X-BAND RF POWER GENERATION VIA AN L-BAND ACCELERATOR SYSTEM AND USES

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Abstract

The development of compact, cost effective sources of high-energy electron beams is a major thrust of the Colorado State University Accelerator Laboratory team. In this paper we describe a way to generate usable X-Band RF power suitable for powering an X-Band accelerating structure to overall potentials significantly higher than what we are presently able to obtain from our L-Band photocathode RF gun system. The concept relies on the use of the L-band accelerator beam to generate the X-band power that is then delivered to a suitable X-band structure. Once powered this X-band structure can be used to accelerate an electron bunch to high beam energies.

GENERAL CONCEPT

The CSU Accelerator Facility will serve as a test bed for particle and laser beam research and development. Our major asset is an L-band rf gun system capable of delivering 6-MeV electron bunches [1], these parameters are given in Table 1. We would like to use this L-band linac as a drive source to generate X-band power for accelerating electron beam with an X-band rf structure without the need for an external X-band power source. This system could then be used to accelerate the beam to an even higher energy that possible with the L-band system alone.

Table 1: Parameters of CSU Accelerator Laboratory

Laser Frequency	81.25 MHz
L-Band RF Gun Frequency	1.3 GHz
L-Band RF Gun Energy	6 MeV
L-Band Macro pulse Length	10 μs
X-band Linac Frequency	11.7 GHz
Repetition Rate	10 Hz
RF gun Charge/Bunch	3.5 nC

From our earlier work, we found that although significant gradients could be achieved with an X-band structure powered via our L-band beam system the integrated potential in the X-band structure was fundamentally limited by the drive beam energy loss [2]. This led us to explore an alternative arrangement where power was generated in a TW structure and then transferred to a separate optimized structure used for acceleration of a secondary beam. This basic arrangement is shown in Figure 1.

Using such an arrangement, we would like to achieve the highest possible energies for our given beam parameters and proposed X-band drive system.

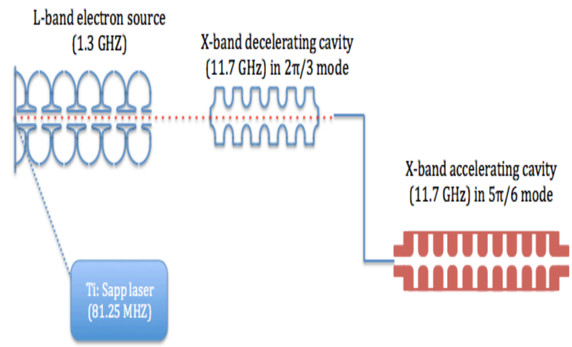

Figure 1: General layout of the two-beam X-band structure.

BEAM STUDIES FOR TWO DIFFERENT CAVITIES

Our study involves two different X-band accelerator structures, one to be used as a decelerating cavity that generates X-band power via the use of the beam from the L-band system, and the second one to be used as an accelerating cavity to achieve the highest practical potential for acceleration of the electron beam.

The one cell geometry for our X-band structures are defined in Figure 2 [3].

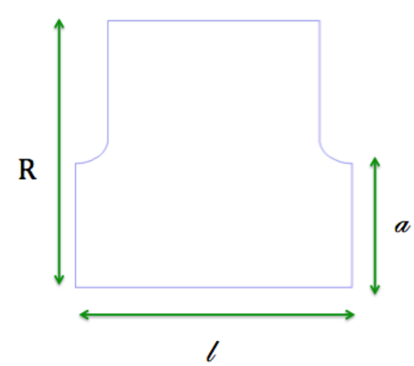

Figure 2: One cell structure of the X-band cavity.

The Beam – Cavity Interaction for the Decelerating Structure

In the decelerating cavity, the aim is to transfer energy from the L-Band RF system to the electron beam, consisting of bunches of charged particles, and then from the electron beam to the RF wave induced in the X-band decelerating structure, thus we design a structure that maximizes this interaction as in ref. 2.

The configuration is unconventional in that the X-band linac does not require a klystron system to achieve high accelerating fields. Rather it uses the power existing in the electron beam to resonantly power the fields in the structure.

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Once the X-band structure has been powered up to the full potential a properly phased electron bunch can then be injected and accelerated, and for a properly designed and configured system can raise the beam energy to nearly twice what would have been available from the L-band system alone.

In this decelerating linac geometry, the iris radius (a) is 0.00512466 m, cavity radius (R) is 0.0110955 and the cell length (l) is 0.0085411 m as in ref. 3. The general parameters of this $2\pi/3$ traveling wave (TW) structure are given in Table 2. The X-band power generated with these parameters is 1.4 MW.

