

# Numerical Simulation of Coupler Cavities for Linacs\*

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## Abstract

We present the numerical procedures involved in the evaluation of the performance of coupler cavities for linacs. The MAFIA code is used to simulate an X-Band accelerator section in the time domain. The input/output coupler cavities for the structure are of the symmetrical double-input design. We calculate the transmission properties of the coupler and compare the results with measurements. We compare the performance of the symmetrical double-input design with that of the conventional single-input type by evaluating the field amplitude and phase asymmetries. We also evaluate the peak field gradient in the coupler.

## I. INTRODUCTION

At SLAC, we have an active program on the Next Linear Collider (NLC) R & D, and couplers are an important part of the accelerator structure work in this program. Indeed, the efficient delivery of power from RF sources such as klystrons to disk-loaded accelerator structures in linear colliders depends crucially on the coupler cavity. There are several requirements to be satisfied by such a cavity. First, it is to be well matched to the feeding waveguides (see Fig. 1) in order to couple the maximum amount of power into the structure to achieve the highest possible accelerating gradient. Second, it must be tuned to the synchronous frequency for the proper phase advance in the structure. Third, it must have minimal deleterious effect on the beam. Fourth, the couplers should ideally have surface fields no higher than the interior. These considerations, coupled with the fact that the geometry is intrinsically three-dimensional, make the design of the coupler cavity a nontrivial problem.

Previously, coupler cavities for disk-loaded accelerator structures have been designed following a set of procedures based on the Kyhl method<sup>[1]</sup>. It involves a sequence of experiments to determine the matching and tuning. Several iterations on actual prototypes may be needed before an optimal configuration can be obtained. The effort can be time-consuming and requires substantial empirical expertise. In this paper, we study an alternative approach by numerical simulation. We build a computer model that approximates closely the coupler cavity. Since changes in dimensions can be easily implemented on the computer, this approach offers a distinct advantage over cold tests in optimizing a design. Furthermore, valuable field information such as asymmetries and peak gradients, for example, is readily obtainable numerically, which otherwise would be difficult to measure experimentally. These advantages provide the motivation for our effort to develop an accurate and reliable computational procedure for matching and tuning this particular RF component.

## II. THE NUMERICAL MODEL

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We model the symmetrical double-input coupler in the 30-cavity structure which was used in high power tests. Instead of all 30 cells, we simulate only a short section which is sufficient for matching the coupler and it is computationally more practical. Fig. 1 shows the mesh geometry we have constructed using MAFIA. It consists of two identical coupler cavities and two regular accelerator cavities. The coupler cavities are fed by WR90 rectangular waveguides through irises. Because the feeds are symmetrical, we only need to model one-quarter of the structure. The magnetic boundaries imposed at the two symmetry planes are consistent with the waveguide fields as well as the fields of the accelerating mode in the structure. The SLAC NLC operating frequency is chosen to be at X-band around 11.424 GHz. Accordingly, the dimensions of the regular cells in our model have been designed for that frequency at the  $2\pi/3$  phase advance per cell. The dimensions of the couplers are different in order to fulfill the matching and tuning requirements described earlier.

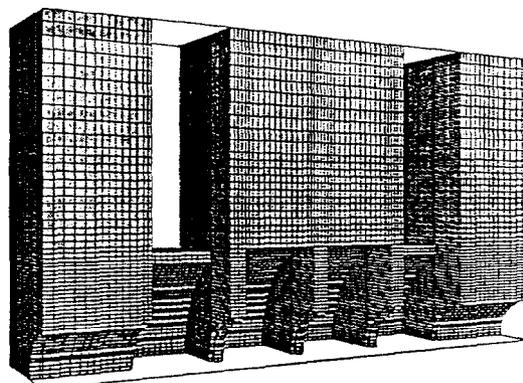


Fig. 1 MAFIA geometry for a 4-cell traveling wave section.

