ELECTROMAGNETIC DESIGN OF NEW RF POWER COUPLERS FOR THE S-DALINAC

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Abstract

The electromagnetic design and design results of new rf waveguide-coax input power couplers for the S-DALINAC are presented. Special consideration is spent on the minimization of the transverse electromagnetic field on the beam axis which would cause an emittance growth of the electron beam.

INTRODUCTION

The superconducting Darmstadt electron linear accelerator (S-DALINAC) is a recirculating machine operating at 3 GHz [1]. Since its first operation in 1987 the S-DALINAC has continuously be improved. Presently, the third generation of components for this accelerator is under development. To allow future nuclear physics experiments with cw beam currents from 150 to 250 µA at electron energies of 14 MeV behind the injector linac rf power of up to 2 kW has to be transferred to the electron beam. The present coax-coax input power couplers at the S-DALINAC with variable coupling are limited to a maximum power of 500 W. To reach power operation up to 2 kW while keeping the emittance growth of the electron beam small waveguide power couplers [2, 3] with minimized transverse kick should be used in the accelerator upgrade.

Recently, the electromagnetic design of a single-waveguide-coax and a twin-waveguide-coax coupler, respectively, for the S-DALINAC has been published [4]. It was mentioned that the single-waveguide-coax coupler allows for a more compact design whereas the rf behavior in terms of S-parameters is similar to that of the twin-waveguide-coax coupler.

In this paper a modified design of the twin-waveguide-coax coupler and its electromagnetic design procedure is presented. It is shown that a compact design similar to that of the single-waveguide-coax coupler is possible.

COUPLER DESIGN

Fig. 1 shows the geometry of the twin-waveguide coupler and the electric field patterns of the two lowest coaxial (TEM, H_{11}) and circular waveguide modes (TM_{01}, TE_{11}), respectively. At the 3 GHz operating frequency of the S-DALINAC the TEM mode and the H_{11} mode can propagate on the coaxial line while the TM_{01} and the TE_{11} mode of the circular waveguide (beam tube in Fig.1) are still evanescent modes. At transition 2 the TE_{11} mode with its asymmetric field distribution is mainly excited by the H_{11} mode. Since the asymmetric electromagnetic field of the TE_{11} mode generates an emittance growth, the excitation of the H_{11} mode must be minimized at transition 1.

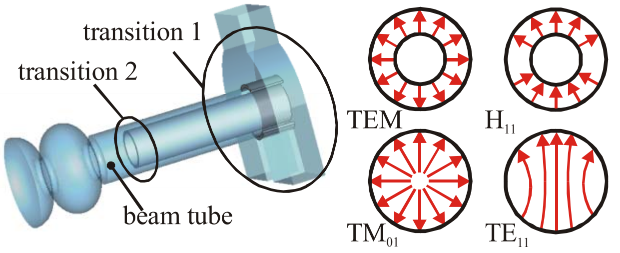

Figure 1: The twin-waveguide coupler and the electric field patterns of the two lowest coaxial modes (TEM, H_{11}) and of the circular waveguide modes (TM_{01}, TE_{11}).

In Fig. 2a the geometry of the twin-waveguide-to-coax transition (transition 1 in Fig. 1) and its parameters are given. The single-waveguide-to-coax transition presented before in [4] is again given in Fig. 2b. In both designs diaphragms are used to minimize the transverse coupler kick. The suppression of the H_{11} mode can be adjusted choosing the opening angle $\varphi_1+\varphi_2$. Once the angle $\varphi_1+\varphi_2$ is chosen the power transfer from the fundamental rectangular waveguide mode H_{10} to the TEM mode of the coaxial waveguide can be maximized by adjusting the height h and the stub length s for the single-waveguide-to-coax transition and additionally the gap width g and the waveguide width w for the twin-waveguide-to-coax transition, respectively.

