SYSTEMATIC DESIGN OF AN S-BAND PILLBOX-TYPE RF WINDOW

A. Jöstingmeier, M. Dohlus and N. Holtkamp, DESY, D-22607 Hamburg, Germany

Abstract

The scattering matrix technique and the MAFIA computer code are employed for the systematic design of an 75 MW S-band pillbox-type window. It is shown that with the standard pillbox-type design the window cannot be matched using ceramic disks with a thickness in the range from 4 mm to 8 mm. Nevertheless such disks are mechanically more robust and easier to manufacture than the usual 3 mm disks. Therefore a new design of the pillbox-type window with an additional inductive iris is presented so that ceramic disks of arbitrary thickness may be used. Furthermore it is demonstrated how the bandwidth of the window can be optimized by fine tuning the thickness of the ceramic disk. The final design of the pillbox-type window with smoothed edges is validated by the application of the MAFIA time domain module.

1 INTRODUCTION

The S-band linear collider at DESY requires approximately 2600 klystrons operating at an output power of 150 MW, a pulse duration of $3\,\mu$s and a repetition rate of 50 Hz. Until 1995 two klystrons have already been built and successfully tested [1]. The klystron has two output waveguides which are split and recombined so that each of the four rf windows has to withstand a peak transmission-power of about 37.5 MW. The production costs of the klystrons can significantly be reduced if each tube contains only two rf windows. In this paper we will report on the systematic design of such a window.

Fig. 1 presents the schematic drawing of a pillbox-type rf window. The practical use of rf-windows in the high-power regime is still a challenging task although strong efforts have been made during the past to improve their reliability [2]. The mechanismen which is responsible for an rf window failure has not yet been understood in detail. Nevertheless it seems to be clear that multipactor electron bombardment of the ceramic disk [3] is mainly responsible for a breakdown.

Computer simulations have demonstrated that the component of the electric field normal to the disk is mainly responsible for this phenomenon. Hence a long pillbox-type rf window has been suggested in [2] which has a length of more than 150 mm instead of 30 mm for the standard window. The axial electric field is effectively suppressed by this new geometry because only the TE$_{11}$ mode is propagating in the empty circular waveguide sections of the pillbox cavity.

The higher order modes which are excited at the transition from the rectangular to the circular waveguide do not interact with the ceramic disk in a long window. Thus we can apply the scattering matrix technique taking only one propagating mode into account. From this analysis we get analytic expressions which are very useful for the window design. Only the scattering matrix corresponding to the waveguide transition will be calculated numerically using MAFIA [4]. Hence the scattering matrix technique leads to a numerically efficient formulation so that a large variety of parameter sets can be studied.

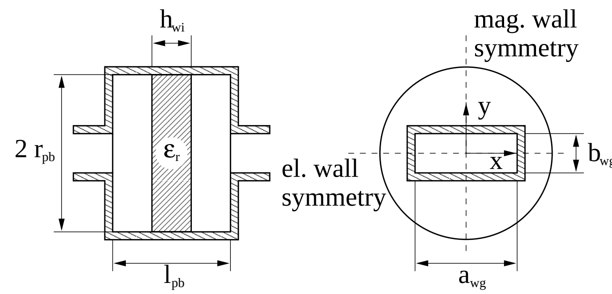

Figure 1: Schematic drawing of the pillbox-type rf window.

Pillbox-type rf windows usually contain ceramic disks with a thickness of about 3 mm. Especially if high purity alumina is to be used it is desirable to increase the thickness of this disks from the mechanical point of view. The analytic design formulas show that such windows cannot be matched if the thickness of the disk is in the range from 4 mm to 8 mm because the input reflection of the transition from the rectangular to the circular waveguide is too small. Therefore a new type of rf window is presented which contains additional inductive irises in order to increase the reflectivity of the waveguide transition.

Both features of the new window, which are an increased thickness of the ceramic disk and a long pillbox cavity, lead to a significant reduction of the bandwidth. Especially if the SLED-option [5] is taken into account the VSWR must be less than 1.1 over a band of about 90 MHz centered at 3 GHz. It is shown how a maximum bandwidth is obtained by properly adjusting the thickness of the ceramic disk.

In order to prevent the structure from arcing we have to round off the sharp edges at the waveguide transition which are characterized by $y =$ constant. Although the inductive irises do not give rise to a singularity of the electric field they are also assumed to be rounded off in the final design which is validated by the time domain module of the MAFIA code.

2 WINDOW DESIGN

Let us assume that the dimensions of the rectangular waveguide and the permittivity of the ceramic disk are

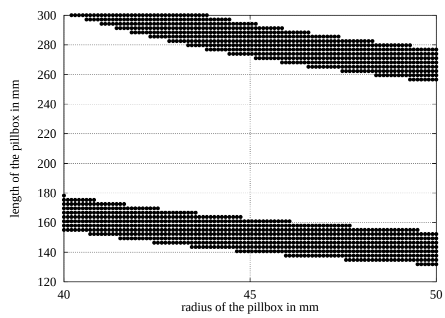

Figure 2: Distribution of possible solutions in the r_{pb} - l_{pb} plane. Parameter: $h_{wi} = 5\,$mm.

