ELECTROMAGNETIC SIMULATIONS OF THE INPUT POWER COUPLERS FOR THE ESS-BILBAO RFQ

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Abstract

An input power system is currently being designed at ESS-Bilbao in order to inject the radio-frequency power provided by a klystron into the Radio Frequency Quadrupole (RFQ) cavity as part of the linear accelerator. In this work, some input power couplers based on a coaxial topology are carefully studied from an electromagnetic point of view. As we will show, the electrical properties of the ceramic window used to ensure the vacuum of the RFQ crucially deteriorates the matching of the devices. To overcome this drawback, a full-wave electromagnetic simulator is used to optimize the coupler dimensions in order to minimize both the return and insertion losses.

INTRODUCTION

ESS-Bilbao linear accelerator (linac) [1] is intended to be an accelerator facility in southern Europe for advanced scientific research and development which fulfils the specifications for a driven injector for ESS [2]. Within the modular design of the linac, the Radio Frequency Quadrupole (RFQ) cavity plays a key role. The main characteristics of the ESS-Bilbao RFQ can be found, for instance, in [3], table I. The 4-vane RFQ will bunch and accelerate particles from the incoming 75 keV up to 3 MeV, with a maximum projected current of 75mA and a Duty Cycle (DC) up to 8%. The RFQ is designed so that the quadrupole mode of the cavity resonates at 352.2 MHz, which is the working frequency for the hole linac. The RF input power needed to feed the RFQ will be provided by two couplers connected in a T-configuration to a klystron. Preliminary studies show that each power coupler should be able to handle a peak power of 450 kW.

In this work, two different input power couplers based on a coaxial topology are presented and carefully studied from an electromagnetic point of view. As it is well known, the electrical properties of the ceramic window used to ensure the vacuum of the RFQ crucially deteriorates the matching of the devices. To overcome this drawback, a full-wave electromagnetic simulator is used to optimize the dimensions of the couplers in order to minimize both the return and insertion losses at the operating frequency of the linac.

DESIGN 1: THE DRUM-LIKE COUPLER

The designed coupler is shown in figure 1. The input and output coaxial dimensions, chosen to ensure a characteristic impedance of $Z_0 = 50\ \Omega$, are shown in table 1. As a first approach, the ceramic window topology has been fixed as a simple cylinder. Specifically, a value of $L\_window = 16$ mm has been chosen. However, this value can be changed at any time if needed since it is a parameter of the model. Actually, the proposed model has been successfully tested up to $L\_window = 35$ mm. Besides the input, output and window coaxial, two new transitions have been added. Each transition is located at one side of the ceramic window. Thus, once the length and the material for the window is chosen, by changing the dimensions of the transitions (both length and radius) and the window (radius), the required matching can be obtained. To this end, some parameters have been defined in the model such us the length (`L_trans1` and `L_trans2`) and both the internal and external radius (`Rext_Trans1, Rint_Trans1, Rext_Trans2 and Rint_Trans2`) of the transitions and the radius of the window (`R_window`).

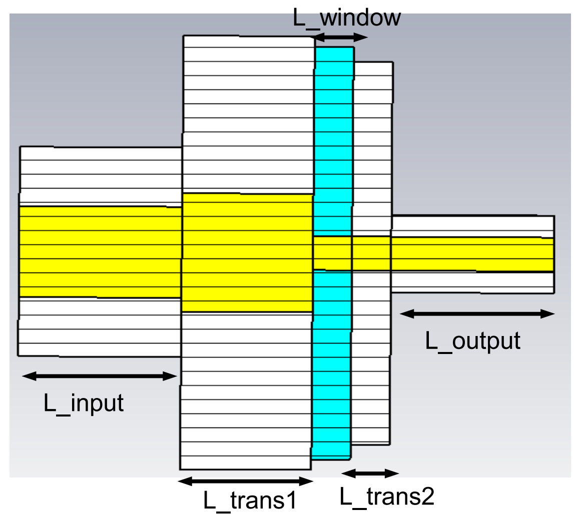

Figure 1: Cut view of the designed drum-like coupler including longitudinal parameters.

