FREQUENCY DOMAIN SIMULATIONS OF CO-LINEAR X-BAND ENERGY BOOSTER (CXEB) RF CAVITY STRUCTURES AND PASSIVE RF COMPONENTS WITH ACE3P

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Abstract

Due to their higher intrinsic shunt impedance X-band accelerating structures offer significant gradients with relatively modest input powers, and this can lead to more compact light sources. At the Colorado State University Accelerator Laboratory (CSUAL) [1] we would like to adapt this technology to our 1.3-GHz, L-band accelerator system using a passively driven 11.7 GHz traveling wave X-band configuration that capitalizes on the high shunt impedances achievable in X-band accelerating structures in order to increase our overall beam energy in a manner that does not require investment in an expensive, custom, high-power X-band klystron system. Here we provide the comparisons of the important parameters achieved using SUPERFISH and OMEGA3P for our Co-linear X-band Energy Booster (XCEB) system that will allow us to achieve our goal of reaching the maximum practical net potential across the X-band accelerating structures while driven solely by the beam from the L-band system.

GENERAL CONCEPT

The CSU Accelerator Facility will initially focus on the generation of long-wavelength, free-electron lasers pulses, as well as the development of electron-beam components and peripherals for free-electron lasers and other light sources. It will also serve as a test bed for particle and laser beam research and development.

One of the most important parts of this accelerator is the linac that was constructed by the Los Alamos National Laboratory for the University of Twente TEU-FEL Project. In addition to the capabilities of this linac we would like to further increase the electron beam energy without additional significant investments. Our idea is to utilize the electron beam from the L-Band RF gun as a drive source for a passive X-band linac structure thus allowing us to increase the beam energy by using the L-band power together with the inherent high shunt impedance of the X-band structure [2].

Figure 1 presents the general layout of our proposed CXEB system. We started with the power extraction mechanism using the beam from the L-band linac passing through the power extraction cavity (PEC). This power is then delivered to the X-band main accelerating cavity (MAC) structures. Then, when a bunch periodically passes through the whole system we can achieve significantly higher beam energies. This is done by simple switching of the photocathode drive laser pulses and shifting the phase onto the cathode such that it puts the bunch into the accelerating phase of all accelerator structures. Finally, we described the achievable photon wavelength with our existing high-energy electron beam using an undulator magnet system for a compact FEL system at CSU. The details of our XCEB will be presented in our paper that is to be published in the following weeks.

X-BAND POWER EXTRACTION CAVITY (PEC)

In our previous studies [3,4] we described the general idea that can provide us some additional electron beam energy via an inexpensive and compact way using our proposed X-band Co-linear energy booster (XCEB) at CSU. We have presented the electromagnetic field mapping studies using SUPERFISH, the Maxwell solver of LANL's Group code [5]. In this concept we used two different types of X-band traveling wave (TW) RF cavity structures. The first one is designed as a power extraction cavity (PEC) that can provide us the needed power via our L-band system. The second one, the main accelerating cavity (MAC), is designed for lower group velocity for efficient RF power deposition to the electron beam in the cavity.

In SUPERFISH, for the specified normalization method and structure length (L), the average axial electric field E_0. stored energy (U), and the dissipated power (P_W) on the metal surfaces with surface resistance (R_{sur}), can be calculated. From these quantities, SUPERFISH reports the cavity quality factor (Q) and shunt impedance per meter (R_s), that can allow us to calculate the achievable power at the end of the X-band PEC.

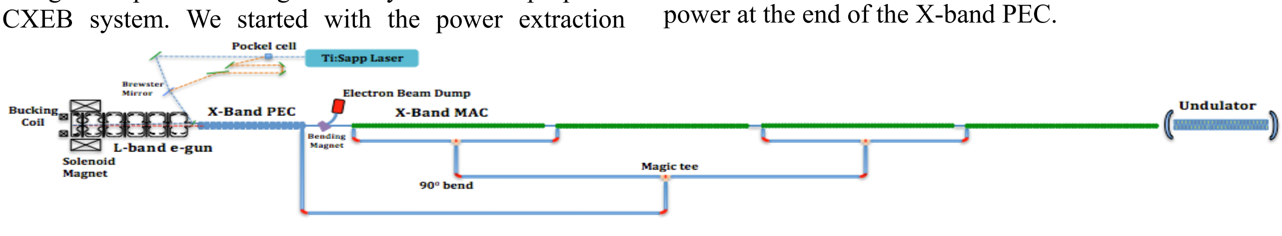
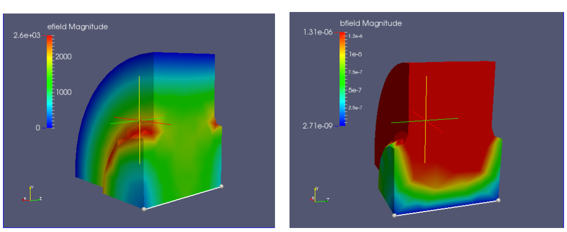


Figure 1: The case of four accelerating structures for the system under study

For more advanced results in 3D we performed our simulations using the parallel computing capabilities of the National Energy Research Scientific Computing Center (NERSC) [6] as well as SLAC's Advanced Computational Electromagnetics Code Suite ACE3P (Advanced Computational Electromagnetics 3D Parallel) [7]. The 3D CAD modeling and visualization were done using the Telis [8] and Paraview [9] software, respectively. Some of the important parameters are compared in Table 1 between SUPERFISH and OMEGA3P [10], an eigen-frequency solver of ACE3P. OMEGA3P results are given for the magnitude of electric and magnetic fields for the single cell of our TW X-band PEC in Figure 2.