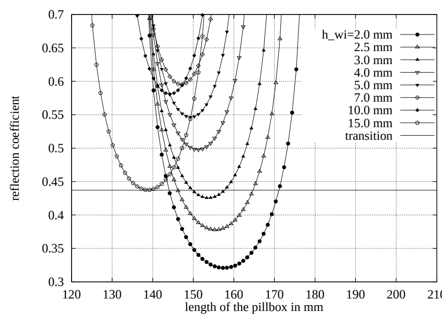

Figure 3: Required reflection coefficient of the waveguide transition as a function of l_{pb} and h_{wi}. Parameter: $r_{pb} = 46\,$mm.

$a_{wg} = 72.14\,$mm, $b_{wg} = 34.04\,$mm and $\varepsilon_r = 10$.

From the application of the scattering matrix technique it turns out that the rf window can only be matched if the window parameters obey certain relations. Fig. 2 shows all possible solutions for which the window can be matched in the r_{pb} - l_{pb} plane assuming $h_{wi} = 5\,$mm. In the considered parameter range two sets of solutions are found which are separated just by one wavelength of the TE_{11} mode in the empty circular waveguide.

For the variation of the radius of the pillbox cavity some transitions from the rectangular to the circular waveguide have been analyzed using MAFIA. Actually the radius of the pillbox cavity has been varied in steps of $2\,$mm. The scattering parameters at intermediate points are then found by the application of an interpolation scheme.

Fig. 3 presents the required input reflection of the waveguide transition as a function of the length of the pillbox cavity for a cavity radius of $46\,$mm whereas the thickness of the ceramic disk serves as a parameter. The input reflection of the waveguide transition is also given as a straight line.

Starting from $h_{wi} = 2\,$mm, the required input reflection of the waveguide transition increases. For $h_{wi} = 2\,$mm, $2.5\,$mm and $3\,$mm, Fig. 2 predicts two solutions for each thickness corresponding to different lengths of the pillbox cavity. But for thicker disks, the parabolas do not intersect with the straight line so that no solution exists. Only if we consider very thick disks, $h_{wi} > 10\,$mm, the required input reflection decreases again. Consequently, the window can only be matched for disks in the range from $4\,$mm to $8\,$mm if we choose a waveguide transition with a higher input reflection.

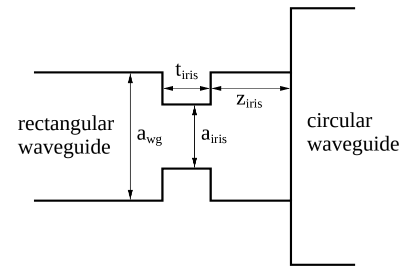

Figure 4: Schematic drawing of the waveguide transition with an inductive iris.

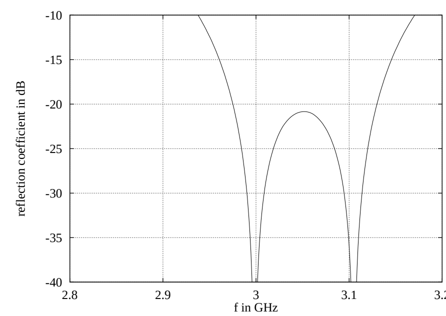

Figure 5: Reflection coefficient of the window as a function of frequency. Parameter: $r_{pb} = 46\,$mm, $l_{pb} = 144.9\,$mm, $h_{wi} = 5\,$mm, $z_{iris} = 40\,$mm and $a_{iris} = 57\,$mm.

In order to increase this quantity we introduce an inductive iris in front of the waveguide transition according to Fig. 4. t_{iris} is assumed to be $5\,$mm. For a given iris one gets a maximum increase of the reflectivity for $z_{iris} = 40\,$mm. For the adjustment of a specific value of the input reflection, which is necessary for the proper design of a window, the width of the iris a_{iris} is used.

We have now all the data together which we need for a systematic design of the window. Let us start assuming the following parameters: $r_{pb} = 46\,$mm, $h_{wi} = 5\,$mm and $z_{iris} = 40\,$mm. According to Fig. 3, the input reflection of the waveguide transition has to be greater than 0.55 in this case. We choose an input reflection of 0.57 which corresponds to an iris width of about $57\,$mm in order to show that really two solutions exist if the input reflection is larger than 0.55. Applying the scattering matrix technique, we actually find two matched windows for $l_{pb} = 144.9\,$mm and $l_{pb} = 154.5\,$mm. Fig. 5 shows the input reflection of the window for $l_{pb} = 144.9\,$mm.

