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# DESIGN CONCEPTS FOR A HIGH GRADIENT C-BAND LINAC

T. B. Bolin*, S. I. Sosa, S. G. Biedron[1,2]
Department of Electrical and Computing Engineering,
University of New Mexico, Albuquerque, USA
M. Dal Forno, ViewRay Inc., Mountain View, USA
J. R. Cary[3], Tech-X Corporation, Boulder, USA
[1]also at Department of Mechanical Engineering, University of New Mexico, Albuquerque, USA
[2]also at Element Aero, Chicago, USA
[3]also at Department of Physics, University of Colorado, Boulder, USA

*Abstract*

During the last decade, production of soft to hard coherent X-rays (up to 25 keV) at XFEL facilities has enabled new developments in a broad range of disciplines. One caveat is that these facilities require a large amount of real-estate and have a high cost. One cost-saving measure is to produce a compact, high accelerating-gradient. Here, we describe design concepts for a high-gradient linac for XFEL applications in the C-band (5.712 GHz). We investigate two different geometries for high-gradient operation, modelled with the electromagnetic software, VSim.

## INTRODUCTION

X-ray Free Electron Lasers (XFEL) are driven by a high energy electron linear accelerator (LINAC), where the need for higher energy X-rays requires higher electron beam energies. To first order, this requires longer linacs and larger infrastructure, which quickly makes the costs prohibitive. Next generation XFELs, such as FEL projects planned at LANL [1] and UCLA [2], will take advantage of high-gradient, compact accelerating structures in the C and X-band frequency regimes, which will allow a better use of the available real estate.

The C-band frequency band ranges from 4 to 8 GHz, in this regime, cavity dimensions are on the order of a few centimetres, making them very compact as compared to cavities used in previous generation light sources. For example, a state-of-art C-band linac with a 50 MV/m accelerating gradient requires approximately 200 m to produce a 10 GeV electron beam, this will be about 700 m long if using more traditional S-band technologies at around 15 MV/m. Selection of the C-band accelerating cavities also enables the capability to produce X-rays which are sufficiently energetic to see into and through the mesoscale for many high-Z materials of interest. The C-band linac would also provide a suitable burst mode which is a mix of the slow, closely spaced pulses generated by S-band accelerators and beams generated in the X-band, where the beam quality is limited by wakes [3]. X-band technology may also be of interest but there are additional fabrication challenges that need to be factored into the budget [4].

### *Design Concepts of C-Band Cavity*

We explore two different design concepts of C-band accelerating cavities for next generation XFEL: a disk loaded waveguide (DLWG) and a multi-cell elliptical cavity. Figure 1 shows the two geometries with the relevant geometric parameters.

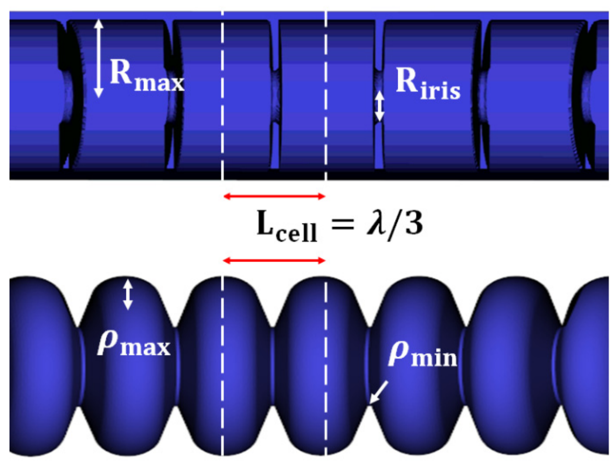


Figure 1: DLWG cavity array (top) and elliptical cavity array (bottom).

The DLWG is essentially a cylindrical waveguide structure with an added periodic array of disk loads that reduce the phase velocity of the travelling wave to match with the electron beam velocity. This structure is equivalent to a multi-cell cylindrical (pillbox) cavity. The elliptical structure is a series of coupled elliptical cavities, which may have increased performance due to reduced multipacting effects. These arrays must be analyzed via numerical techniques. They both have a cell length equal to $\lambda/3$ to match the phase velocity of the travelling electromagnetic wave to the velocity of relativistic electrons, this corresponds to a $2\pi/3$ phase advance between adjacent cells. The design concepts should accommodate multiple considerations including high accelerating gradient, low field breakdown rates, various fabrication techniques, choice of material, and the possibility of cryocooling [5]. Here we present preliminary electromagnetic considerations of the DLWG and elliptical structures.