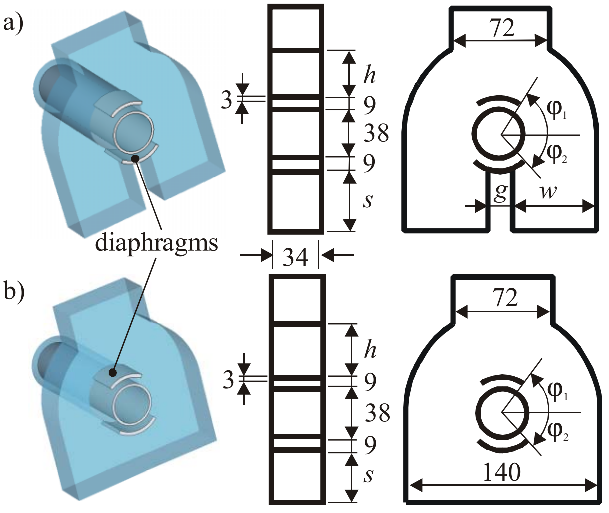

Figure 2: The twin-waveguide-to-coax (a) and the single-waveguide-to-coax (b) transition of the waveguide-to-coaxial couplers under investigation (unit of length is mm).

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EM DESIGN PROCEDURE

The excitation of the H_{11} coaxial mode can be adjusted by choosing the opening angle $\varphi_1+\varphi_2$ of the waveguide-to-coax transitions in Fig. 2 and optimizing the remaining parameters h, s, g, and w.

In Fig. 3 the electromagnetic design procedure of the twin-waveguide-to-coax transition is illustrated. First, initial values for h, s, g, w and $\varphi_1 = \varphi_2$ are chosen. Then, the parameters h, s, g and w are varied in order to minimize the reflection of the fundamental waveguide mode H_{10}. In the next step, φ_1, and φ_2 are adjusted for a maximum suppression of the H_{11} mode at transition 1 in Fig. 1. The second and third step of the design procedure are repeated until optimized values for h, s, g, w, φ_1 and φ_2 are reached which means that the reflection $S_{H10,H10}$ and the transmission $S_{H11,H10}$ can not further be suppressed for the given opening angle $\varphi_1+\varphi_2$.

The design procedure of the single-waveguide-to-coax transition follows the same scheme except that only four parameters, namely h, s, φ_1, and φ_2 have to be adjusted.

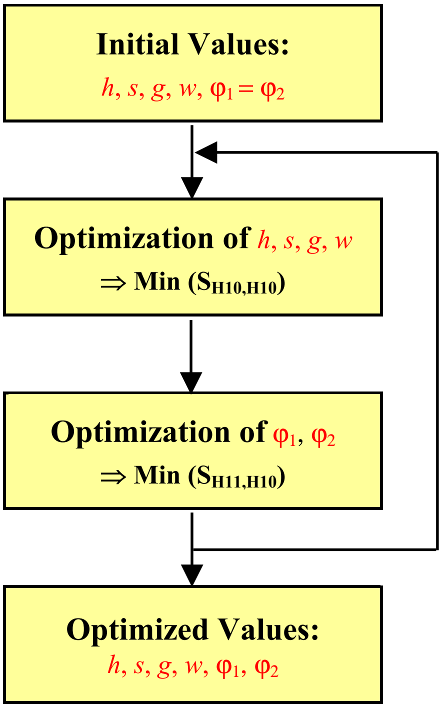

Figure 3: The electromagnetic design procedure of the twin-waveguide-to-coax transition.

WAVEGUIDE-TO-COAX TRANSITIONS

In Fig. 4 and 5 the design results of electromagnetic simulations for three twin-waveguide-to-coax transitions and three single-waveguide-to-coax transitions, respectively, with different opening angles are shown. The electromagnetic simulations were performed by means of CST MICROWAVE STUDIO ® [5] and usage of the integrated optimization tool. As can easily be seen the overall behavior of both designs is similar. Thus, the description of the twin-waveguide-to-coax transition is sufficient. An important characteristic of the modified twin-waveguide-to-coax transition (see also [4]) is that its total dimension is of the same order as that of the single-waveguide-to-coax transition.