Given a coupler geometry, we perform a MAFIA simulation in the time domain. Power is fed continuously at the input waveguide port in the  $TE_{10}$  mode at a particular frequency, starting with a smooth initial rise and reaching 1 watt at flat-top. The input power couples to the accelerating mode via the irises, propagates through the section and exits by way of the output coupler. The simulation extends over many filling times of the section until a traveling wave at steady-state is reached. At the end of the run, the reflection coefficient  $S_{11}$  at the input waveguide port and the transmission coefficient  $S_{21}$  at the output waveguide port are evaluated. In addition, the electric field on axis and in designated regions of interest is recorded for subsequent post-processing.

## III. MATCHING AND TUNING OF COUPLER CAVITY

The cross-section of the coupler cavity is shown in Fig. 2(a). There are three dimensions to be determined: the coupler diameter, the iris aperture and its thickness. Assuming that the iris thickness is held fixed, the design program is then to choose the two remaining dimensions in such a way that the matching and tuning are optimal.

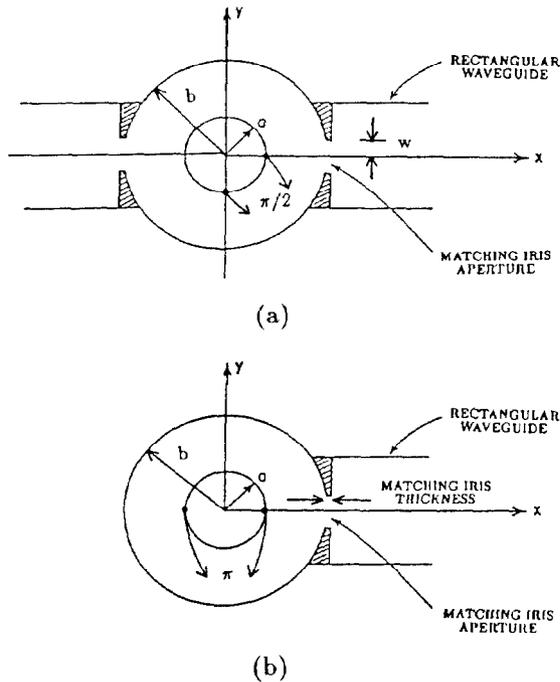


Fig. 2 Schematics of (a) symmetrical double-input coupler; (b) single-input coupler.

These conditions are assessed as follows. As far as matching is concerned, we look for the minimum VSWR for the section. In the simulation, this corresponds to the smallest reflection coefficient  $S_{11}$  at the input waveguide port. Fig. 3 shows the time history of  $S_{11}$  for a typical case when the coupler is matched. We see that the steady-state can be reached after several filling times and the amount of reflection is quite acceptable (VSWR = 1.023 in this case).

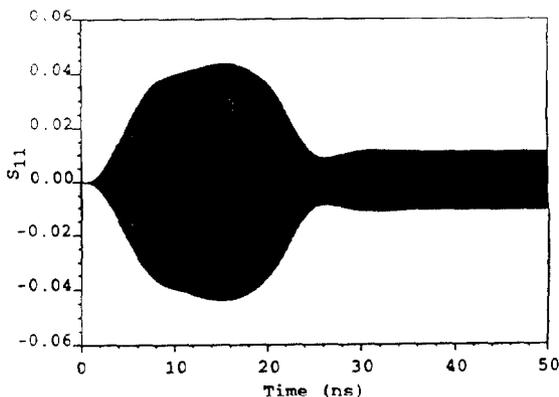


Fig. 3 The reflection coefficient as a function of time for a matched coupler

To evaluate tuning, we examine the amplitude and phase variations of the electric field on axis. One can write

$$E_T(z) = |E_T(z)|e^{-i\theta_T(z)}, \quad (1)$$

where the time variation has been left out. In the MAFIA run at steady-state, the electric field on axis along the structure is stored over several cycles which can be Fourier-analyzed to obtain  $E_T$  and  $\theta_T$ . They are plotted in Figs. 4(a) and (b) for the same matched case mentioned above. The dashed lines mark the boundaries between cells. In both plots we see that the field is periodic in the

