magnetic fields on the circular to rectangular waveguide joint by varying its shape. We found the elliptical shape with dimensions as shown in Figure 1 to be the most optimal. After we optimised the joint shape, we then made minor adjustments to the circular waveguide radius and length to minimize the reflection at 2856 MHz.

Next we analysed ghost modes analytically and the trapped and ghost modes with HFSS. In the search for these modes we explored variations in ceramic permittivity ε=9.6 ± 0.4, and thickness of 4 ± 0.2mm. Tolerance studies exploring the dependence of the reflection and bandwidth on the ceramic thickness and permittivity were conducted by first varying the thickness of the ceramic and then the permittivity with HFSS.

RESULTS

Figure 2 shows the reflection vs. frequency for the window with varying thicknesses of the ceramic. For the nominal case of ε = 9.6 and thickness of 4 mm the reflection at 2856 MHz is less than -90 dB and the bandwidth at -20 dB is 50 MHz and more than 100 MHz at -3 dB. Keeping the ceramic permittivity constant, the ceramic thickness is varied in 0.1mm increments on either side of the nominal. The reflection is less than -45 dB at 2856 MHz in the worst case of ± 0.2 mm.

Figure 3 shows the reflection vs. frequency for the window with varying permittivity of the ceramic. Keeping the ceramic thickness at 4 mm, the ceramic permittivity is varied in ε = 0.2 increments on either side of the nominal. The reflection is less than -35 dB at 2856 MHz in the worst case of ε = 9.6 ± 0.4, which is satisfactory for a practical design.

The maximum electric field in the ceramic at 65 MW is 1.75 MV/m and the maximum magnetic field is 17 KA/m.

The maximum electric and magnetic fields on the metal appear on the ellipticaly-shaped joint between the circular and rectangular waveguides shown in figure 1. Figures 4 and 5 show the surface electric and magnetic fields, respectively, for one quadrant of the window, with views of the ceramic and the maximal on the metal. These fields are scaled for 65 MW transmitted through the whole window. The maximum electric field on the joint between the circular and rectangular waveguides is 11 MV/m and the maximum magnetic field is 20 kA/m. As a comparison, the SLAC 5045 klystron uses a dual window. Each window has a maximum electric field of 3.3 MV/m on the ceramic and 11.6 MV/m on the circular to rectangular waveguide joint with half of 65 MW transmitted through it. The new design is a vast improvement considering that we would need only one window instead of two, and with much lower surface fields.

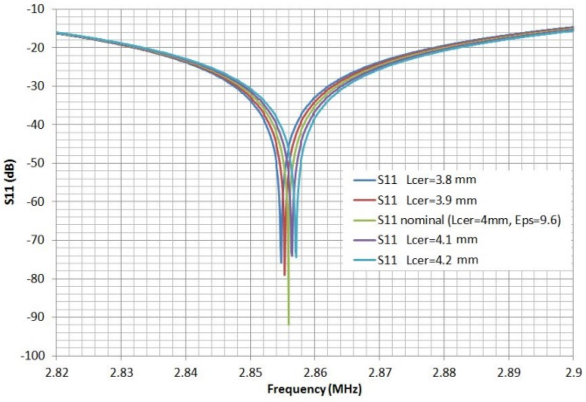

Figure 2: Reflection vs. frequency for varying ceramic thicknesses.

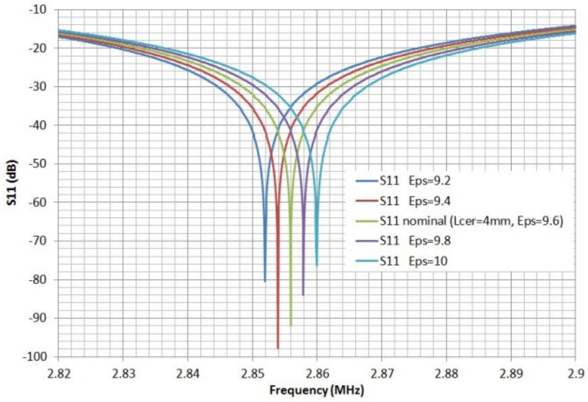

Figure 3: Reflection vs. frequency for varying ceramic permittivity.