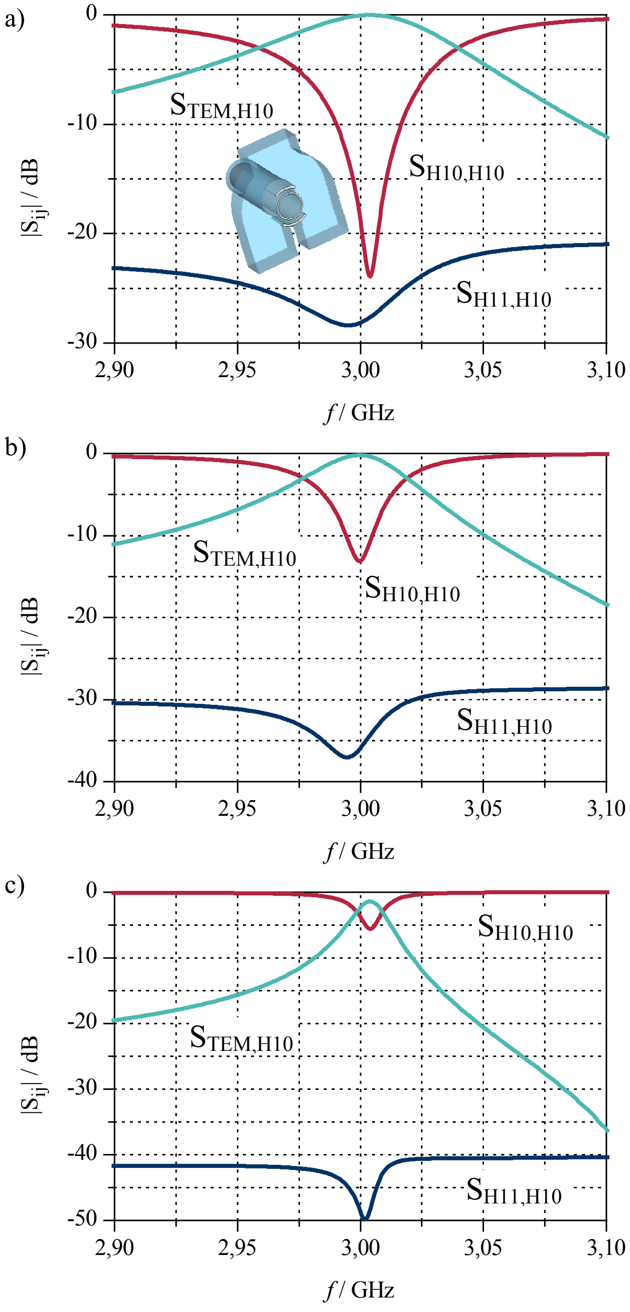

Figure 4: Reflection magnitude $|S_{H10,H10}|$ / dB and transmission magnitudes $|S_{TEM,H10}|$ / dB and $|S_{H11,H10}|$ / dB against frequency for three different twin-waveguide-to-coax transitions with different opening angles $\varphi_1+\varphi_2$:

a: $h = 34.1$, $s = 43$, $g = 18$, $w = 61$, $\varphi_1 = 56.2°$, $\varphi_2 = 49.3°$

b: $h = 36$, $s = 45$, $g = 5.6$, $w = 67.2$, $\varphi_1 = 44.6°$, $\varphi_2 = 41.6°$

c: $h = 37$, $s = 49$, $g = 2.4$, $w = 68.8$, $\varphi_1 = 32.4°$, $\varphi_2 = 28.7°$

(unit of length is mm; H_{10} is the fundamental mode of the rectangular waveguide, other modes as in Fig. 1).

