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PLANAR ACCELERATOR STRUCTURES FOR MILLIMETER WAVELENGTHS*

N.M. KROLL‡, M.E. HILL†*, X.E. LIN†, R.H. SIEMANN†,
D.C. VIER‡, D.H. WHITTUM†, AND D.T. PALMER†
‡*University of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093*
†*Stanford Linear Accelerator Center, Stanford University, Stanford CA 94309*
**Harvard University, 42 Oxford Street, Cambridge MA 02138*

Abstract

The fabrication of a muffin-tin planar accelerator structure for operation in the 90 GHz range is discussed in Reference. [1]. Fabrication problems subsequently encountered led us to consider an alternative structure, a structure which can be thought of as a muffin-tin with the sides removed and replaced by a pair of side chambers which act as side terminations (Fig. 1). With the side chambers removed, the structure when viewed from the side presents two periodic arrays of vanes facing one another from above and below the beam plane and which extend towards the beam plane from upper and lower plane metallic surfaces. The vane pairs are the analogs of the beam iris in cylindrical structures, and the space between the irises and terminated by the upper and lower plane metallic surfaces correspond to the cavities. Because the general appearance of this view is zipper like, we will refer to the structure as the ”zipper” structure. The side chambers are envisaged as extending with uniform cross section from the input to the output cavities.

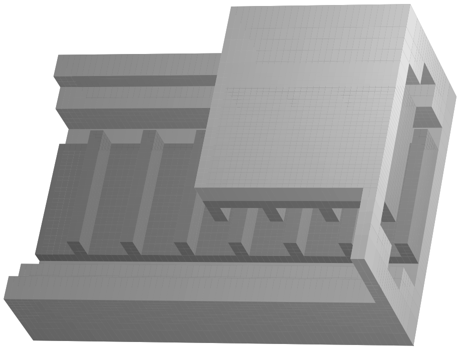

Figure 1:

1 INTRODUCTION

The design and fabrication of a traveling-wave muffin-tin accelerating structure at 90 GHz is presented in Reference. [1]. A prototype seven cell structure was constructed, and because it was to be used only for RF cold tests it was clamped together rather than assembled in a vacuum suitable manner. RF measurements are reported in Reference. [2]. MAFIA simulations indicated that the coupler achieved a fair match and the agreement with S_{11} measurements was reasonably good. Bead pull measurements of accelerating field amplitude and phase were also in reasonable agreement with expectations. On the other hand the transmission (ie S_{12}) achieved was disappointingly low, indicating about one half the power was dissipated within the structure. The electrical contact of the muffin-tin cells' walls with their bases depended upon the effectiveness of the clamping of a copper plate to the back of a row of rectangular holes. Subsequent structures (25 cells) attempted to improve this electrical contact by diffusion bonding the two parts together, but the vane side walls were unable to support the forces involved and no successful structure emerged from this attempt. Material research into a dispersion strengthened copper, Glidcop AL-15, has been conducted to avoid the cell to cell iris distortion reported in Reference [3].

In order to mitigate this problem we imposed on structure design a requirement that there be no brazed or diffusion bonded conducting joints between the vanes (ie the walls which form the cavity cells) and any other part of the structure. An example of such a structure is a muffin-tin with the side walls of the cells omitted. Thus the conducting junction between the vanes and the end walls, required for the muffin-tin, is eliminated. The cells can then be formed by machining grooves into a plate with width equal to that of the structure. Thus the junction between the vanes and the rear surface of the cell cavities is integral to the fabrication procedure and no separate bonding is needed. A generic example of the sort of structure that we have in mind is shown in Fig. 1. The spaces beyond the side ends of the vanes forms a kind of chamber which we refer to as side chambers. Because of the appearance of the structure when viewed from the side with the side chamber exposed, it has been dubbed a zipper structure.

In the following sections we describe some RF properties and constraints which led to the zipper design proposed in this paper (section 2). This is followed by a description of the proposed fabrication procedure (section 3), and a discussion of coupler design where an unanticipated problem was encountered (section 4). We end with concluding comments.

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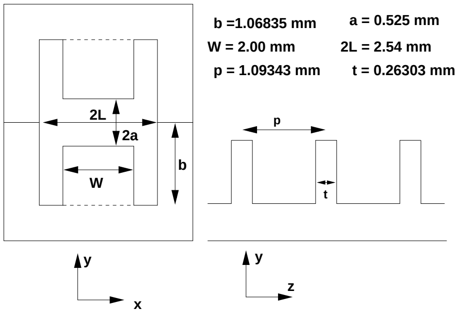

Figure 2: Section views of the zipper structure.

