A mm-Wave Coupler Design

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Abstract

An unsymmetric coupler has been designed for a planar mm-wave (120 GHz) structure. Measurement results, which verify the design, are also presented. The coupler design is based on three requirements: matching to the feeding waveguide, proper phase advance (namely half the phase advance of other cells) and surface fields comparable to those of the inner cells (to control dark current). This design differs from conventional coupler designs by two points. First, the structure is open and special care is necessary to avoid the excitation of TEM-waves. Second, because of the small size of the structure, the geometry is adapted to micro-mechanic fabricational techniques (e.g. LIGA).

1 INTRODUCTION

With the development of micro-mechanic fabricational techniques and the advent of power sources in the frequency range above 100 GHz, a whole new frequency band has been opened up to particle acceleration applications. A cooperation between Argonne Natl. Lab. and TU Berlin has been set up to explore the potential [1]. At very high frequencies, accelerators can be made extremely small in transverse size. This main feature may warrant for some interesting commercial applications. On the other hand, the tiny size makes power dissipation the chief problem to solve. The current status of research is outlined in a few presentations at this conference [2]–[5]. The development of several different accelerator components has been started at Argonne.

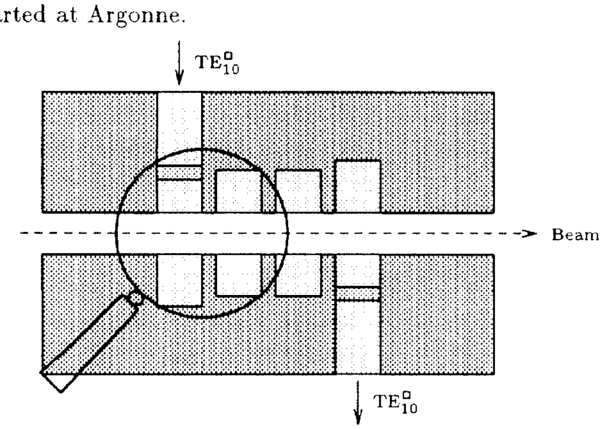

Figure 1: yz-cut of the mm-wave structure (scale 10:1). Both coupler cavities with waveguides, along with two cavities and the beam pipe are shown. The magnifying lens depicts the extension shown in more detail in Fig.2.

Here we present the numerical design and measurement of an unsymmetrical coupler cavity for the mm-wave structure. The procedure of such a numerical coupler design has been worked out by Ng and Ko [6]. Fig.1 shows the schematics of the investigated structure.

2 COUPLER DESIGN

The simulations were done using the MAFIA [7] code. MAFIA comes shipped with macros that compute scattering parameters in time domain. These have already been successfully applied for the design of a window [8]. CW scattering parameters are obtained by extending the simulation time into steady state. The MAFIA User's Guide states, that the speed of computation is about one order of magnitude faster compared to computations in frequency domain. It also says that convergence problems may be avoided that way.

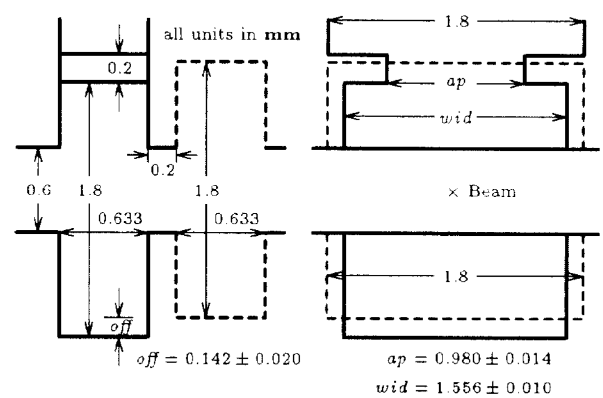

Figure 2: Dimensions of the unsymmetrical input coupler. Tolerances are for $\Delta S_{21} \leq 0.01$ from MAFIA runs with 80 000, 100 000 and 120 000 mesh points.

