Window Design with MAFIA

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Abstract

A window design scheme using the MAFIA code is presented. Two sample windows in UHF and Ku-band are designed. The UHF window is dimensioned for high power CW operation (narrow band). It consists of a single ceramic, with the possibility to direct a blower. The Ku-band window is designed for pulsed operation. It consists of two single windows. Sensitivity calculations are carried out using a mode matching code which calculates S-parameters of axis-symmetric geometries. An arbitrary number of cross section changes and different material fillings (dielectrics) is allowed.

1 Introduction

The window is a bottleneck in the RF supply system. Operation disruption has been reported at SRS [1]. Main failure mechanisms are heating (losses in the dielectric or in the anti-multipactor coating) and multipactoring mechanical damages [2]. With ever higher accelerating gradients and therefore higher power requirements the window design will demand increased attention.

2 UHF-band Window

MAFIA [3] versions 3.10 and higher have the capability to compute S-parameters of arbitrary waveguide components. Simulation is done in time domain, with an incident wave at one port. The stationary S-parameters are obtained after some 25-50 time steps. Typically 20,000-60,000 meshpoints were used, which sums up to 30-60 minutes user time on a RS6000/320 for each simulation.

The window was designed to be installed in a waveguide WR1800 (dimensions 18"×9", frequency $f_{RF} = 476$ MHz). The MAFIA mesh is shown in Fig.1. Note that only a quarter of the structure was modelled to exploit all symmetries. Design performance is displayed in Table 1.

A single window design was preferred to multiple windows (say three or five) distributed over the waveguide cross-section. The general feeling was that costs would rise and chances to fail would be higher. Here the design steps taken are listed:

1. Choice of window size and material. The first step was to select a ceramic (material and size). Alumina (Al_2O_3) was preferred to beryllia (BeO) on grounds of lower cost and easier handling (non-toxic, copper brazeable). A dielectric constant $\epsilon_r = 9.5$ was assumed. The waveguide height restricts the possible window aperture. Leaving room for a small copper sleeve, the aperture was set $d_{ap} = 8''6/8$. The window thickness is determined in the next step.

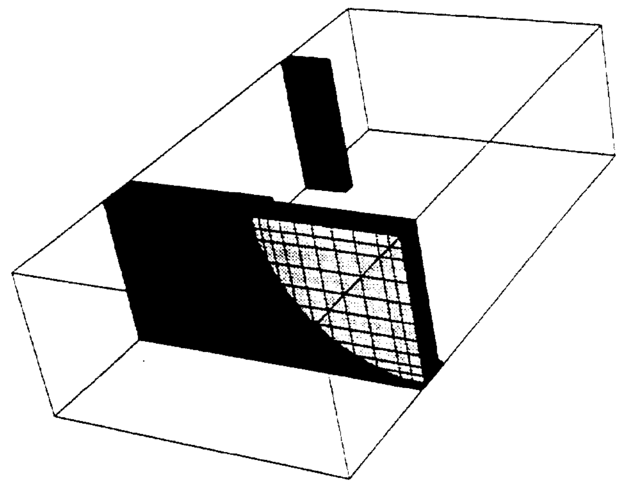

Figure 1: MAFIA mesh of the window.

2. Window simulations. The window reflection was computed with MAFIA. Some 5-10 simulations were required to determine the dependence of reflection with the window

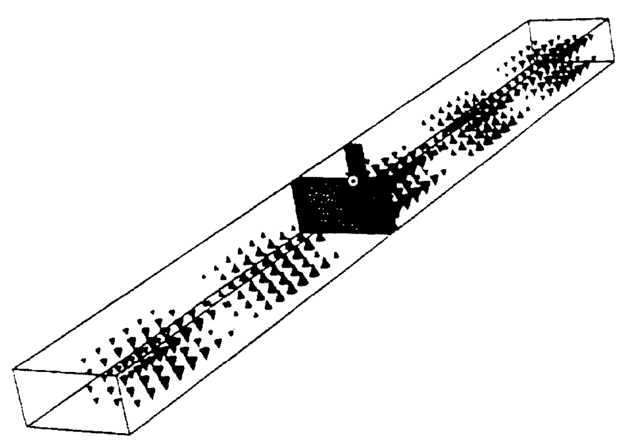

Figure 2: MAFIA mesh of the trapped mode calculation.