Table 1: Parameters for TW X-band PEC

Parameter	SUPERFISH	ACE3P
Frequency	11.7008 GHz	11.7001 GHz
Phase advance per cell	2π/3 Radians	$2\pi/3$ Radians
Inner radius to wavelength ratio	0.11	0.11
Transit time factor	0.7109	0.708
Quality factor	6456.11	6449.36
Cell length	0.0085411	0.0085411
Shunt Impedance	104 MΩ/m	104 MΩ/m



(a) (b)

Figure 2: Magnitude of E field (a) and B field (b) fields of the single TW X-band PEC using OMEGA3P

RF POWER GENERATION VIA X-BAND PEC STRUCTURE

In this section we will describe the power extraction mechanism and relevant bunch structure to achieve the expected RF power in X-band PEC structure.

We can calculate the extracted power for a Gaussian bunch passing through an X-band PEC structure that has a certain length and shunt impedance using the equation [11]:

$$P = \frac{\omega}{4c}\left(\frac{R}{Q}\right)\frac{L^2 I^2}{\beta_g}\left(\frac{1-e^{-\alpha L}}{\alpha L}\right)^2 F^2(\sigma)$$

At steady state a 6 MeV will lose 5 MeV of beam energy upon passage through the PEC. After the end of the PEC we can bend our 1 MeV electron beam into an electron beam dump. The last cell of the PEC has been designed with an output coupler where we can extract the 1.37 MW of generated X-band RF power and direct it to our MAC structures. The beam dynamics details in the time domain for our X-band PEC are being presented in another paper at this conference [12].

Average Current Calculation

A high QE cathode will be used with our existing Ti:Sapp laser operating at an 81.25 MHz pulse rates to extract 5 nC bunch charge giving a drive current of 0.4 mA.

Switching in a Single Bunch for Acceleration

By using a pockel cell system in our laser to periodically switch out a laser pulse and delay it by a know amount we can send a single, low-charge (100–200 pC) bunch through the system at a phase that will be favourable for acceleration. A shift of 20 degrees at L-band is 180 degrees at X-band. With such a shift the bunch will experience acceleration in the L-band linac as well as both the PEC and MAC raising its energy for our case up to 23.6 MeV.

COUPLER DESIGN

For our beam conditions we chose to use the last cells in our X-band PEC structure. Due to the high gradient (□30 MV/m) we decided to extract the generated RF power from an optimized slot structure to a tapered waveguide that has dimension ended with WR-90 type X-band rectangular waveguide dimensions. This coupler matches the TE10 mode of the waveguide with the traveling wave of the X-band PEC. The coupling constant is adjusted to provide a proper match under equilibrium conditions. We use the same procedure for the MAC structure but this time with an input coupler at the beginning of the TW structure that is designed to operate on the $5\pi/6$ mode.

X-BAND MAIN ACCELERATING CAVITY (MAC) STRUCTURE

Our L-band system is capable of generating beam for over 10 μs, i.e. significantly longer than the fill time of typical X-band structures. This then argues for a structure with a very slow group velocity as it will allow us to fill a longer cavity and capitalize on the long L-band RF pulses.

In these configurations we can divide the power into two or four different structures to achieve a higher integrated potential than possible with a single structure; furthermore, if the input power and shunt impedance are fixed, the maximum energy gain over a structure of given length depends on maximizing the total attenuation

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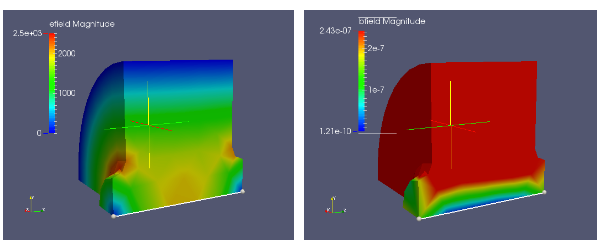
parameter. Then, by using the quality factor and group velocity parameters, we can calculate the optimal accelerating cavity length. The cavity parameters for the MAC structures are given in Table 2.

Table 2: Available Potential and Maximum Energy Gain Values for 0.64 m Length MAC

Frequency	11.69998 GHz
Phase advance per cell	$5\pi/6$ Radians
a/lambda	0.1
Quality factor	7539
Total length per section	0.638 m
Relative group velocity	0.95%c
Number of X-band cells	60
Filling time per section	223 ns
Available potential (4section)	9.25 MV/m
Maximum energy gain (4 section)	23.6 MeV



(a) (b)

Figure 3: Magnitude of E (a) and B (b) fields of the single TW X-band MAC using OMEGA3P.

Possible Photon Wavelength at the End of CXEB

The 23.6 MeV high-energy electron beam can be used for reaching IR wavelengths, possibly in an FEL configuration, using our existing undulator that has been used for THz generation at University of Twente [13]. With our proposed CXEB the energy increases to 23.6 MeV and we can achieve 16.2 µm wavelengths with our system. This is as opposed to our current capability of 300 micron using the nominal 6 MeV beam.

CONCLUSION

In this study we provided the 3D design of the TW X-band PEC and MAC structures that will allow us to achieve higher energies in a compact way. Our calculations showed that we can achieve 1.4 MW of extracted power with our X-band PEC structure. Then using an optimized RF coupler structure we can achieve 23.6 MeV maximum energy with four TW linac structures at the end. Finally, the resultant high-energy electron beam can be used with our existing hybrid undulator for achieving photons at MID-IR range.

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