DESIGN, FABRICATION AND RF MEASUREMENT OF A MM-WAVE ACCELERATING STRUCTURE

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Abstract

This paper presents a new design of a planar linear W-band accelerating structure (Muffin Tin). It is a traveling wave, constant impedance structure with an operating frequency of $91.392\ GHz$ (32 times the SLAC frequency) and is designed for the $2\pi/3$-mode. The design includes a new power coupler, with a cavity geometry optimized for high shunt impedance. A 7-cell prototype was fabricated by wire electro-discharge machining (EDM). A scalar measurement system for S-parameters was developed to determine the RF parameters of the prototype. Measured results are presented and compared to results of numerical simulations.

1 INTRODUCTION

MM-wave RF-structures have the potential of a break-through technology. Transverse dimensions are extremely small and it is conceivable to build modules where the RF-structures and power-sources are integrated together with magnetic focusing devices and beam monitors. A module then needs only connections to power supplies, vacuum pumps and electronics to become a working accelerator. However, the mechanical tolerances of the different components are very tight. For instance, the structure tolerances are in the oder of a few microns only if one does not want to tune individual cells. Today, modern microfabrication has developed at least two technologies which meet the required tolerances. These are wire electro-discharge-machining (EDM) and deep x-ray lithography (LIGA). Both technologies require planar structures. Therefore, we have started an intense research on planar structures which are all derivatives of the basic muffin-tin geometry [1]. Although we pursue both technologies, LIGA and EDM, the first and present structure is wire EDM 'ed being appreciably cheaper for prototypes.

2 MECHANICAL DESIGN AND FABRICATION

The first ideas for the design of the structure are written down in [2]. The prototype is a 7 cell structure designed for wire EDM fabrication. Therefore special points like technological limitations were taking into account. Figure 1 shows the explosion view of the structure. The top and the bottom plate are the mechanical support and the cavity bottom plates, the middle sheet is the structure with cavity section, beam pipe, pumping slots, input/output coupler with detoured wave guides with integrated taper and holes for screws and alignment pins. The power couplers are planar and input and output are from both sides, left and right. The dashed line indicates a sacrificial region, which will be cut away later. It serves for stabilization during machining. The thickness of this sheet is $2b$. The design makes two different kinds of bead pull measurements possible: the conventional longitudinal pull through the beam pipe and a pull with a transverse dielectric fiber, positioned and pulled in the pumping slots. Therefore it is necessary to detour the wave guide from the input and output coupling cells to the exterior boundary of the structure. The connected WR-10 flange is as large as half the structure and overlaps the pumping slots which are needed for this transverse fiber bead pull measurement. Further the size of the first and last cells $g = 0.864\ mm$, are smaller than the size of a WR-10 wave guide $wg = 1.27\ mm$, that means tapering in this direction is also necessary. Some improvements, like a new power input/output coupler with integrated taper and a better transmission are presented in [3].

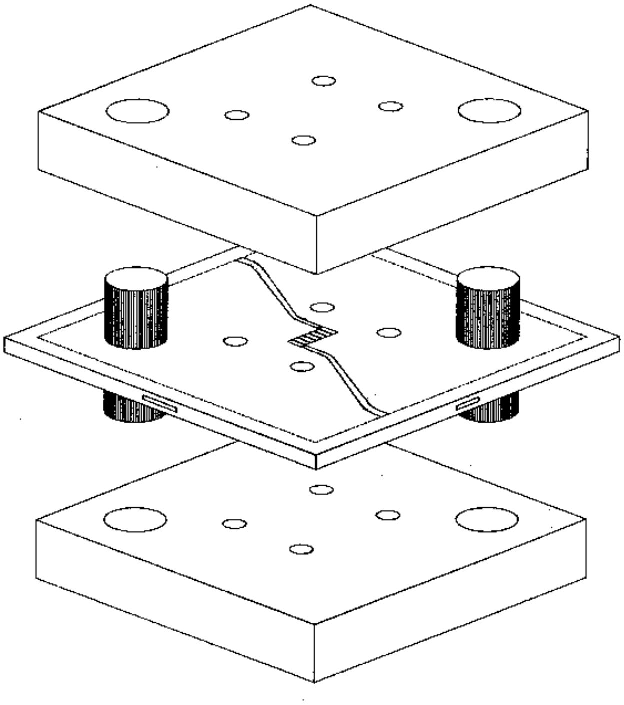

Figure 1: Explosion view.

Figure 2 shows a zoom of the cavity section. The iris thickness was fixed to $t = 0.23\,mm$. The aperture for the beam influences the bandwidth, shunt impedance and wakefields. An aperture to wavelength relation of $a/\lambda = 0.16$ is chosen, which results in an aperture of $2a = 1.05\,mm$. The width of the cavity is $w = 2.363\,mm$. The depth of the cavity is $2b = 2.54\,mm$ which is the size of the standard WR-10 wave guide and a small advantage because no tapering in this direction is necessary. The length of one cavity in beam direction is $g = 0.864\,mm$.

