# Fabrication and Measurement of a 10× Scale Model of a Double-sided Planar mm-wave Linac Cavity Structure *

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*Abstract*

A double-sided planar mm-wave linear accelerating cavity structure has been investigated. An 80-cell constant impedance structure working with $2\pi/3$-mode traveling wave was chosen as an accelerator section. A $10\times$ scale model of the structure has been fabricated and the basic electrical performances have been tested. The nodal shift measurement technique with a rectangular detuning plunger was used to measure the phase advance between the cells with a vector network analyzer.

## 1 INTRODUCTION

The mm-wave accelerating cavity structure has been investigated for linac application [1][2]. The operation of the structure is aiming a $2\pi/3$-mode traveling wave in the 60-120GHz frequency range. The cavity structure is planar so cooling is easier from top and bottom. Higher-order modes are less likely to develop and they can be damped easily using the side openings. The side openings provide easier vacuum pumping slots. The fields on the z-axis cause transverse forces of quadrupole character which can be used for focusing. The double-sided planar cavity structure was attractive since it is of simple geometry and best suited for the LIGA (in German acronym: Lithographie, Galvanoformung, Abformung) process. This technique uses deep x-ray lithography and has been advancing rapidly in the micromachining area. For initial studies, the frequency was chosen to be around 120GHz for the optimum LIGA process. Since then, microfabrication techniques have been advanced such that a several millimeter structure can be manufactured.

For readily available network analyzers in the frequency range up to 26GHz, a $10\times$ scale model of a constant impedance structure has been fabricated and tested. This scale model is used to study the basic characteristics of a double-sided planar structure before having a mm-wave structure. The electrical parameters of the scale model are not the same as those for the 120GHz structure. Table 1 shows the parameters of the structures for the two frequencies when the dimensions are $10\times$ greater. For a 12GHz periodic structure, the MAFIA [1] computer program was used to calculate the electrical parameters. The coupling constant and the group velocity are common to both frequencies. Thus, the frequency pass band characteristic must be similar.

Table 1: Electrical parameters of a 120GHz structure and its 10x scale model.

| Parameters | Frequency(GHz) | |
|---|---|---|
| | 120 | 12 |
| $Q$ | 2160 | 6821 |
| $r_o\ (M\Omega)$ | 312 | 98.6 |
| $k$ | 0.0475 | 0.0474 |
| $v_g/c$ | 0.043 | 0.043 |
| $\alpha\ (m^{-1})$ | 13.5 | 0.428 |
| $\ell\ (cm)$ | 7 | 68.3 |
| $\tau$ | 0.945 | 0.292 |
| $T_{fill}\ (nsec)$ | 5.4 | 52.9 |

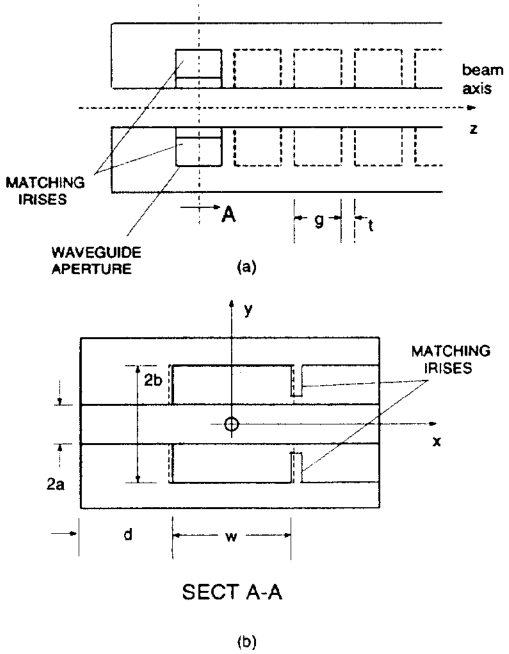

Figure 1: The double-sided planar structure with an input coupler. a) longitudinal b) transverse cut