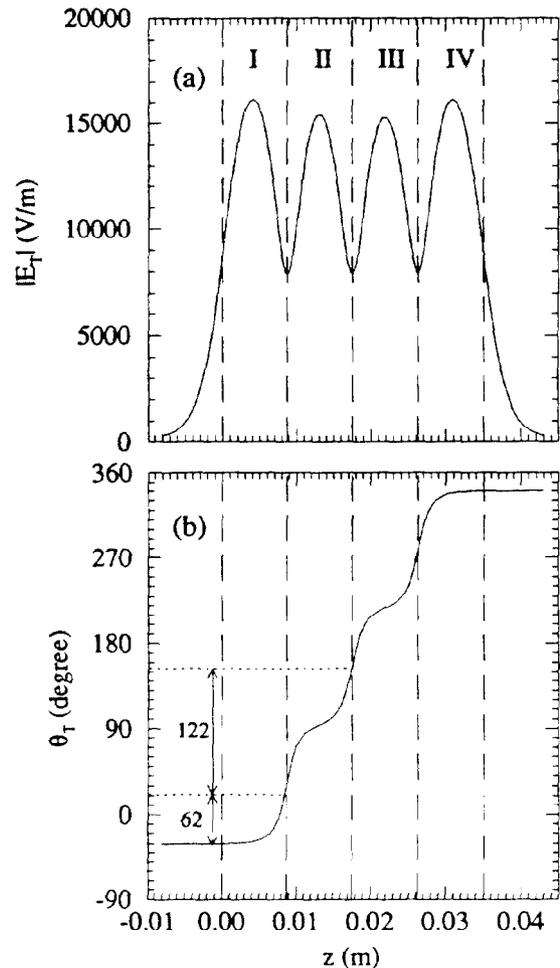


Fig. 4 Amplitude and phase variations for a matched coupler. Regions I, II & III, and IV are the input coupler cavity, the two structure cells and the output coupler cavity, respectively.

regular cells. We also notice that it is symmetric about the center of the structure which should be the case when the couplers are nearly matched. In this case the fields look identical whether power is fed in at the input or output end. The phase advance in the two regular cells is  $122^\circ$ , close to the expected value of  $120^\circ$  at the driving frequency of 11.42 GHz. In the coupler cavities, the phase variation is zero across roughly half the cavity and totals to  $62^\circ$  for the whole cell. This suggests that the field in the half of the coupler cavity near the cut-off beam pipe is essentially a standing wave while the traveling wave in the other half advances by half the phase shift as compared to the regular cell. These results confirm earlier data from dielectric bead perturbation measurements<sup>[3]</sup>. As pointed out in that paper, the field amplitude and phase variations can provide a means by which the tuning of the coupler can be accurately determined. Numerically such a procedure is much easier to implement than in actual cold tests. A detailed account of the numerical procedure can be found in Ref. 4.

#### IV. COMPARISON WITH EXPERIMENTS

In designing the symmetrical double-input coupler for the 30-cavity section, we performed a systematic numeri-

cal search for the optimal dimensions, using the matching and tuning conditions described above. We varied the cavity diameter and iris aperture, then calculated the VSWR and phase shifts in each iteration. With the coupler dimensions that we found for optimal matching and tuning, one can vary the frequency to explore the bandwidth. Fig. 5 shows a comparison of VSWR versus frequency between the MAFIA simulations and experiments<sup>[5]</sup>. Near the desired operating frequency of 11.424 GHz, the agreement is very good and the dimensions of the actual coupler are very close to those used in the MAFIA model. This is encouraging because it means that we can reasonably model the geometry for design purposes without expending an unrealistic amount of computational resources.