Table 1: Coaxial Dimensions for the ESS-Bilbao Couplers

Coax. Section ($50\ \Omega$)	**Diameter Outer Cond., (mm)**
Input	100
Output	35.65

Window Materials

As stated in the introduction section, the choice of the material for the RF window is a key issue from an electromagnetic point of view, since the electrical properties of the

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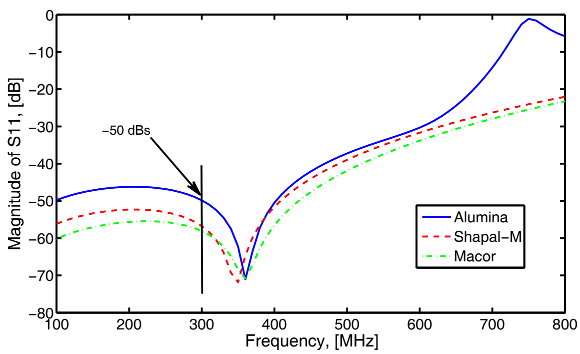

Figure 2: S_{11} obtained for the drum-like coupler shown in figure 1. An optimization process has been carried out for each of the window materials.

materials can ruin the matching required for the coupler. In order to show the versatility and robustness of the proposed coupler topology, three materials with quite different electrical properties have been considered:

- **Alumina**: this is the material most commonly used in the bibliography. Its dielectric constant ε_r varies from 9 to 9.9 depending on its purity. In this work $\varepsilon_r = 9.4$ and a dielectric loss tangent tan $\delta = 0.006$ have been chosen.
- **Shapal-M**: this is a machinable grade of Aluminium Nitride. According to the documentation, Shapal-M can be machined into complex shapes with high precision. The thermal conductivity is five times more than alumina while the mechanical strength is comparable. The dielectric constant is $\varepsilon_r = 7.1$ and the dielectric strength of 40 KV/mm (AC, 1 mm thickness) The main applications of this material are related to vacuum parts.
- **Macor**: Macor MGC (machinable glass ceramic) is a white, odorless, porcelain-like material composed of 55% fruorophlogopite mica and 45% borosilicate glass. According to the data sheet, this material is recommendable when you need the performance of a technical ceramic: high use temperature, electrical resistivity, zero porosity. Besides, it will lower costs and substantially reduce the time between design and actual use. The main electrical properties are $\varepsilon_r = 5.8$ (at around 352 MHz), tan $\delta = 0.006$ and a dielectric strength at 25^oC of 9.4 KV/mm (AC, 12 mm thickness). There is a wide variety of applications for this material including constant vacuum techniques.

Optimization Results

For each one of the window materials described in the previous section, an optimization of the parameters of the model has been carried out by means of a full-wave electromagnetic simulator. In all the simulations, the dimensions

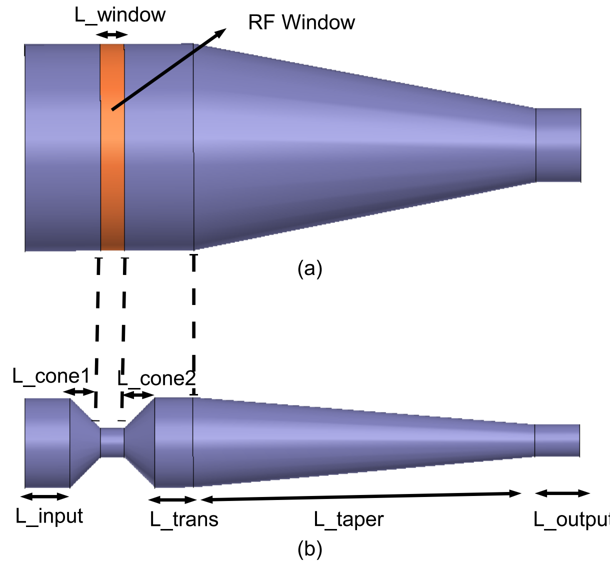

Figure 3: Nose-cone coupler designed at ESS Bilbao. (a) Outer conductor and window view; (b) Inner conductor.

of both the input and output coaxial (table 1) as well as the length of the window ($L\_window = 16$ mm) have been fixed. Moreover, copper is assumed for both the inner and outer conductors of the coupler. The optimization goal has been set to obtain $S_{11} < -50$ dBs (much more strict than the usually considered 30 dBs) in a wide frequency band (300-400 MHz).