After the design was finalized, we investigated the trapped and ghost modes for this window. The study included the variation in the ceramic permittivity and thickness based on the anticipated manufacturing variation. We found that the nearest ghost modes are more than 200 MHz away from the nominal 2856 MHz. and the nearest trapped mode is more than 60 MHz away.

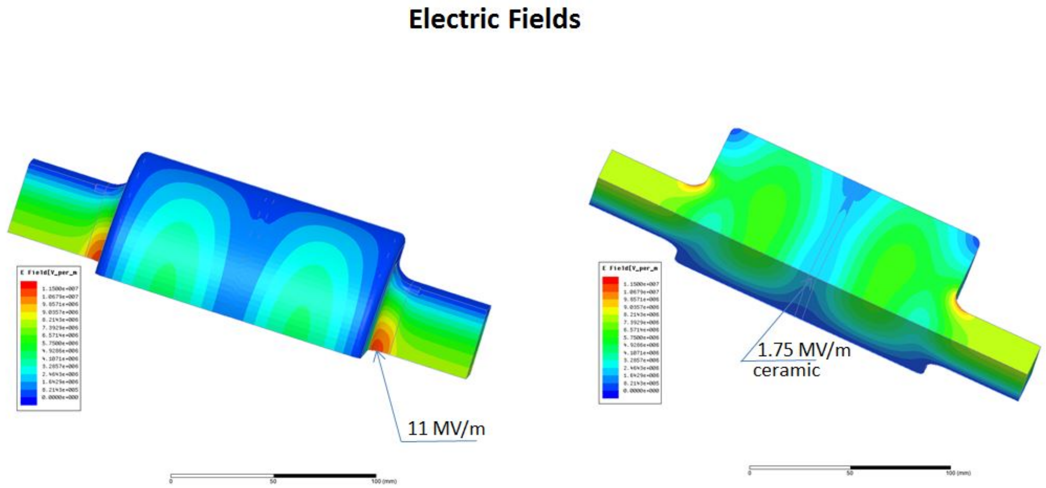

Figure 4: Surface electric field on window quadrant scaled for 65 MW power transmitted through the whole window.

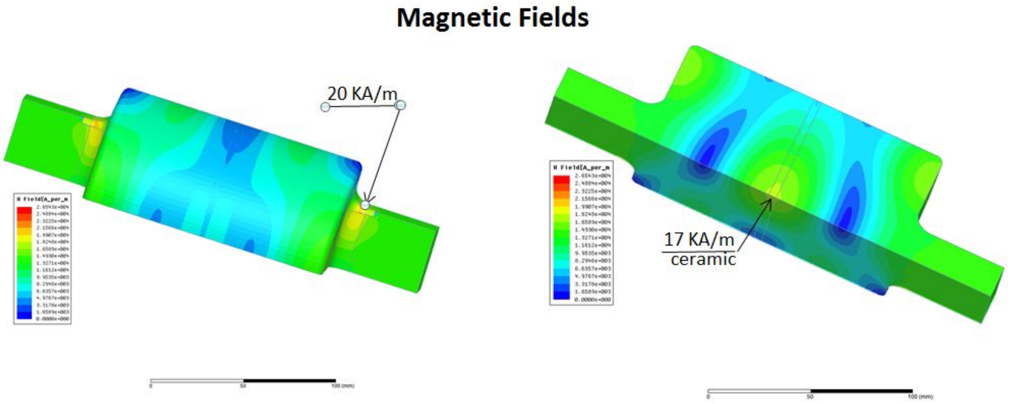

Figure 5: Surface magnetic field on window quadrant scaled for 65 MW power transmitted through the whole window.

SUMMARY

We have developed a comprehensive procedure for designing and optimizing RF windows. Using these procedures, we have designed an S-band window which should comfortably operate at 65 MW, has much lower surface fields than the current S-band windows on the SLAC 5045 klystrons, and a single window of the design offered here can replace the dual window of the 5045. At the time of this publication, this window is in the manufacturing process for experimental verification at SLAC.

ACKNOWLEDGMENT

We thank Michael Nicolls for simulating the existing SLAC 5045 dual window for comparison purposes.

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