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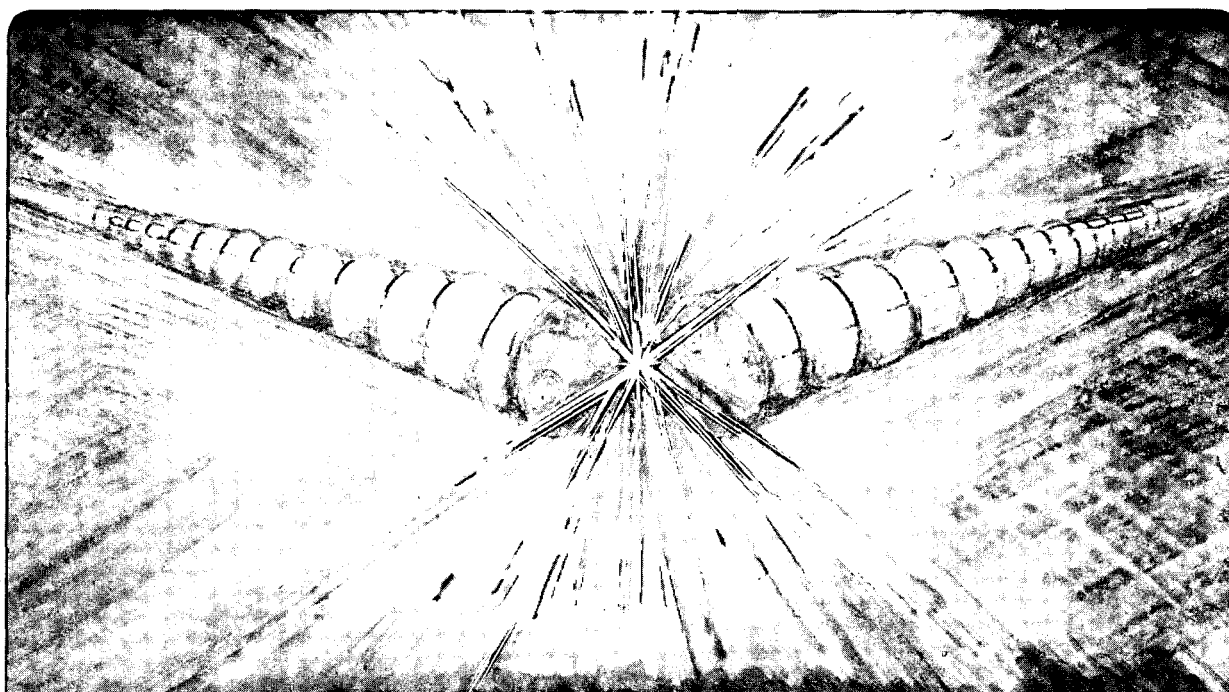
## Accelerator & Fusion Research Division

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**Design of Inductively Detuned RF Extraction Cavities  
for the Relativistic Klystron Two Beam Accelerator**

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April 1995

# DESIGN OF INDUCTIVELY DETUNED RF EXTRACTION CAVITIES FOR THE RELATIVISTIC KLYSTRON TWO BEAM ACCELERATOR\*

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## ABSTRACT

An inductively detuned traveling wave cavity for the Relativistic Klystron Two Beam Accelerator expected to extract high RF power at 11.424 GHz for the 1 TeV Center of Mass Next Linear Collider has been designed. Longitudinal beam dynamics studies led to the following requirements on cavity design:

- a) Extraction of 360 MW of RF power with RF component of the current being 1.15 kAmps at 11.424 GHz,
- b) Inductively detuned traveling wave cavity with wave phase velocity equal to  $4/3$  the speed of light,
- c) Output cavity with appropriate  $Q_{ext}$  and eigenfrequency for proper matching.

Furthermore, transverse beam dynamics require low shunt impedances to avoid the beam break-up instability. We describe the design effort to meet these criteria based on frequency-domain and time-domain computations using 2D- and 3D- electromagnetic codes.

## I. INTRODUCTION

An LBL-LLNL team has presented recently a preliminary point design for an 11.424 GHz power source for a 1 TeV Center of Mass Next Linear Collider (NLC) based on the Relativistic-Klystron Two-Beam-Accelerator (RK-TBA) concept [1].

The point design requires that the bunched drive beam delivers 360 MW of rf power with an rf current of 1.15 kA (600 A DC) at 11.424 GHz in each of the 150 rf extraction cavities in a 300-m long RK-TBA unit. To achieve this goal, and to maintain longitudinal beam stability over these long distances, the extraction cavities must be inductively detuned; furthermore, in order for a 3-cell disk loaded cavity structure to behave like a traveling wave structure with no reflected waves, the output ports must be properly matched. To maintain low surface fields to avoid breakdown, we consider traveling-wave structures.

The required cavity parameters have already been discussed elsewhere in this conference [2]; here we will present electromagnetic calculations to determine the structure of the extraction cavities. We have chosen in this design effort one specific path to meet the general requirements. The procedure adopted is by no means unique, and we anticipate further optimizations and more detailed calculations in the future.