Both solutions have a bandwidth corresponding to a VSWR $= 1.1$ of approximately $30\,$MHz which is much too small. The bandwidth can significantly be enhanced if we make use of both solutions simultaneously. For that the two frequencies at which the window is matched have to be centered around the design frequency, see Fig. 6. This is achieved by properly choosing the length of the pillbox cavity.

The reflection coefficient at the design frequency which is related to the bandwidth of the window can then be adjusted by the thickness of the ceramic disk which is illus-

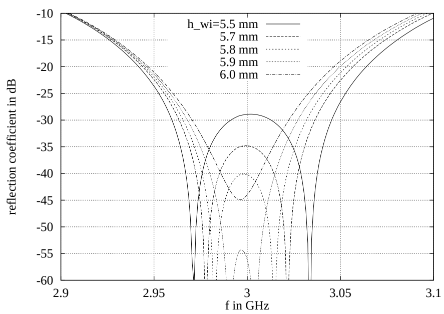

Figure 6: Reflection coefficient of the window as a function of frequency and the thickness of the ceramic disk. Parameters: $r_{pb} = 46$ mm, $l_{pb} = 148.9$ mm, $z_{iris} = 40$ mm and $a_{iris} = 57$ mm.

#	h_{wi} in mm	Δf in MHz	
		VSWR $= 1.05$	VSWR $= 1.1$
1	5.5	–	94
2	5.7	67	83
3	5.8	60	77
4	5.9	52	72
5	6.0	44	66

Table 1: Bandwidth as a function of the thickness of the ceramic disk.

trated in Fig. 6. From Fig. 3 it is clear that the solutions move closer together if the thickness of the ceramic disk is increased. This leads to a smaller reflection coefficient at the design frequency but also to a reduction of the bandwidth. Thus one has to find a trade-off between these two quantities. In Table 1, the bandwidth of the window is given for several values of h_{wi}. E.g., the VSWR is still less than 1.1 over a frequency range of 94 MHz for $h_{wi} = 5.5$ mm. However in this case one has to cope with a reflection coefficient of -28.9 dB at the design frequency.

For the final design of the window we use a waveguide transition with rounded edges according to Fig. 7. Detailed investigations using the MAFIA electrostatic module yield that a rounding radius of 10 mm leads to a field enhancement of about 30% which seems to acceptable. Furthermore it is preferred to use semicircular irises with a radius of 9 mm instead of those which sharp edges which is also illustrated in Fig. 7.

Fig. 8 presents the input reflection of the final window design as a result of the scattering matrix technique and the MAFIA time domain module. The agreement between both methods is quite well. Optimizing the bandwidth yields a useful frequency range of about 80 MHz and a reflection coefficient at the center frequency which is less than -33 dB.

3 CONCLUSIONS

The scattering matrix technique and the MAFIA computer code have been applied in order to design a modified S-band high-power pillbox-type window. It has been shown that for a ceramic disk with a thickness in the range from 4 mm to 8 mm the input reflection of the rectangular-circular waveguide transition has to be increased so that the overall window is matched at the design frequency. It has been demonstrated by MAFIA computations that the required input reflection of the waveguide transition can be obtained by an inductive iris one quarter wavelength in front of the rectangular-circular waveguide transition. Moreover it has been shown that the thickness of the ceramic disk has to be properly chosen for an optimum bandwidth of the window. A final design of the window with rounded off edges has been proposed; and the performance of this structure has been checked applying the time domain module of the MAFIA computer code.

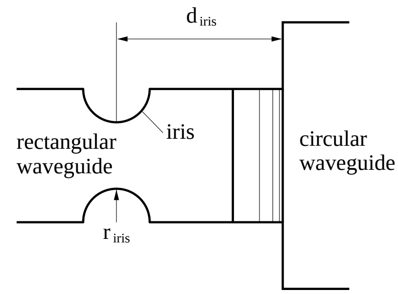

Figure 7: Schematic drawing of the waveguide transition with rounded edges.

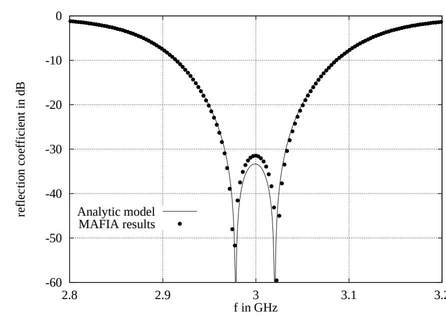

Figure 8: Reflection coefficient as a function of frequency with $r_{pb} = 46$ mm, $h_{pb} = 150.4$ mm, $h_{wi} = 6.1$ mm, $d_{iris} = 40$ mm, $r_{iris} = 9$ mm.

4 REFERENCES

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