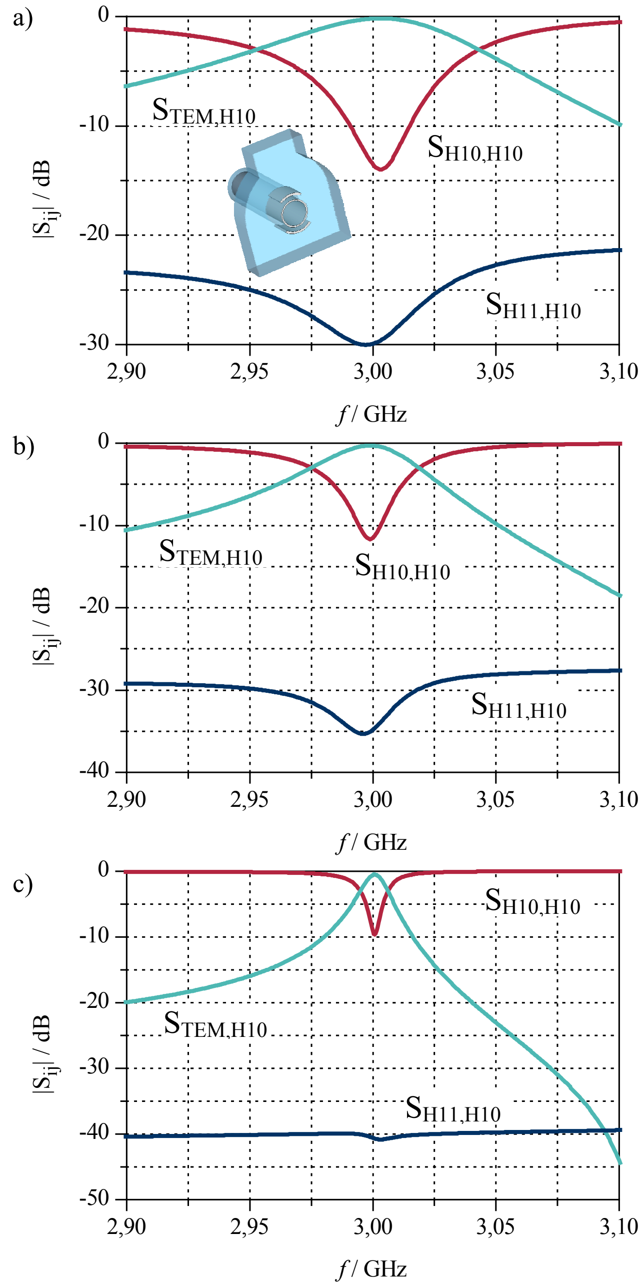

Figure 5: Reflection magnitude $|S_{H10,H10}|$ / dB and transmission magnitudes $|S_{TEM,H10}|$ / dB and $|S_{H11,H10}|$ / dB against frequency for three different single-waveguide-to-coax transitions with different opening angles $\varphi_1+\varphi_2$:

a: $h = 37.3$, $s = 36.1$, $\varphi_1 = 55°$, $\varphi_2 = 47.9°$

b: $h = 36.9$, $s = 39.5$, $\varphi_1 = 45.3°$, $\varphi_2 = 39.8°$

c: $h = 33.4$, $s = 42$, $\varphi_1 = 34.2°$, $\varphi_2 = 30.1°$

(unit of length is mm; H_{10} is the fundamental mode of the rectangular waveguide, other modes as in Fig. 1).

As can be seen from the dependence of the excitation level of the H_{11} mode from the opening angle $\varphi_1+\varphi_2$ in Fig. 4, decreasing the opening angle by about 20° reduces the excitation of the H_{11} ($|S_{H11,H10}|$) mode by some 10 dB. The excitation of the H_{11} mode is about -50 dB for an opening angle of 60°, resulting in an excitation of the TE_{11} mode in the beam tube (see. Fig. 1) by less than -50 dB. Further investigations have shown that the excitation level of the H_{11} mode can be reduced to less than -50 dB choosing an opening angle of about 40°. But this would result in a reflection of the fundamental waveguide mode H_{10} of more than -10 dB and a significant decrease of the transmission $S_{TEM,H10}$ to less than -3 dB as follows from Fig. 4. Fig. 4 provides also information on the bandwidth of the twin-waveguide-to-coax transition. Decreasing the opening angle $\varphi_1+\varphi_2$ results in a smaller bandwidth. The bandwidth is nearly 80 MHz for an opening angle of 100° (see Fig. 4a.) and approximately 10 MHz if an opening angle of 60° is chosen (see Fig. 4c.).

At this point, some general design rules for the twin-waveguide-to-coax transition and the single-waveguide-to-coax transition, respectively, can be summarized:

1. Diaphragms in the waveguide-to-coax transitions are used to minimize the transverse coupler kick. In particular the excitation of transverse electromagnetic fields in the beam tube (see Fig. 1) can be reduced to less than -40 dB.
2. The level of excitation of the H_{11} mode at transition 1 of the coupler designs (see Fig. 1) can be adjusted choosing the opening angle $\varphi_1+\varphi_2$.
3. The overall behavior for a given opening angle $\varphi_1+\varphi_2$ of the rf waveguide-coax input power couplers can be optimized varying some few coupler dimensions (see Fig. 2) .

CONCLUSIONS

A new twin-waveguide-coax coupler is proposed for the S-DALINAC upgrade. The rf behavior in terms of S-parameters and its dimensions are similar to that of a single-waveguide-coax coupler of which design data is also given in this paper. At the present state of research it seems that the main advantage of the twin-waveguide-coax power coupler over the single-waveguide-coax coupler is, that it allows for smaller transverse coupler kicks at the same opening angle $\varphi_1+\varphi_2$.

ACKNOWLEDGEMENT

The authors would like to thank M. Dohlus (DESY, Hamburg) for helpful discussions.

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