## II. THE EXTRACTION CAVITY DESIGN

Present designs evolve around traveling-wave-structures with 3 cells of 8-mm inner radius. The rf output is extracted through 2 separate ports in the 3<sup>rd</sup> cell, with 180 MW each transported through separate waveguides, and fed directly into the two input couplers of the high gradient structure.

The tools we have used to calculate the rf properties of the cavity are URMEL and SUPERFISH for 2-D frequency-domain calculations, ABCI and TBCI for 2-D time-domain calculations, and MAFIA for 3-D frequency- as well as time-domain calculations. The calculations in frequency-domain are obtained for standing-wave solutions. We have followed a procedure described in a paper by Loew et al. [3] to convert these results to traveling-wave properties.

The design procedure is carried out in several steps, starting with the simplest approximations, and adding more realistic features with each successive iteration. At each step we calculate the rf properties of the cavity including frequency, the  $(R/Q)$ , and group velocity for the longitudinal mode, and the synchronous frequency and shunt impedance of the dipole mode; we also calculate the field enhancement factor to determine the surface field for assessing breakdown risks. The field enhancement factor calculated by URMEL is defined as the ratio of the maximum amplitude of the electric field in the whole structure to the average electric field along the axis (including the transit time factor) for standing-wave solutions. The enhancement factor that we are

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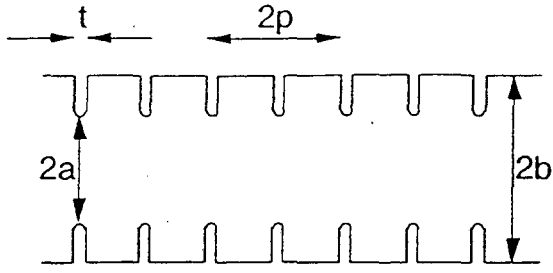


Figure 1: Schematic cross section of the infinitely periodic structure.

interested in is defined for traveling-wave structures without the transit time factor.

### III. INFINITELY PERIODIC STRUCTURE

First, we want to determine roughly the geometry of the overall structure. As a starter, we construct a 3-cell disk-loaded traveling-wave structure that is synchronous with the beam ( $v_p=c$ ). The rf structure should give 360 MW with a tightly bunched drive beam with an rf current of 1-1.5 kA. We choose initially a conventional  $2\pi/3$  structure with cell length ( $p$ ) of 8.75 mm. The power extraction formula gives a requirement of  $(R/Q)/v_g$ . URMEL is exercised for an infinitely periodic structure, varying the inner radius  $a$  and outer radius  $b$  of a disk-loaded structure, and the set of solutions with  $v_p=c$  is obtained, following the procedure of Thompson, et al. [4]. For each value of the aperture radius satisfying  $v_p=c$ , the cavity parameters  $R/Q$  and  $v_g$  are determined. Figure 1 shows a schematic cross section of the cells.

The inductively detuned structure is next constructed by a variation of the previous step. What we want is a structure whose resonant frequency remains unchanged, but the wavelength is increased by a factor of 1.33. This will result in a phase velocity of  $1.33c$ , which is the desired detuning angle to maintain longitudinal beam stability. To achieve this, we choose to fix the cell length at  $p=8.75$  mm as before, and reduce the outer radius  $b$  for each value of  $a$ , until the  $2\pi/3$  field configuration becomes a  $\pi/2$  configuration at the same frequency of 11.424 GHz. Each wavelength now extends over 4 cells, instead of the 3 cells. The  $R/Q$  and  $v_g$  for this new configuration are determined with URMEL. The required geometry is determined by ensuring that the corresponding  $R/Q$  and  $v_g$  provides the right power extraction. The solution is  $a=8$  mm,  $b=12.5$  mm,  $R/Q=13.5 \Omega$  and  $v_g=0.28c$ . Slight-refinements from this geometry are obtained by numerically iterating on the power extraction formula to account for the

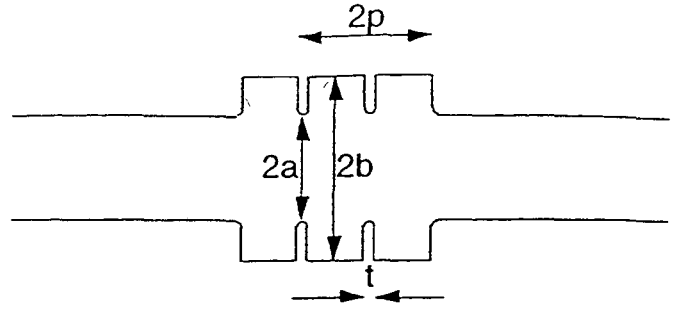


Figure 2: Schematic cross section of the 3-cell cavity with beam pipes.

reduction in power due to inductive detuning. The field enhancement factor is 1.5.