*tbolin@unm.edu

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## EM MODELING OF ACCELERATING STRUCTURES

VSim is an electromagnetic and plasma analysis software developed by Tech-X and based on the Vorpal engine [6, 7]. VSim is well suited for the electromagnetic and charged particle problems like the ones involved in the cavity design process. We use VSim for the analysis of both the DLWG and the elliptical structures, where both geometries were created using the constructive solid geometry tool from VSim.

To set up the general geometric parameters so that we can tune the structures to the chosen target frequency of 5.712 GHz, we need to determine the $TM_{010}$ eigenmode. Because these are traveling wave structures and the electrons are high energy, we want the phase advance between cells to be $2\pi/3$ phase advance between adjacent cells to maximize the energy transfer to the beam. Furthermore, because these are periodic structures, we need to look at the passband modes of the two geometries. VSim calculates the eigenmodes of any user defined geometry using a filter diagonalization method (FDM) algorithm [8]. Figure 2 shows the longitudinal electric field for the DLWG in two different passband modes, the $2\pi/3$- mode and the $\pi$-mode. The analogous passband modes for the elliptical structure are shown in Fig. 3.

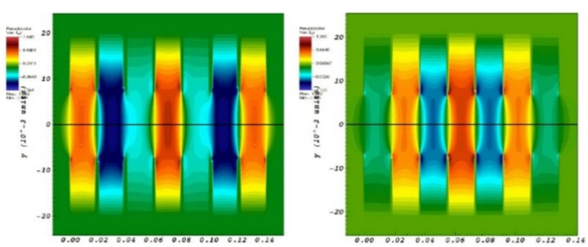

Figure 2: Passband modes of the DLWG periodic structure: 2π/3-mode (left) and π-mode (right).

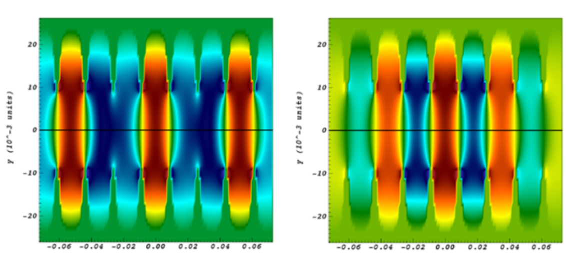

Figure 3: Passband modes of the elliptical multi-cell structure: 2π/3-mode (left) and π-mode (right).

By determining the relevant passband modes and the corresponding frequencies we determine the dispersion diagram corresponding to each of the periodic structures. Figure 4 shows the dispersion diagram for both the DLWG and elliptical accelerating concept geometries, where the geometry parameters have been set so that the frequency corresponding to the $2\pi/3$ -mode is 5.712 GHz. The dispersion curve from the simulations shows how the phase velocity can be varied through a change in ω.

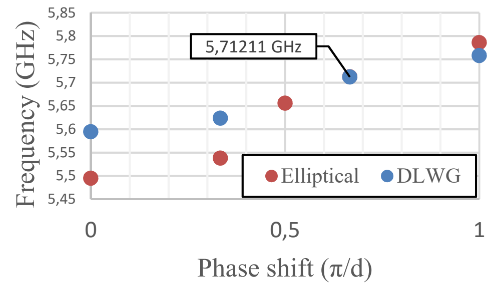


Figure 4: Dispersion diagram for both DLWG and elliptical geometries.

Similarly, the parameters defining the geometric shape for this electromagnetic mode at C-band are presented in Table 1, where $R_{cav}$ is the radius of the cavity, $R_{iris}$ is the radius of the beam aperture, $\rho_{min}$ is the radius defining the iris curvature and $\rho_{max}$ is the radius at the equator for the elliptical cavity.

Table 1: Geometry Parameters Defining the DLWG and Elliptical Structures

| | **DLWG** | **Elliptical** |
|---|---|---|
| Phase advance | 2π/3 | |
| $TM_{010}$ freq. (GHz) | 5.712 | |
| Cell Length (mm) | 17.5 | |
| $R_{cav}$ (mm) | 21 | 24 |
| $R_{iris}$ (mm) | 7 | 9 |
| $\rho_{min}$ (mm) | - | 1.51 |
| $\rho_{max}$ (mm) | - | 6.20 |

## CONCLUSION

We are using VSim to investigate two different geometries for accelerator applications at a C-band frequency. For next generation XFEL technology, we require these traveling wave cavities to operate on the 2π/3-mode at 5.712 GHz. On-going work focuses on geometry optimization for high-accelerating gradient and low breakdown rates. Particle simulations and cryocooling studies are also planned, as well as use of VSim on the THETA supercomputer at Argonne Leadership Computing Facility to expedite the computing time.

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