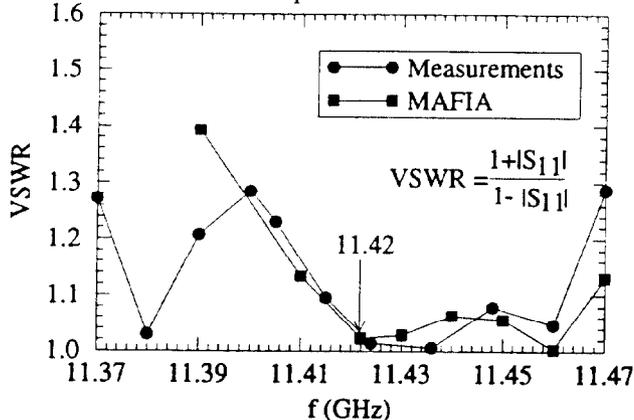


Fig. 5 VSWR versus frequency from MAFIA and measurements.

## V. FIELD ASYMMETRIES IN COUPLERS

Conventional couplers are of the single-input type (see Fig. 2(b)) where power is fed in from a single waveguide. This configuration inherently introduces field asymmetries across the beam aperture in the form of a dipole component. The amplitude asymmetry leads to a shear force which spreads the bunch while the phase asymmetry results in a deflecting force on the bunch<sup>[6]</sup>. As discussed in Ref. 6, the amplitude asymmetry can be corrected by offsetting the cavity with respect to the beam axis. The effect of phase asymmetry on the beam can be reduced by tilting the coupler cavity or by feeding successive sections from opposite sides.

In the symmetrical double-input coupler, assuming that the fields in both feeds are equal in amplitude and have the same phase, the dipole component is eliminated by virtue of symmetry. The remaining asymmetries are then due to the quadrupole component which can be measured by comparing fields at points 90° around the beam aperture (see Figs. 2(a) and (b)). In Table 1, we list the asymmetries for the single-input coupler before and after offset, and for the double-input coupler. The data for the single-input coupler are taken from Ref. 6 while those for the double-input are obtained from the MAFIA simulation of the matched case. We conclude from the results that the field asymmetry should be negligible near the beam axis in the double-input coupler. This makes it a superior design over previous single-input types. Presently, the input couplers for the 75 cm and 1.8 m structures being planned at SLAC have incorporated this double-input feature.

Asymmetry	Single-input before offset	Single-input after offset	Double-input
$\frac{\Delta E}{E} \Big _{\pi}$	10%	0.1%	0
$\Delta\phi \Big _{\pi}$	1.5°	1.5°	0
$\frac{\Delta E}{E} \Big _{\frac{\pi}{2}}$			6%
$\Delta\phi \Big _{\frac{\pi}{2}}$			0.1°

Table 1. Amplitude and phase asymmetries for single-input and double-input couplers. The designations “ $\frac{\pi}{2}$ ” and “ $\pi$ ” correspond to asymmetries shown in Fig. 2(a) and (b) at  $r = a$ .

## VI. PEAK FIELD GRADIENTS

One of the problems of common concern in accelerator structures is RF breakdown, which occurs when the peak electric field gradients reached in these structures exceed a certain critical value. At SLAC, an X-band 30-cavity accelerator section has been RF processed up to a stable accelerating field of about 100 MV/m, for a peak input power of 100 MW. While it is difficult to determine the locations of peak gradients experimentally, these can readily be obtained from our simulations. The maximum peak gradient was found to be 240 MV/m and occurs near the top part of the disk next to the first structure cell. Our result is in reasonable agreement with the measurement of the 30-cavity structure<sup>[7]</sup>, where damage was seen near the top part of the coupler disk. Furthermore, the maximum peak gradient in the structure cell is found to be very close to that in the coupler from our simulation.

## V. CONCLUSION

A numerical procedure for matching and tuning couplers has been developed, and good agreement has been found between simulations and experiments. The advantage of the double-input over single-input geometry has been shown in terms of lower field amplitude and phase asymmetries, and the location of the peak gradient in the coupler cavity has been identified. The present paper demonstrates that numerical simulations can provide very useful shortcut to cut-and-try prototyping in the design and analysis of linac coupler cavities.

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