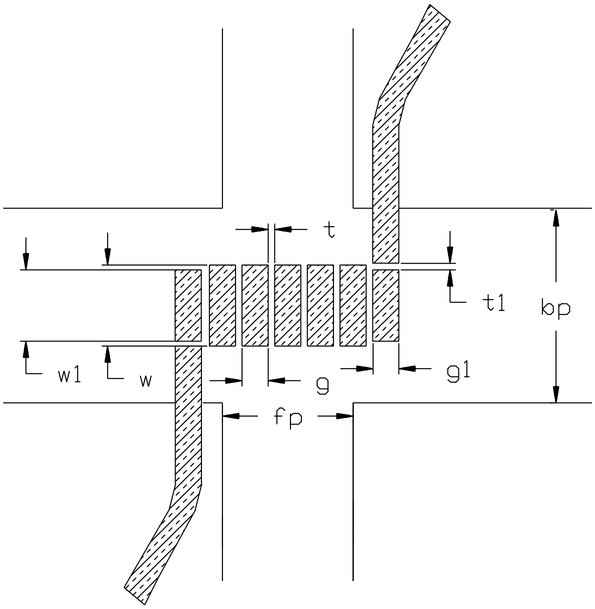

Figure 2: Top view of the cavity section.

A problem was to match the coupler to the structure, because we wanted a single depth structure, which is easier to fabricate. This required a cut iris, a very complicated step in fabrication. To do this, the wire has to tilt[1], see figure 3. This operation is very sensitive, because we need a high accuracy for this iris roof. The edge could cause problems in later models but not in this cold test model. A big disadvantage is this second depth if you want to realize it with LIGA. Figure 4 shows the final realized structure.

3 RF DESIGN AND NUMERICAL SIMULATION

The aimed operating frequency is $91.392\,GHz$, 32 times the SLAC frequency ($2.856\,GHz$), and corresponds to a wavelength of $\lambda = 3.283\,mm$ with cavity dimensions in the sub millimeter range. It is a traveling wave constant impedance structure, designed for the $2\pi/3$-mode with a period length of $p = 1.094\,mm$ The inner cavity geometry is designed for an optimized shunt impedance. The basic RF parameters have been calculated with our new code GdfidL [4] and are listed in table 1. For the calculation of the maximum length L_{max} of the structure, we used a τ of 0.8 ($\tau = \alpha L$). Using this L_{max}, we get a maximal number of accelerating cells on one structure of $N_{max} = 178$. The theoretical results of the reflection and transmission coefficient, computed with GdfidL, are shown in figure 5.

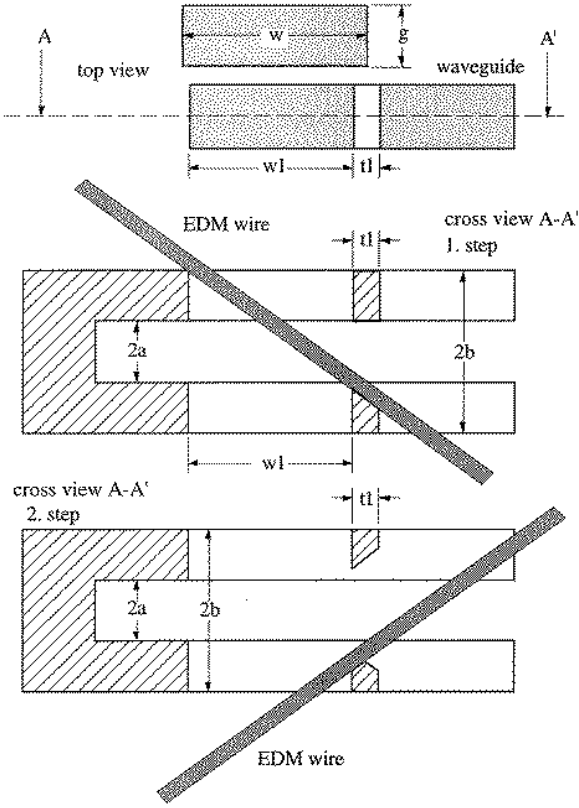

Figure 3: Cross section for wire EDM.

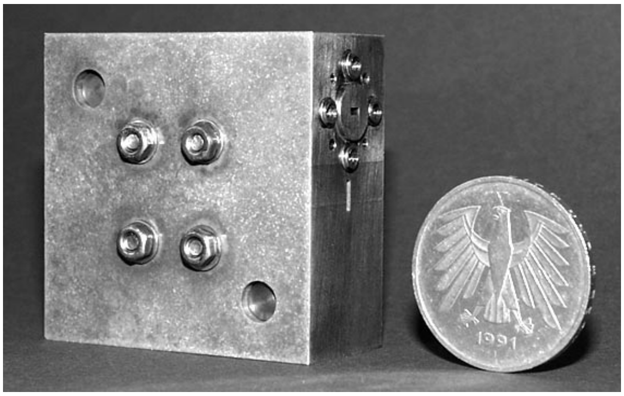

Figure 4: Realized structure.

$$\begin{aligned} r\,/\,Q_0 &= 81.6\,k\Omega/m \\ Q_0 &= 2490,\; r = 200\,M\Omega/m \\ v_g/c_0 &= 9.4\% \\ \alpha &= 4.1\,m^{-1} \\ L_{max} &= 19.5\,cm \end{aligned}$$

Table 1: Basic RF parameters.