Three geometry parameters were up for design. These are the coupler offset *off*, the matching iris aperture *ap* and the coupler cavity width *wid* (Fig.2). The latter determines the resonance of the coupler cavity and it was therefore expected to be the most sensitive parameter. It was placed first within the design process (minimizing $1/S_{21}$, Fig.3). Secound in sensitivity comes the iris aperture *ap*, which was used to adjust the reflection S_{11} (Fig.4). Finally the coupler offset *off* was varied to minimize leaky TEM-waves (Fig.5). The effect of all three parameters on the design values was nicely decoupled and only a few iterations were neccessary. The tolerance is $\geq 10\mu$m for the three parameters (Fig.2).

The design process was automated. A FORTRAN program was written, which uses a bracketing and a minimizing routine from the Numerical Recipes [9].

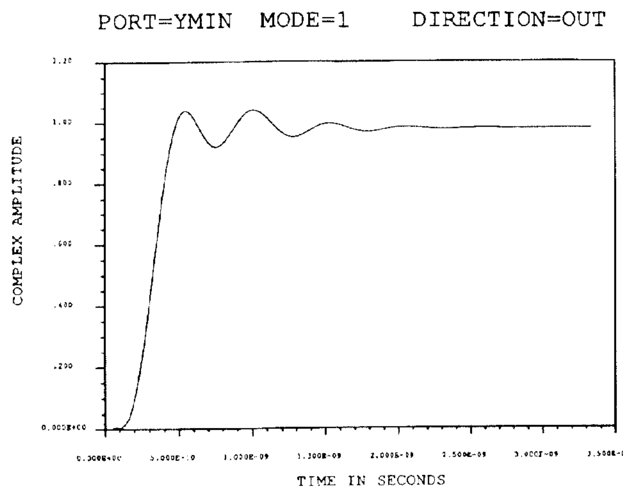

Figure 3: Envelope of S_{21} of the coupler in time domain.

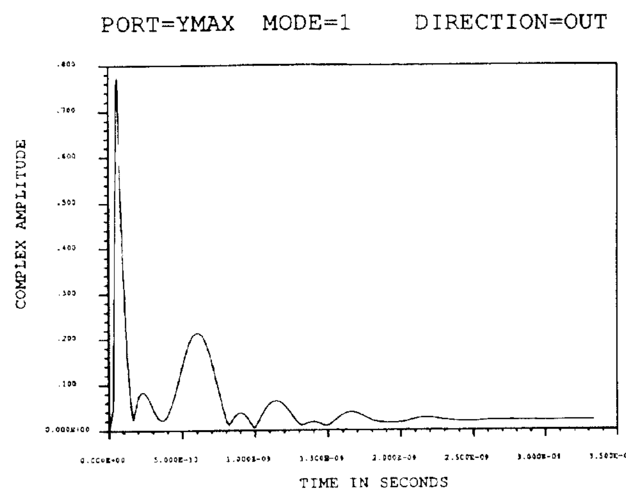

Figure 4: Envelope of S_{11} of the coupler in time domain.

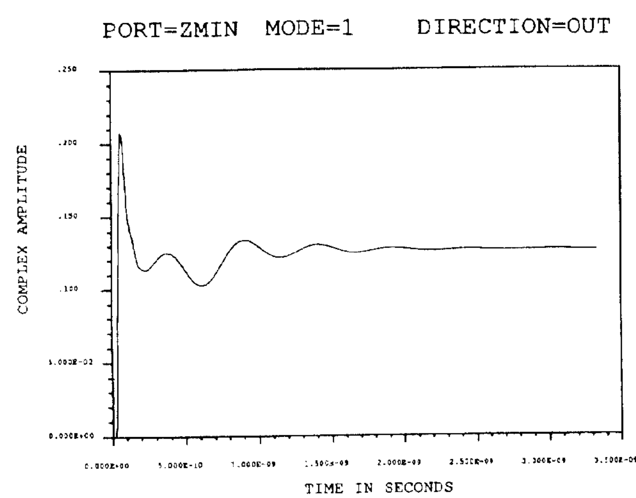

Figure 5: Envelope of the lowest port mode of the coupler at z_{min} in time domain (lost to the beam pipe).