Table 2: Beam – Cavity Interaction Parameters for X-band Decelerating Cavity Structure

L-Band Bunch Charge	3.5 nC
L-Band Final Beam Energy	6 MeV
X-band Max. Gradient	62.7 MV/m
X-Band Shunt Impedance	57 MΩ/m
X-Band Eff. Shunt Impedance	33.1 MΩ/m
X-Band Q	6656
Damping Factor (t/τ)	0.1
X-Band Cell length	0.0854 m
Number of X-Band cells	18
Total length of X-Band structure	15.3 cm
Available X-Band Potential	5 MV

The Accelerating Structure

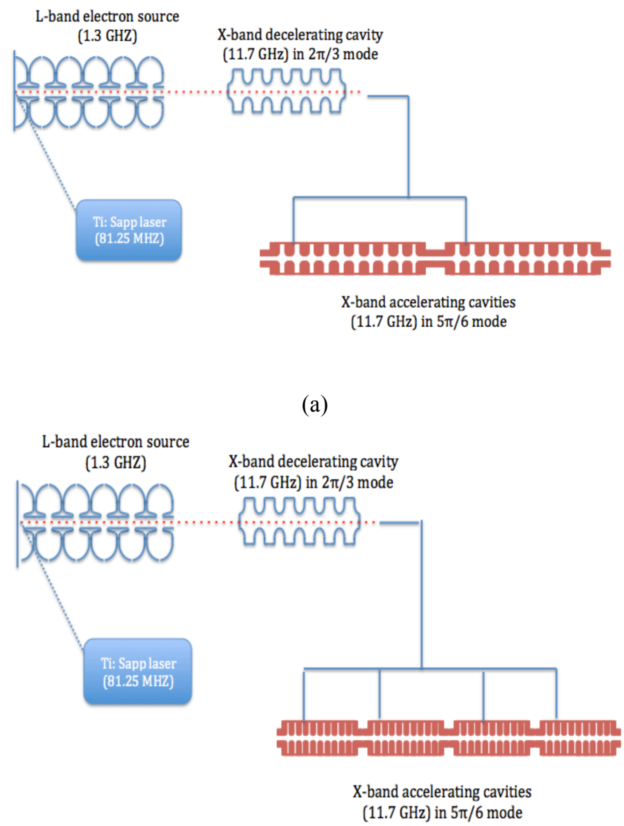
In this design we wish to maximize the energy gain in an optimum length and get highest integrated potential at the end of one or more the cavities; therefore, we chose to design a new geometry, and change the phase advance from $2\pi/3$ to a higher mode, $5\pi/6$. This slows the group velocity and allows us to increase the length of structure and provide more opportunity to increase the integrated potential [4].

The resulting geometry of the accelerating structure becomes (a) is 0.002566233 m, the cell length (l) 0.010676375 m, and the cell radius (R) decreases in this case as in ref 3.The general parameters of this structure are given in Table 3.

Table 3: Beam – Cavity Parameters for X-band Accelerating Cavity Structure

Dec. Cavity Final Beam Energy	11 MeV
Phase Advance	$5\pi/6$
a/λ	0.1
Acc. Cavity Shunt Impedance	185.7 MΩ/m
Acc. Cavity Quality Factor	7474
Acc. Cavity Cell length	0.010676375 m
Group Velocity (v_g/c)	0.95%

This basic configuration, i.e. an L-band gun system beam powering a decelerating cavity used to generate X-band power and all the power fed into a single optimized accelerating cavity achieves an integrated potential significantly higher than our original direct attempt; however, we considered three different scenarios that allowed us to achieve a higher potential with our new proposed system. The two different configurations are shown in Figure 3.



(b)

Figure 3: a) Two accelerating structure case b) Four accelerating structure case for the system under study.

In these configurations we divide the power into two or four different linacs 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 parameter. In this case it becomes 1.26 [5]. Then, by using the quality factor and group velocity parameters from table 3, we can calculate the optimal accelerating cavity length. The beam loading parameters for the accelerating structures are given in Table 4.

Table 4: Available Potential and Maximum Energy Gain values for 0.72 m length accelerating cavity

Total Length of One Section	0.72 m
Number of X-Band cells	69.4

Filling time for 1 Section	259 ns
Available Potential after 1 section	16.2 MV/m
Available Potential after 2 sections	22.9 MV/m
Available Potential after 4 sections	32.4 MV/m
Max. Energy gain after 1 section	12.6 MeV
Max. Energy gain after 2 sections	17.5 MeV
Max. Energy gain after 4 sections	24.8 MeV

As seen, by use of multiple accelerating structures, we can achieve a significantly higher integrated potential (Table 4) than in the single accelerating structure case.

DISCUSSION AND FUTURE STUDIES

We have shown that by proper design we can, by utilizing the beam from our L-band linac, resonantly excite an X-band decelerating structure to meaningful accelerating gradients. In our initial design example we achieved up to 5-MV additional accelerating gradient. Configured properly this implies that we can periodically achieve beam energies near double our original 6 MeV and potentially reach roughly 11 MeV in occasional single pulses without the need for an additional X-band power source after L-band structure. Additionally, after gaining 11 MeV, we can achieve higher potential by using accelerator structures that are designed and configured in a two-beam configuration. However, the amount of the potential that we can get depends on the higher mode of the cavities and the number of structures. Therefore, to optimize our case, we will continue to study the possible higher modes that can give higher integrated potential and check the limits of having more accelerating structures.

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