FREQUENCY DOMAIN SIMULATIONS OF RF CAVITY STRUCTURES AND COUPLER DESIGNS FOR CO-LINEAR X-BAND ENERGY BOOSTER (CXEB) 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) 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 frequency domain simulation results using the ACE3P Electromagnetic Suite's OMEGA3P and S3P for our proposed Co-linear X-band Energy Booster (CXEB) 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 [1] 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 [2]. 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.

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.

X-BAND PEC STRUCTURE

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. 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) [5], is designed for lower group velocity for efficient RF power deposition to the electron beam in the cavity. In our previous studies we have presented the electromagnetic field mapping of the PEC and MAC structures using SUPERFISH, the Maxwell solver of LANL's code group [6].

In here we provide the results of more advanced 3D simulations that we performed using the parallel computing capabilities of the National Energy Research Scientific Computing Center (NERSC) [7] as well as SLAC's Advanced Computational Electromagnetics Code Suite ACE3P (Advanced Computational Electromagnetics 3D Parallel) [8]. The 3D CAD modeling and visualization were done using the Telis [9] and Paraview [10] software, respectively.

We started our simulations studying how different boundary conditions effects the PEC parameters and because we would like to increase our CPU time efficiency on the super computing facility. In this part of the study, while we were applying traveling wave boundary conditions at the both ends of the half and quarter PEC single cell geometries, we kept the mesh size constant and similar to what we used for the whole cell. The parameter comparison results and the magnitude of the electric and magnetic fields for the each symmetry of the single cell of our TW X-band PEC using OMEGA3P [11], eigen frequency solver of ACE3P are given in Table 1 and Figure 2.

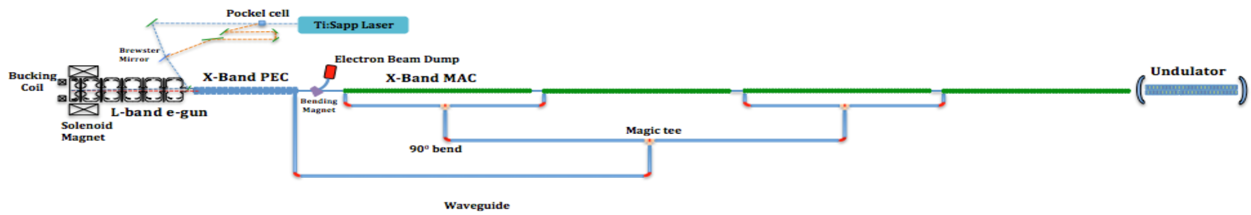
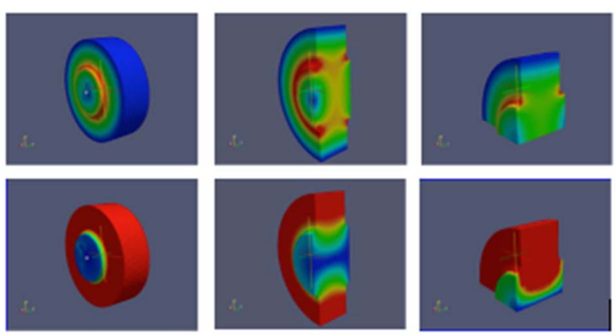


Figure 1: General layout of CXEB system [12].

Table 1: Parameter Comparison of TW X-band PEC Single Cell for Different Symmetries using OMEGA3P

Parameter			
Symmetry	Full	Half	Quarter
Mesh Number	11591	8955	5962
FEM order	2	2	2
Inner radius to wavelength ratio	0.20	0.20	0.20
Outer radius [mm]	11.0275	11.0275	11.0275
Frequency [GHz]	11.69559	11.699435	11.699753
Quality Factor	6646.03	6649.69	6649.135



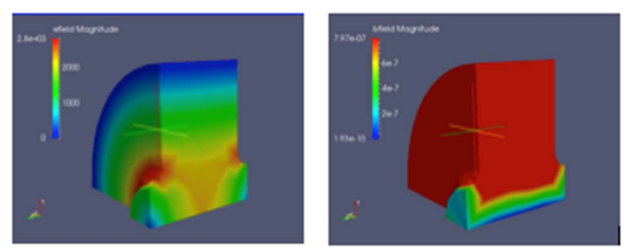
(a) (b) (c)

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

Some of the important parameter comparisons (using SUPERFISH and OMEGA3P) for the single cell of our TW X-band PEC are given in Table 2. The magnitude of the electric and magnetic fields for our single cell TW X-band PEC using OMEGA3P in Figure 3.

Table 2: Parameters for TW X-band PEC

Parameter	SUPERFISH	ACE3P
Phase advance per cell [Radian]	$2\pi/3$	$2\pi/3$
Cell length [mm]	8.5411	8.5411
Inner radius to wavelength ratio	0.10	0.10
Frequency [GHz]	11.700176	11.699852
Quality factor	6456.11	6448.53
Shunt Impedance MΩ/m	110.329	110.2



(a) (b)

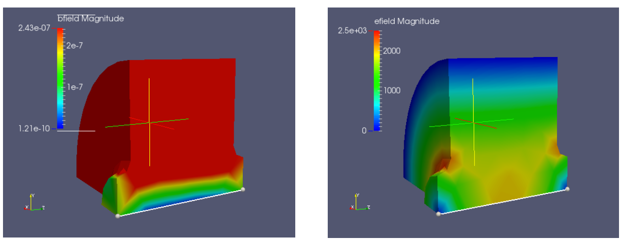
Figure 3: Magnitude of E field (a) and B field (b) fields of the single TW X-band PEC using OMEGA3P.