During one design cycle, the FORTRAN program would edit a MAFIA command file and start MAFIA through a system call to a UNIX environment. Approx. six hours later, the MAFIA result file would be read and the design parameter (*off*, *ap* or *wid*), as well as the minimized function ($1/S_{21}$, S_{11} or $S_{31,\mathrm{TEM}}$) would get passed on to the minimizing routine. This routine would then determine the next design parameter trial value and a new design cycle would begin. In total about three weeks of cpu-time were consumed. Table 1 gives a survey on the power flow for the designed structure. We note that about 3% of the input power are lost to the outside through radiation.

Port mode(s)	P_{out}
$S_{21}(\mathrm{TE}_{10})$	0.9668
$S_{11}(\mathrm{TE}_{10})$	0.0033
$\sum$ sides	0.0046
$\sum$ beam pipe	0.0326
$\sum$ all modes	1.0073

Table 1: Normalized outgoing power at the ports.

3 MEASUREMENTS

A 10:1 scale model was built to verify simulation results. For practical reasons some minor changes were accepted (e.g. the cavity gap was 6 mm, instead of 6.33 mm). Also, in absence of a suitable calibration set, a simple response calibration was used. It is expected, however, that this sort of measurement will suffice to assess simulation results.

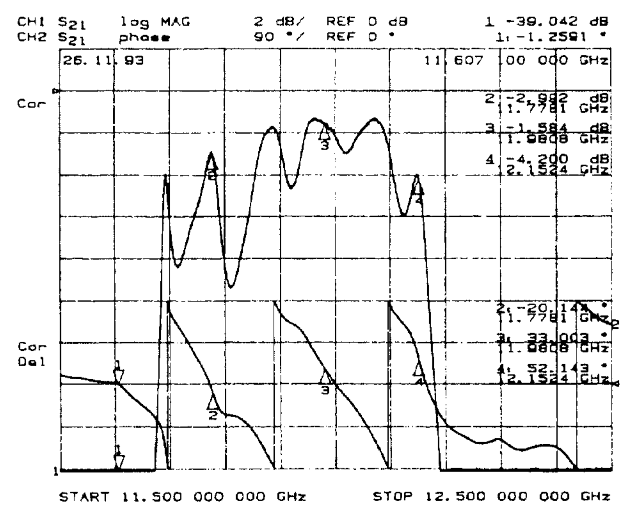

Figure 6: Measured amplitude (above) and phase (below) of S_{21} of a 10:1 scale model. The cursors are set (0, $\pi/3$, $2\pi/3$ and π-modes) from a previous S_{11} measurement.

Upon inspection of Fig.6 it is noted that the bandwidth is about 545 MHz (the 0-mode has no transmission). This corresponds to a coupling factor of 0.045, which was predicted in [1]. Further it is seen that the passband is considerably smoother around 12 GHz. This stems from the fact that a matched coupler cavity mimmicks the infinite structure (a perfect coupler would yield a flat passband). Thus we can estimate the coupler bandwidth to be about 125 MHz. The phase at 12 GHz is 2π, which is correct for a $2\pi/3$-mode in a two-cell, two-coupler structure. Attempts to tune the coupler cavity failed.

4 TAPER DESIGN

At very high frequencies (V-band and above) mainly overmoded waveguides are used to reduce power loss and to propagate more power. However does unintentional mode conversion increase with waveguide size. Corrugated waveguides have a better separation from competing modes. Our intention is to transport power from the source through a corrugated, circular waveguide. The propagating mode would be the hybrid HE_{11}-mode, which concentrates fields around the waveguide center. This beam-like behavior allows us to optically couple to the waveguide feeding the coupler. No mechanical attachment would be required, thus relaxing the alignment tolerance.