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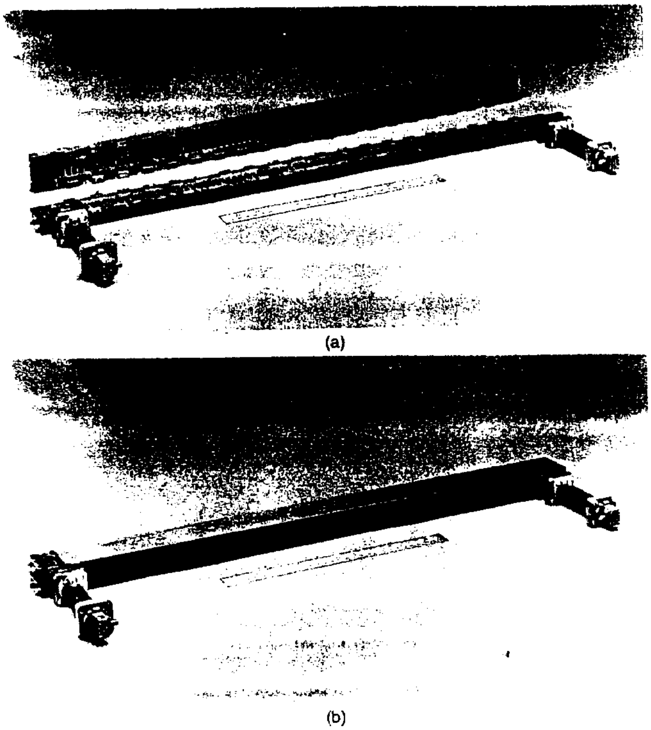

Figure 2: 10× scale model of the double-sided structure assembly. a) opened, b) closed.

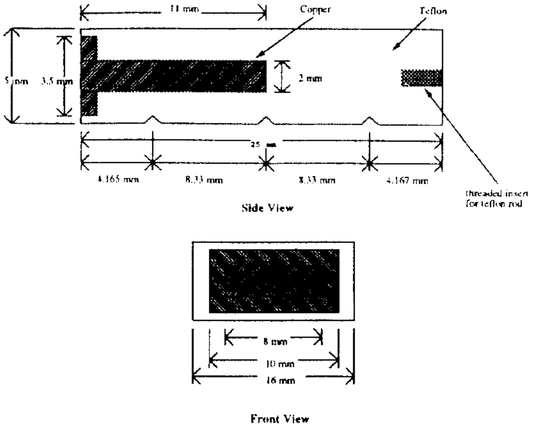

Figure 3: Design of a rectangular detuning plunger for planar cavity structure

## 2 MEASUREMENT SETUP

Previously the measurement of the phase advance between the cells was done with a slotted line at the input [3,4]. This nodal shift technique was used in the phase measurement of the planar structure. The availability of vector network analyzers can ease the measurement without using the slotted line and manual measurement. The nodal shift measurement is made to measure the phase advance between the cells. The cavity structure has been tested without further fine tuning adjustment in the cavity dimensions. The temperature was not carefully controlled for the structure.

The parameters of the periodic structure in Figure 1 were calculated with the MAFIA computer program and the input/output couplers were designed using the High Frequency Structure Simulator (HFSS) [5]. For 12 GHz ($\lambda = 2.5mm$) the dimensions used are (all in mm)

$$\begin{aligned} a &= 3, \quad b = 9 \\ w &= 18, \quad d = 8 \\ g &= 6.33, \quad t = 2. \end{aligned}$$

The period length g + t was chosen for the $2\pi/3$-mode

$$2\pi \frac{g+t}{\lambda} = \frac{2\pi}{3} \tag{1}$$

and the iris thickness t was fixed through the structure for practical reasons. The length of the side openings, $d$, was taken large enough such that the fields have decayed sufficiently. The aperture 2a is, in principle, a free parameter and influences the pass-band bandwidth as well as Q-value, shunt impedance, and wake fields. The value given above is a trade-off between the different requirements. The dispersion relationship is given in Figure 2.

The metal plunger with teflon guide is shown in Figure 3 with the dimensions. The plunger was used in the cavity structure as shown in Figure 4 to measure the cell-to-cell phase advance.

## 3 MEASUREMENT

The measurement result of the 80-cell 10× scale model is discussed in this section. The reflection constant at the input of the network with two reflections is approximately given by

$$\Gamma - \Gamma_{in} = \Gamma_{pl}\, e^{-j2\theta} \tag{2}$$

where $\Gamma_{in}$ is the input reflection constant and $\Gamma_{pl}$ is the reflection at the plunger. Using the above approximation to the input reflection coefficients, the measurement has been corrected.