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[1] Special thanks to Dennis Palmer, SLAC.

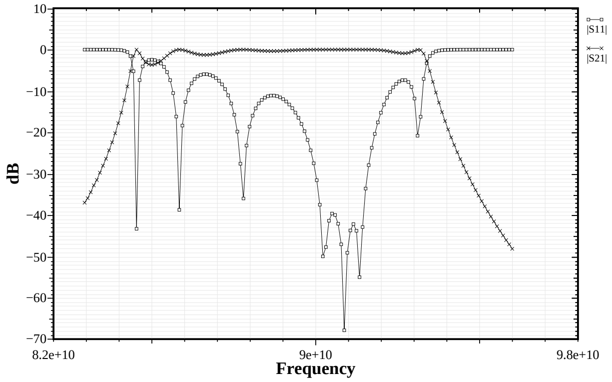

Figure 5: Reflection and transmission coefficient, GdfidL [4] simulation.

4 MEASUREMENT

The following chapter shows a possibility to do a transmission and reflection measurement with a scalar measurement system for signals in the $90\ GHz$ range. Figure 6 show the block diagram of the scalar measurement system.

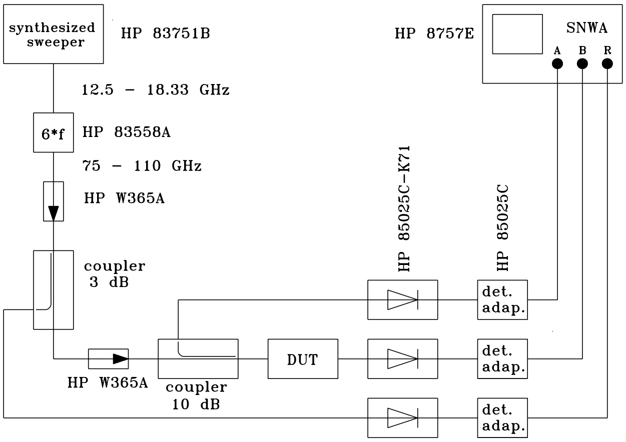

Figure 6: Block diagram of the scalar measurement system.

The source is a *HP 83751B* high power synthesized sweeper, working in a frequency range from $12.5\ GHz$ to $18.33\ GHz$. A *HP 83558A* mm wave source module sextuples the output frequency range to the $75\ GHz$ to $110\ GHz$ mm wave range. After multiplying the signal range 6 times, the resultant mm wave power goes through an isolator to avoid reflection and is splitted in a *MILLITEC* $3\ dB$ three port directional coupler. 50% of power goes to the reference channel and 50% of power feeds the test structure. All measured signals are connected via three crystal detectors, consisting of a detector adapter *HP 85025C* and a W-band wave guide detector *HP 85025C-K71*, to the scalar network analyzer *HP 8757E*. The splitted power goes via some WR-10 wave guides to a *HP* $10\ dB$ three port directional coupler and feeds the test structure. The output port of the structure is connected to a crystal detector for transmission measurement. For reflection measurement, we couple $-10\ dB$ of the reflected power to a crystal detector. The results of the transmission and reflection measurement are presented in figure 7.

The measured frequency response is in good qualitative agreement with the numerical simulation. The structure looks detuned, maybe the coupling iris, which was very sensitive in simulation and unfortunately the hardest thing to make for the machine shop, got bigger and the coupling cells got smaller. The measured $4\ dB$ loss in transmission is not yet understood. We believe that it has to do with the bad contact between the irises and the cavity. Therefore, we will try next to operate the structure on an isolated resonance and measure the Q-value.

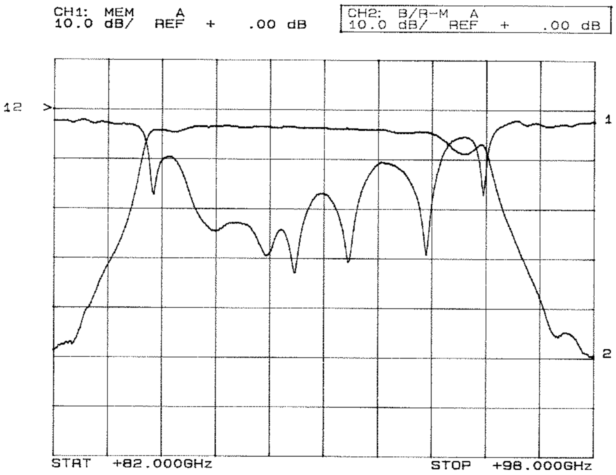

Figure 7: Reflection and transmission coefficient, measurement.

5 REFERENCES

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[2] R. Merte, “First Design of a W-Band Muffin Tin, Cold Test Model”, Internal Note, Inst. f. Theoretische Elektrotechnik, TU-Berlin.

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[4] W. Bruns, “GdfidL: A finite difference program for arbitrarily small perturbations in rectangular geometries”, IEEE Trans. Magn. Vol. 32, No. 3 May 1996.