In a first attempt a taper was designed to match the coupler feeding waveguide to a straight oversized waveguide fed with a TE_{10} mode (Fig.7). Apart from the wider aperture, this design will not offer a better match for optical coupling. The next step towards a design will be to determine the radiated field pattern from the corrugated waveguide at the taper input and match this field to the TE_{10} mode at the taper output.

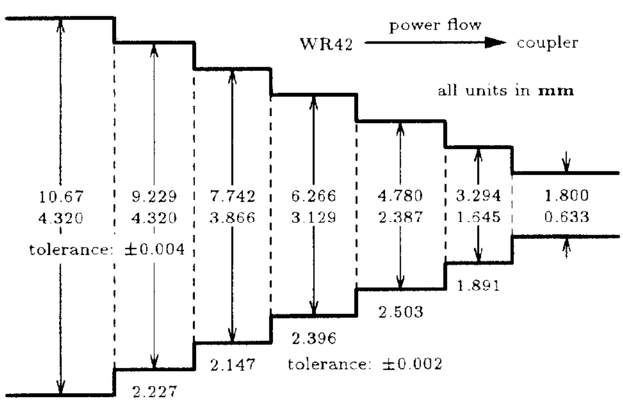

Figure 7: Dimensions of the taper. Tolerances are for $\Delta S_{11} \leq 0.01$. Required bandwidth: 2 GHz.

The numerical taper design was handled differently than the coupler design. A mode matching code for rectangular waveguides was at hand, which typically is faster by two orders of magnitude than MAFIA. Instead of three parameters for the coupler, 10 parameters were to be determined. Thus the adoption of a Simulated Annealing algorithm is attractive [9]. Briefly the method simulates a cooling process observed in nature, when a slowly cooled liquid will crystallize in the lowest possible energy state. The minimizing process is controlled by the temperature.

First a global minimum of the minimizing function $S_{11}S_{22}/S_{21}^2$ was searched at high temperatures ($\approx$ 100 iterations). This step is important, since waveguide applications exhibit many local minima. Next, the temperature was lowered sequentially to allow the algorithm to creep into the minimum ($\approx$ 1000 iterations). Then the mode number was increased for another low temperature cycle. Fig.7 shows the optimized geometry. Finally the result was checked with MAFIA (Fig.8). MAFIA shifts the resonances 1–2 Ghz towards lower frequencies and suggests a higher mode conversion. At 120 GHz a power fraction of 0.90 (-0.45 dB) is transmitted. The remaining power goes to mode conversion and is reflected towards power source. More geometry steps were introduced without significant improvement.

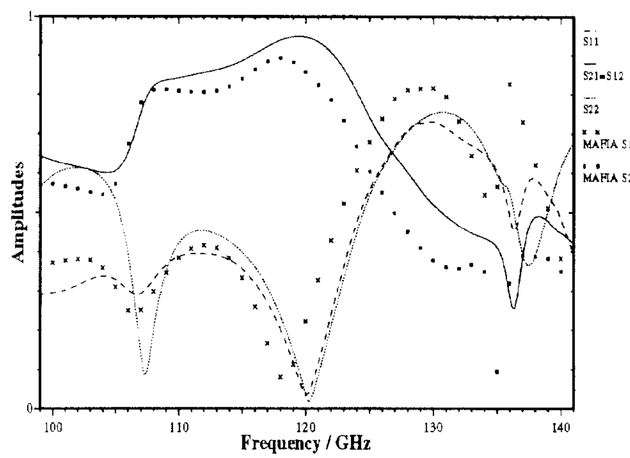

Figure 8: Transmission and reflection of the taper. Results from mode matching (220 modes) are drawn in lines, MAFIA (86 000 mesh points) as dots.

5 ACKNOWLEDGEMENT

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