2 RF PROPERTIES OF THE PROPOSED DESIGN

The general configuration and the principal dimensions of the proposed zipper structure are shown by the section through a vane pair and perpendicular to the beam shown in Fig. 2. The structure has reflection symmetry with respect to a centered x-z plane and a centered y-z plane and the couplers are being designed in a manner which preserves this symmetry. Modes are classified by the reflection properties of E_z with respect to these planes, monopole for even-even, quadrupole for odd-odd, dipole-y for odd-even, and dipole-x for even-odd. A MAFIA [4] simulation based Brillouin diagram for the modes within a 50 to 100 GHz range is shown in Fig. 3. The fundamental or accelerating mode is the lowest monopole mode. The light line crosses it at 120 degree phase advance at the design frequency, 91.392 GHz. The lowest dipole mode band is the lowest band and it is noteworthy that it couples strongly to the fundamental TE mode which propagates down the beam tube, a rectangular waveguide like structure, 2.54 by 1.05 mm.

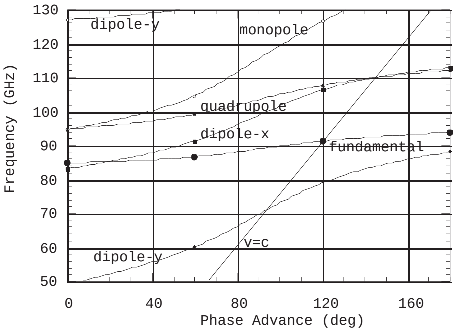

Figure 3: Dispersion diagram of the preferred case zipper structure.

The simulation yields a Q of 1605, R/Q 54.3 ohms per cell, and a group velocity of 0.098 c. The acceleration voltage has a quadrupole like variation characterized by a 1.83% droop 0.2 mm from the center in the x direction. One notes that the band separation is small due to the rather large lateral dimensions and the large end chambers. Careful design is required to avoid overlap of the two monopole bands. The overlap of the dipole-x and fundamental bands appears to be inevitable, but fortunately the coupler structures couple only to monopole bands. We view this mode structure as an undesirable feature but cannot at this stage assess the extent to which it will cause problems.

3 MECHANICAL DESIGN

The present structure we are designing is a symmetrically feed 25 cell constant impedance traveling wave structure. The rf coupling scheme used is a quarter wave transformer. The designed operating mode and frequency of the device is $f_{\frac{2\pi}{3}} = 91.392$ GHz. The cell to cell iris in this novel rf structure do not bear any mechanical loads during a thermal bonding cycle. The mechanical integrity of the structure is also improved by the using a dispersion strengthened material, Glidcop AL-15, as the base material.

The integrated structure is comprised of three layers. As seen in Figure 4 the top and bottom layers are identical and are comprised of the internal 23 cells and the WR-10 waveguide feeds. The two steps located in Figure 4 are used to match the structure with a quarter wave matching transformer that is integrated into the middle interlayer

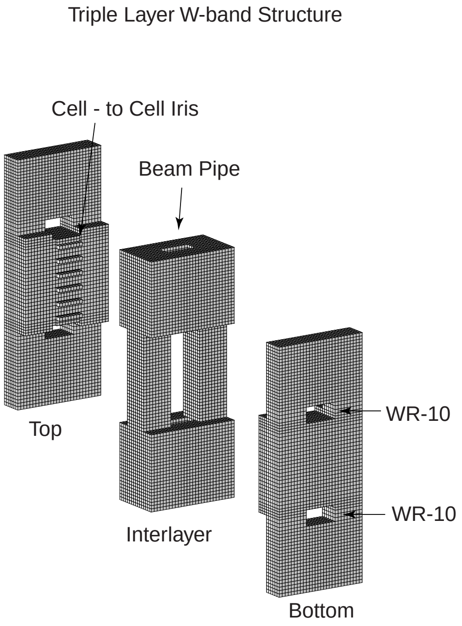

Figure 4: Expanded view of the triple layer stack W-band traveling wave constant impedance structure

The middle layer determines the input and output coupler iris position and transverse size, beam pipe and side chamber, and its termination. The thickness of this layer also determines the cavity iris separation.

When assembled these three layers are self aligning in the longitudinal direction due to the quarter wave matching transformers, which fit into the top and bottom layers and form the matching sections into the traveling wave accelerator. Two alignment pin are used to fix the transverse alignment of the structure, while the vertical alignment is determined by the the flatness and parallelism of the three components of the triple layer stack. The alignment of the individual cavities that are formed in the top and bottom layers are well aligned since they are machined out of a single base material block during a single wire EDM machining step.