The results obtained are shown in figure 2. As it can be seen, an outstanding performance of the coupler for each of the considered window materials is obtained.

DESIGN 2: THE NOSE-CONE COUPLER

Although the drum-like coupler exhibits an outstanding performance from a matching point of view, its behavior in terms of multipacting and arcing remains unknown[1]. Since these side effects sometimes occur when sharp transitions exist in the structures under analysis, it could be mandatory to avoid such transitions from the model. Therefore, an alternative topology for the coupler has been investigated in order to avoid such sharp transitions but keeping the outstanding electrical behavior of its predecessor. The topology of this coupler is inspired on the SNS coupler [4]-[5].

The designed coupler is shown in figure 3. The input and output coaxial dimensions (table 1) as well as the window topology (a simple cylinder of length $L\_window = 16$ mm) are the same that for the drum-like coupler. Moreover, as it happens in the first design, the length of the RF window can be changed at any time if needed since it is actually one more parameter in the model. The proposed model has been successfully tested up to $L\_window = 35$ mm. Compared to the drum-like coupler, the sharp transitions in the

[1] This issue will be addressed shortly.

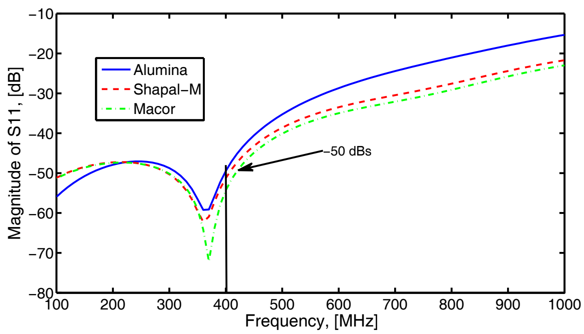

Figure 4: S_{11} obtained for the nose-cone coupler shown in figure 3. An optimization process has been carried out for each of the window materials.

outer conductors have been removed. A perfect matching is now achieved by smoothly changing the dimensions of the inner conductors. As it can be seen, two conical sections (`L_cone1` and `L_cone2`), a transition section (`L_trans`) and a taper section (`L_taper`) have been defined. By properly changing the dimensions of the previous parameters, the required matching can be obtained.

Window Materials

The same materials described in the previous design are now used for the present coupler. Therefore this allows us again to show the effectiveness of the proposed model.

Optimization Results

Once again, a 3D electromagnetic simulator is used to optimize the parameters of the model in order to obtain an outstanding electrical behavior of the coupler for each of the proposed window materials. The optimization goal has been set to obtain $S_{11} < -50$ dBs (much more strict than the usually considered 30 dBs) in a wide frequency band (300-400 MHz).

The results obtained are shown in figure 4. As it can be seen, an outstanding performance of the coupler for each of the considered window materials is obtained.

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CONCLUSIONS AND FUTURE WORK

In this work, two different designs of a power coupler for the RFQ have been presented and carefully studied from an electromagnetic point of view. By using a 3D electromagnetic simulator, both prototypes have been successfully optimized for several windows materials with quite different electrical properties, thus showing the robustness and effectiveness of the proposed designs. At this stage, it seems clear that the window material to be used in the final design must be chosen taking into account thermal and mechanical considerations exclusively.

As future work, once an electromagnetic model of the final ESS-Bilbao RFQ is available, both coupler designs must be tested with it. Since the coupling in the cavity is inductive, this will involve the design and parametrization of a coupling loop for the couplers. In parallel, a multipacting and arcing study of the proposed models must be carried out.

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