For a lossy N-port network, the dissipated power in the system is

$$\begin{aligned} P_{diss} &= \frac{1}{2}\sum_{n=1}^{n}(a_n a_n^* - b_n b_n^*) \\ &= \frac{1}{2}[a](1-[S][S^*])[a]^* \end{aligned} \tag{3}$$

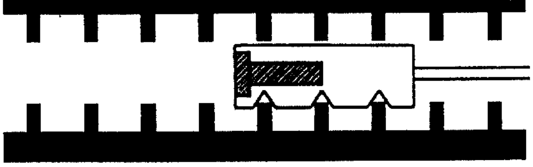

Figure 4: Measurement setup of a cavity structure with a detuning plunger

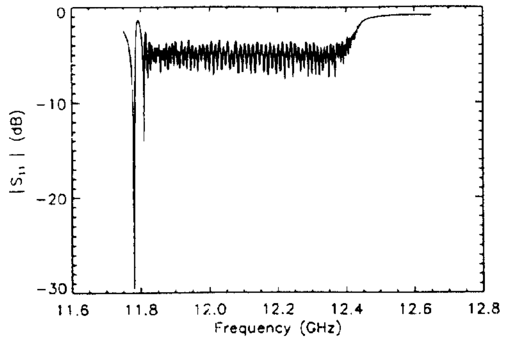

Figure 5: Measured $S_{11}$ of the cavity structure with untuned couplers

where $a_n$ and $b_n$ are the incident and reflected traveling waves at the n-th port, respectively, and [s] is the $N \times N$ scattering matrix of the structure. Figures 5 and 6 show the $S_{11}$ and $S_{21}$ of the structure without complete tuning. The coupling constant is $k \simeq 0.05$, which is slightly greater than the simulation result. From Table 1, the structure loss must be $2.5dB$ and Eq. (3) is satisfied.

The couplers were tuned with external tuners and a nodal shift measurement was performed. Figure 7 shows the measured phase advance between the cells. Using a vector network analyzer, the phase of the input reflection at the input coupler was measured at each detuning plunger position. The computer data acquisition was performed with the manual plunger positioning. By using the measured input reflection without the detuning plunger, the input mismatch was removed from the data with the plunger, using Eq. (2), to correct the data. The signal source frequency was varied until finding the $2\pi/3$-mode.

## 4 CONCLUSION

A nodal shift measurement has been made with a 10× scale model of the double-sided planar accelerating cavity structure for 120GHz. This structure has been built and tested at 12GHz. A frequency for traveling wave mode with a $2\pi/3$ phase advance per cell has been located. The phase advance between the cavity cells is close to 120° but not uniform. Tuning of the input/output coupling cavities is to be performed for better matching without using external tuners. The temperature control of the structure should be performed for more accurate results.

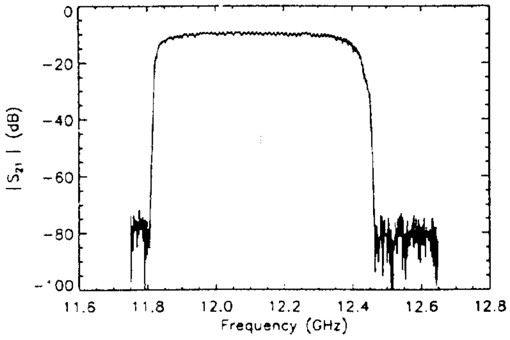

Figure 6: Measured $S_{21}$ of the cavity structure with untuned couplers

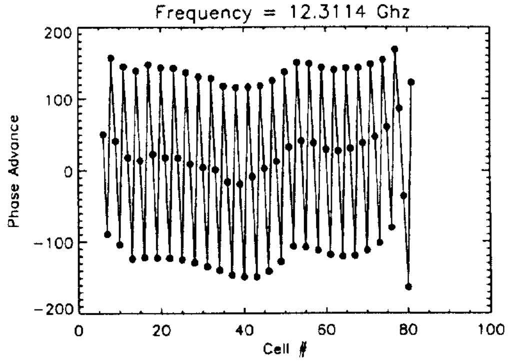

Figure 7: Measured phase advance between the accelerating cells for a $2\pi/3$ mode

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