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Parameter	Value
Operation frequency	476 MHz
Reflection	0.008 (- 42 dB)
Bandwidth $\|S_{11}\| \leq 0.1$	0.033
VSWR between window and inductive element	1.11

Table 1: Performance data.

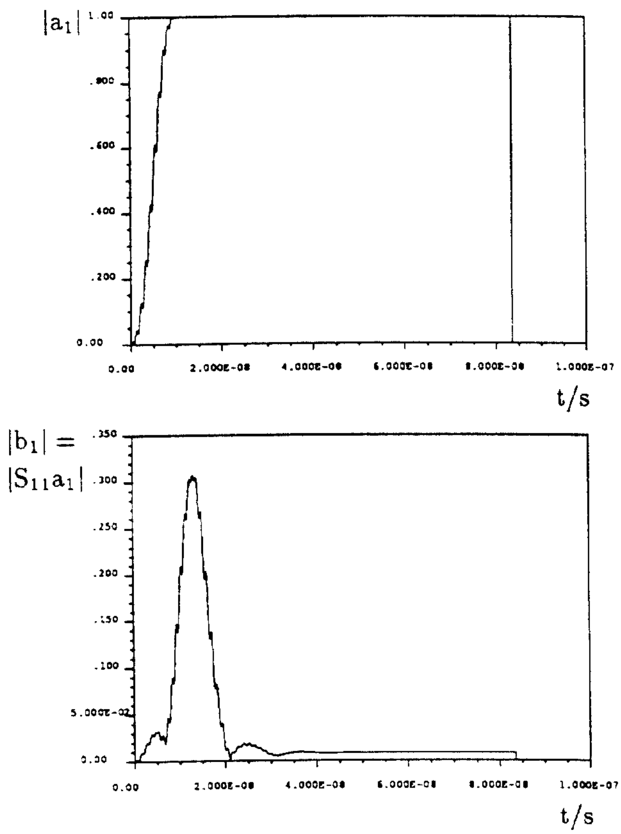

Figure 3: Envelopes of the input pulse and S_{11}.

thickness and find zero reflection ($|S_{11}| = 0$ @ $d_{th} = 2.38$ cm). Next the thickness was rounded to some available size, thereby introducing some reflection ($S_{11} = 0.101 \cdot e^{-j1.9^\circ}$ @ $d_{th} = 0''7/8$).

3. Matching element. Matching was performed with an inductive element. Again MAFIA was used to model the element. This step required less CPU-time since the mesh was coarse. Three simulations were needed, as the reflection depends almost linearly on the aperture of the element. The element with the same absolute value of reflection as the window was selected.

4. Matching element position. With MathCad the exact element position was computed (cancellation of reflected waves).

The matching introduces standing waves:

$$VSWR = |S_{21}^{ind}| \cdot \left(\sum_{n=1}^{\infty} |S_{11}^{win}|^n \cdot |S_{11}^{ind}|^{n-1} + \sum_{n=1}^{\infty} |S_{11}^{win}|^n \cdot |S_{11}^{ind}|^n \right) = 1.11$$

5. Final MAFIA runs. The reflection of the complete window design (window and inductive element) was checked. Fig.3 shows the resulting envelopes of the input pulse and $|S_{11}|$. The geometry is shown in Table 2.

Geometry	Size, material
Waveguide	WR1800 (18" × 9")
Window material	Al_2O_3, $\epsilon_r = 9.5$
Window diameter	8"3/4
Window thickness	0"7/8
Inductive element width	1"1/2
Inductive element thickness	0"1/2
Distance between window and inductive element	8"11/64

Table 2: Window geometry and ceramic material.

Variable u	$\|\Delta S_{11}\|$	$(\|\Delta S_{11}/\Delta u\|)$
Dielectric constant ϵ_r	0.028	0.3
Window diameter	0.048	0.45 1/cm
Window thickness	0.017	0.8 1/cm
Inductive element width	0.0017	0.04 1/cm
Inductive element thickness	0.00015	0.02 1/cm
Distance between window and inductive element	0.0018	0.009 1/cm
Frequency	0.06	12.0 1/GHz

Table 3: Window sensitivity with a variation of parameters of about 1%.