4 COUPLER DESIGN AND BAND INTERFERENCE PROBLEMS

The standard simulation based coupler design procedure is based upon the determination of S matrix parameters of a four cell structure consisting of the input and output cells and two intervening identical structure cells. Coupler match is verified by requiring at the operating frequency first, that S_{11} = 0 and second, that the accelerating fields in the two intervening cells have identical amplitudes and phases as functions of z except that the phase in the second cell is shifted by a z independent constant ψ from that in the first cell, where ψ is the phase advance constant associated with the cell Brillouin diagram at the operating frequency. Further confirmation may be obtained by adding a third intervening cell and verifying that the analogous conditions still hold. Many different waveguide to cell coupling iris designs and various modifications in coupler cell dimensions were explored. While we favored a quarter wave transformer design for fabrication simplicity, capacitative and inductive thin irises were also tried. We were, however, never able to come close to satisfying the conditions on the accelerating field.

The procedure described above is based upon the assumption that under steady state excitation at fixed frequency within the pass band of the acceleration mode that the fields in the interior cells can always be represented by some linear combination of the forward and backward propagating wave solutions appropriate to the drive frequency. This is expected to hold for any frequency within the pass band and independently of the S matrix parameters.

A simple test of whether or not this is the case is described below.

Let $F(z_o)$, $B(z_o)$ be the complex forward and backward wave amplitudes of some field component, say E_z at the point z_o along the beam axis. Then

$$E_z(z_o + np) = F(z_o)e^{-jn\psi} + B(z_o)e^{jn\psi} \qquad (1)$$

with $|\frac{B(z_o)}{F(z_o)}|$ independent of z_o, and p the period of the structure. Then by simple algebra

$$\frac{E_z(z_o + p) + E_z(z_o - p)}{E_z(z_o)} = 2\cos(\psi) \qquad (2)$$

This is a very strong constraint because it says that the LHS of Eq.(2) must be the same for all values of z_o for which Eq.(1) holds, must be real and lie on the interval $[-2, 2]$, and indeed must yield a value of $\cos(\psi)$ in agreement with that obtained by, say, a single cell periodic boundary conditions frequency domain simulation. If the test results is affirmative, then a further useful result is

$$|\frac{B(z_o)}{F(z_o)}| = |\frac{2jsin(\psi) + \Delta}{2jsin(\psi) - \Delta}| \qquad (3)$$

where

$$\Delta = \frac{E_z(z_o + p) - E_z(z_o - p)}{E_z(z_o)} \qquad (4)$$

Note that here the RHS of Eq.(3) must be independent of z_o.

This test fails badly for coupler test simulations involving small numbers of interior cavities. We are investigating the presumption that the test fails because of the presence of evanescent higher order modes associated with higher propagation bands. The second monopole band, which is very close to the acceleration band, is considered be a likely candidate, especially since its field configuration is such that its excitation by the coupler geometry is likely to be as large as that of the acceleration mode. If that is the case then the problem should disappear well into the interior of a sufficiently long structure, and simulation, using GdfidL [5], of a structure with 23 interior cells indicates that this is the case. From the behavior of the test with respect to cell position, we conclude that the standard matching procedure should be successful if applied to the interior cells of a structure with at least 15 to 20 cells.

5 CONCLUSION

The upper band contamination problem clearly imposes a computational burden on matched coupler design. We will know how large when we have succeeded in doing it. Fortunately the evanescent modes are non propagating and therefore will have very little interaction with the beam. On the other hand they do contribute to copper losses, reduce R/Q, and may increase peak fields. The design discussed in this paper was selected from a number of similar structures primarily because it had the best shunt impedance. The separation between the upper band and the acceleration frequency was nearly twice as great for one of the alternate designs and the penalty in shunt impedance loss was small. The increased separation should decrease the penetration of the evanescent mode into the structure.

While the RF properties so far determined for zipper type structures are not ideal, it does appear to be able to be fabricated and further investigation aimed at possible construction is planned.

6 REFERENCES

[1] P.J. Chou et al., PAC97, page 464

[2] P.J. Chou et al., PAC97, page 672

[3] D. T. Palmer et al., PAC99 ,THCR3

[4] F. Ebeling et al., MAFIA User Guide, 1992.

[5] W. Bruns, *IEEE Trans. Magn.* 32, pp. 1453-1456, 1996