X-BAND MAC STRUCTURE

Our L-band system is capable of generating beam for over 10 μs. 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. The parameters for the TW X-band accelerating structure, namely the MAC structure, are given in Table 3. The magnitude of the electric and magnetic fields for our single cell TW X-band MAC using OMEGA3P in Figure 4 [13].

Table 3: Parameters for TW X-band MAC

Parameter	SUPERFISH	ACE3P
Phase advance per cell [Radian]	$5\pi/6$	$5\pi/6$
Cell length [mm]	10.67637	10.67637
Inner radius to wavelength ratio	0.10	0.10
Frequency [GHz]	11.76998	11.699723
Quality factor	7598.7	7587.7
Shunt Impedance MΩ/m	153.67	153.4



(a) (b)

Figure 4: Magnitude of E (a) and B (b) fields of the single TW X-band MAC using OMEGA3P.

COUPLER DESIGN FOR TW X-BAND STRCUTURES USING ACE3P SUITE

Coupler design is an important design consideration because of the power transfer needs to be done as efficiently as possible. Another important decision point is the coupler type. Because our TW power is high enough (in MW range) instead of a coaxial cable we chose to use a waveguide type coupler that has a slot at the upper end of the last cell to couple to the proper mode. We use a regular WR-90 type X-band rectangular waveguide attached to a tapered section between the slot and waveguide. After that periodic boundary conditions (PBC) are applied on both ends of a PEC single cell and adjustments are made to achieve the desired frequency (Figure 5).

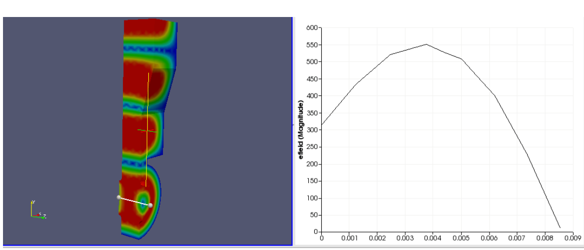


Figure 5: OMEGA3P result of the coupler cavity cell using PBC.

To check we used another technique to evaluate the coupler design using waveguide boundary condition (WBC) at the waveguide port end; however, with this technique, because the waveguide boundary condition is broadband we shortened the neighbor cell to reach the desired mode and frequency. This coupler again matches the TE10 mode of the WR-90 type waveguide after a tapered waveguide section. The coupling constant is adjusted to provide a proper match under equilibrium conditions shown in Figure 6 using S3P [14].

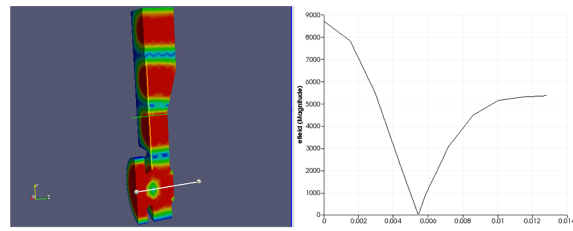


Figure 6: S3P result of the coupler cavity using WBC.

Finally, we attached the coupler cavity structure to the 2 regular X-band PEC cells as the $2\pi/3$ phase advance per cell repeats itself every 3 cells. The attached 3-cell PEC structure is shown in Figure 7 for the optimization of the reflection coefficient using S3P.

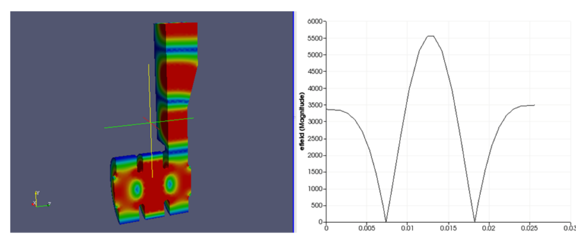


Figure 7: S3P result of X-band PEC and attached coupler cavity result using WBC.

We use the same procedure for the MAC coupler structures but this time it is designed to operate on the $5\pi/6$ mode. We attached the coupler cavity structure to the 5 regular X-band MAC cells as the $5\pi/6$ phase advance per cell repeats itself every 6 cells. The attached 6-cell MAC structure is shown in Figure 8 for the optimization of the reflection coefficient using S3P.

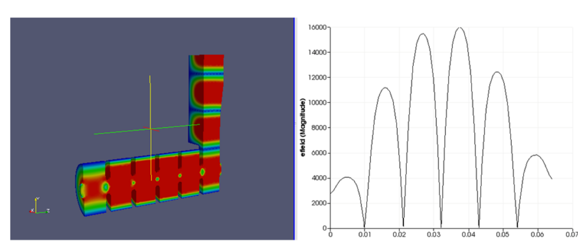


Figure 8: S3P result of X-band PEC and attached coupler cavity result using WBC.

CONCLUSION

In this study we provided the 3D frequency domain simulation results of the TW X-band PEC and MAC structures using OMEGA3P. We also presented the relevant coupler designs and design methodologies that we performed using OMEGA3P and S3P.

ACKNOWLEDGMENT

We wish to thank the senior management of CSU for their support of the accelerator laboratory and accelerator education. We also wish to thank the Stanford Linear Accelerator Center (SLAC) Advanced Computing Division (ACD) for ACE3P simulation discussions and NERSC for the time on their computers.

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