Sensitivity calculations were carried out with a variation of parameters of about 1%. Results are shown in Table 3. Obviously the sensitivity of the window size and material is highest, whereas tolerances of the inductive element are relaxed by about one order of magnitude.

Finally, the design was examined for trapped modes. Long waveguide sections were shortened (see Fig.2). No trapped modes were discovered within the frequency range of interest (one was discovered at $f = 913$ MHz).

3 Ku-band Window

The Ku-band window has been designed for a circular waveguide at 18 GHz. It consists of two thin windows spaced 4.8 mm apart in an outer pipe of 6.09 mm diameter. A cooling agent can thus flow through the space between the windows to reduce the possible thermal failure. Thin irises have been added for more flatness and to increase the bandwidth. The geometry is shown in Fig.4 and some parameters are given in Table 4.

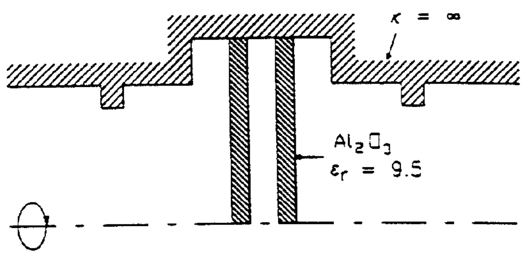

Figure 4: Geometry of the Ku-band window, Al_2O_3.

Parameter	Value
Operation frequency	18 GHz
Reflection	0.01
Bandwidth $\|S_{11}\| \leq 0.025$	0.04
Waveguide	C190
Window material	Al_2O_3, $\epsilon_r = 9.5$
Window radius	6.09 mm
Window thickness	2.89 mm
Distance between windows	4.8 mm
Iris radius	5.4 mm
Distance between a window and one iris	14.2 mm

Table 4: Parameters of the Ku-band window.

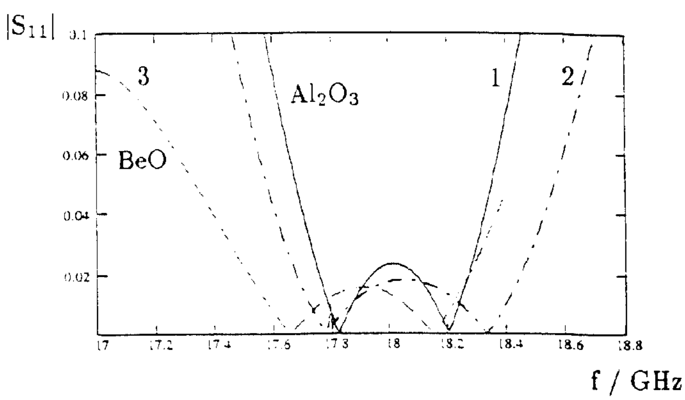

Figure 5: Frequency dependency of $|S_{11}|$.

A mode matching code which calculates the S-parameters of axis-symmetric geometries with an arbitrary number of cross section changes and various material fillings have been used to check the results and to calculate some tolerances. The structure has a bandwidth of $B \approx 3\%$ with $S_{11} \leq 2.5\%$ (curve 1, Fig.5). With additional irises the curve became flatter and the bandwidth increased up to $B \approx 4\%$ (curve 2, Fig.5). The parameter with the highest sensitivity is the window thickness which determines the center frequency. Other parameters were uncritical with respect to the bandwidth within 1% mechanical tolerances.

Finally, we checked the design for trapped modes. In fact, this provisional design shows two trapped modes at $\Delta f = \pm 520$ MHz away from the operation frequency. But we have good hopes to shift them further away by changing the thickness of the ceramics.

The parameters for a single BeO-window have been calculated, too. We achieved $|S_{11}| = 0.1$ with a bandwidth of $B = 12\%$, however the design is very sensitive to the window thickness. BeO is toxic and has brazing difficulties, but on the other hand it has a thermal conductivities close to copper [4]. For this structure trapped modes appeared at $\Delta f = \pm 370$ MHz.

The frequency behavior of $|S_{11}|$ for both windows was calculated with a mode matching code and is shown in Fig.5.

4 Acknowledgement

One of us (B. L.) likes to thank R. A. Rimmer for valuable discussions.

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