### IV. FINITE STRUCTURE (2-D)

The finite cell structure is included by modeling the detuned 3-cell structure with finite beam pipes. The effect of the modified geometry on the field configuration and cavity parameters are then studied. Figure 2. shows a schematic cross section of the 3-cell cavity with beam pipes. As calculated by SUPERFISH a 3 cm beam pipe on each side of the structure will adequately contain the fringe fields. The cavity fields still retain their  $\pi/2$  structure. Wakefield calculations using ABCI/TBCI was performed to find the resonant frequencies and impedances of the structure and to compare the results with the frequency-domain calculations to check for consistency. The resonant frequencies as well as the relative impedance behavior agree with those calculated in frequency-domain.

A very important point to note is that the dipole wake is heavily damped. This is due to the strong coupling of the cavity field to the  $TE_{11}$  mode in the beam pipe. This results in a very low  $Q$ . To translate the wake calculation to the  $Q$  of individual cells in a coupled cavity formulation is somewhat subtle, and has not been fully understood yet but initial estimates suggest that the dipole  $Q$  for the first and last cavity of our 3-cell structure could be as low as 10.

### V. FINITE STRUCTURE (3-D)

Finally, the 3-D aspects of the output ports are studied using MAFIA. Recalling that the matching condition demands that the frequency and  $Q$ -value of the last cell be uniquely determined to absorb the reflected waves from the 3-cell structure, MAFIA is exercised by variation of the geometry of the output until the right value of  $Q$  and  $\omega$  for proper matching are

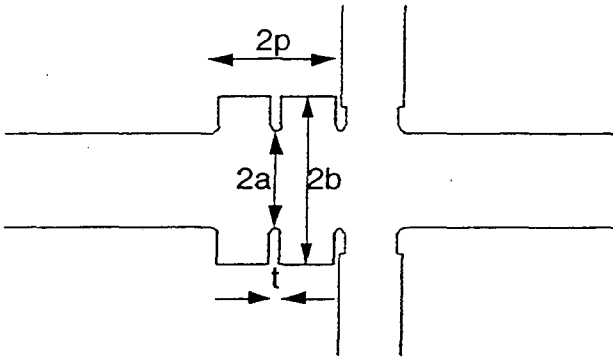


Figure 3: Axial cut of the 3-D cavity with output structures.

obtained. Figure 3 shows an axial cut of the 3-D cavity with output structures.

The output structure consists of two WR90 RWG waveguides attached to the last cell of the cavity. The shorter (0.4" long) side is oriented along the z-axis. The last cell is required to have a  $Q_{ext} < 10$  in order to have only a forward traveling wave in the cavity.

The determination of the external Q of the 3-D cavity with output structure is based on the Kroll-Yu method [5]. For a given waveguide iris aperture several calculations (at least four) are performed varying the length of the output waveguide. The phase change along the waveguide,  $\psi$ , is defined as  $2\pi D/\lambda_g$ , where  $\lambda_g$  is the waveguide wavelength and D is the waveguide length. The mode of interest (in our case the  $\pi/2$  mode) is identified and the frequency recorded. From the phase change versus frequency relationship the external Q is approximately given by  $-(1/2)f(d\psi/df)$ . Taking into account the whole structure we calculated  $Q_{ext} \approx 80$  for various waveguide iris apertures. The equivalent Q for the 3<sup>rd</sup> cavity can be shown, using a method developed in Ref. [1], to be less than 10.

The calculation of the  $Q_{ext}$  of the last cell for a  $\pi/2$  mode configuration is facilitated from the fact that such configuration is obtained naturally by applying Neuman and Dirichlet boundary conditions at the left and right boundaries of that cell. Using the Kroll-Yu method we calculated a  $Q_{ext} \approx 5$  for a waveguide iris aperture of 1.24 cm, a value of  $Q_{ext}$  that is within that required to meet the matching condition. Figure 4 shows the phase versus frequency curve.

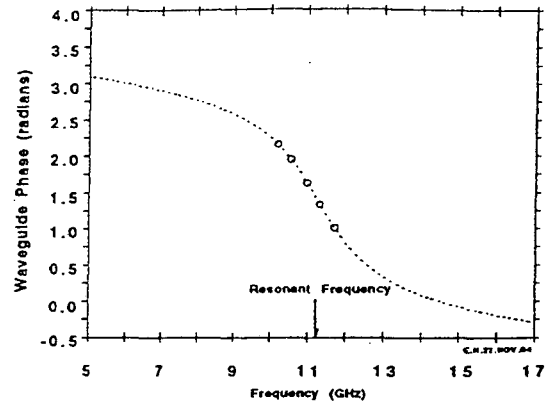


Figure 4: Phase versus frequency curve for last cell.

## VI. CONCLUSION

We do not consider the cavity geometries obtained so far to be final in any sense. There are still large degrees of freedom for design modifications, and further refinements will be conducted to reduce transverse focusing fields and to ensure minimal surface fields over the entire 3-D structure. The calculated Q's are close to the values required to satisfy the matching condition. The induction cavity design needs to be optimized to make sure that both the longitudinal as well as transverse impedances are adequately small.

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