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Title: LEBT Buncher / Feed Forward / Frequency Generation: System Design Document (SDD)

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Los Alamos
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LANSCE MODERNIZATION PROJECT

LEBT Buncher / Feed Forward / Frequency Generation: System Design Document (SDD)

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Component Overview

The LAMP Low Energy Beam Transport (LEBT) transfers a continuous beam at 100 keV from the ion source to RFQ in LEBT. A LEBT buncher imposes an energy tilt to initiate velocy bunching in the chopped beam pulse about 25 ns long to form a short MPEG bunch. One possible option for the LEBT buncher based on a two-gap LC-circuit driven structure was considered in [1], which is similar to the existing LANSCE low-frequncy buncher (LFB). Another possible option is a non-resonant element driven by a pulse-forming-network that provides a single pulse at the repetition frequency of MPEG beam, with a period of 1.8 μs [2].

The LEBT operation is synchronized with the accelerator timing system.

Requirements

The requirements for the LAMP LEBT chopper system are determined mainly by the LEBT beam dynamics design. The main requirements are listed in Table 1.

Table 1. Requirements for the LAMP LEBT Buncher.

Identifier	**Requirement**	**How met**
Effective voltage *V*	Should be sufficient to compress the MPEG bunch < 5 ns; defines the length needed for bunch compression.	LEBT beam dynamics design; buncher design
Buncher length *L*	Should be minimized	Buncher electromagnetic design
Buncher aperture *a*	Should allow the beam to pass without scraping	LEBT beam dynamics design

Relevant Parameters

Two important parameters for the LAMP LEBT buncher are the beam energy in LEBT (100 keV) and the beam size at the buncher location. The present LAMP conceptual design uses the input parameters from the preliminary design outlined in Ref. [2]. They are listed in Table 2.

Table 2. Parameters of the LAMP LEBT Buncher.

Parameter	**Value, units**	**Design**
Operating frequency	16. 7708 MHz	n^{th} subharmonic of 201.25 MHz. Here n = 12 [1]

Effective voltage $V_{eff} = VT$	5 kV	[3], defined by the buncher distance to RFQ
Buncher aperture radius a	1.8 cm	[3]
Repetition frequency	100 Hz	Operates only during macro-pulses of 625 μs repeated at 100 Hz.

Other parameters of the buncher system are derived based on these main parameters.

Design Decisions

Buncher design.

Option 1. LC-driven two-gap enclosure was developed in [1] using 3D modeling with CST Studio [4].

While details of the LAMP LEBT design continue to evolve, the original study [3] envisioned using the same mechanism as in the LANSCE front end for creating higher-charge bunches for WNR (MPEG beam). The beam energy in the LEBT is 100 keV, which corresponds to $\beta = v/c = 0.0146$. 3D modeling of LAMP LFB with CST Studio [4] in Ref. [1] used a two-gap enclosure LC-driven at 16.77 MHz, see in Fig. 1. The gap width was chosen to be 0.4 cm; the beampipe inner radius is 1.5875 cm, the same as in the LANSCE LFB. The overall LFB length along the beamline is 22 cm.

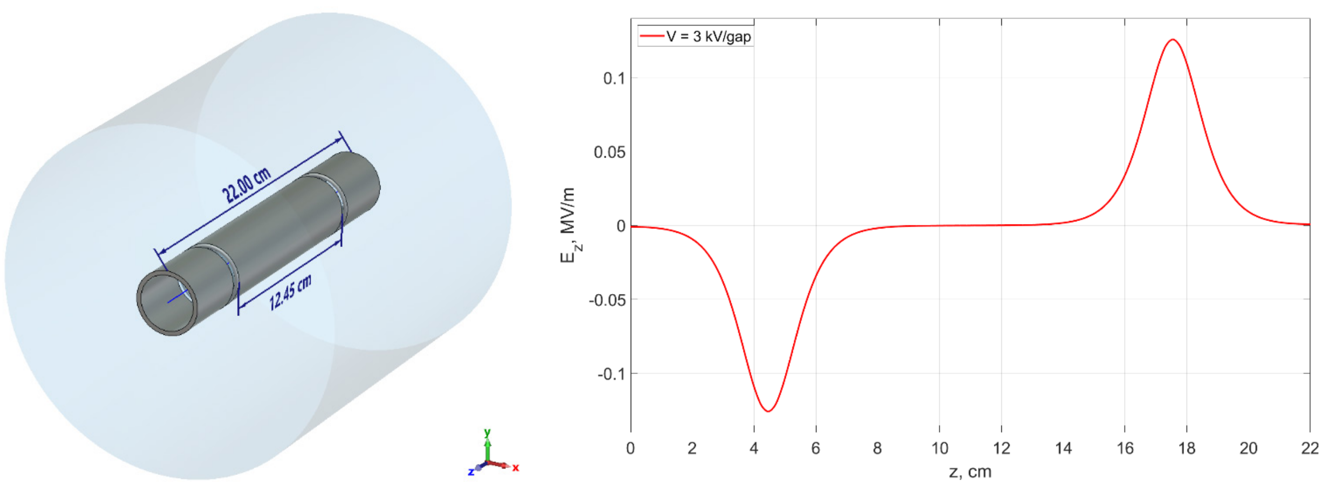

Figure 1: Left: CST model of LAMP LFB: beam pipe (grey), vacuum volume of enclosure (transparent blue), blue line shows beam axis. The outer walls and supporting rod are not shown. Right: on-axis electric field in LFB normalized to the voltage 3 kV/gap.

In this LFB model, with applied voltage 3 kV/gap, the length a 25-ns-long bunch must drift to complete its velocity bunching is $L_b = 2.03$ m.

This option has a high TRL because of the experience with the existing LANSCE LFB. The modifications required for LAMP LFB are minimal and well understood.

Option 2. A non-resonant structure with one or two gaps driven by a pulse-forming-network that produces single pulses at the repetition frequency of MPEG beam, with a period of 1.8 μs [2]. This option would allows a LEBT buncher to be placed much closer to the RFQ. The TRL level of this option is rather low, 1-2.

Pulser.

The pulser design choice depends on the option chosen for the LFB, see above.

For option 1, it will be similar to the existing LANSCE setup: an LC-circuit driver and amplifier. High TRL.

For option 2, the pulser design TBD. Likely a higher voltage will be required to reduce bunching length. Low TRL.

Overall, the LFB buncher design similar to the LANSCE LFB (option 1) is preferable based on high TRL and minimal risk.

Other systems.

Mechanical.

The mechanical setup for LFB will be similar to that for the LANSCE LFB, only shorter, see Fig. 1.

Controls / LLRF.

The frequency control system for the LEBT Buncher portion of the accelerator uses a tuner within the water-cooled cavity to maintain the resonant frequency of the cavity. The tuner system on the LEBT bunching systems will be activated by either a phase detector between the forward and cavity signals or an amplitude detector on reflected power signal. These detection functions will be implemented digitally in the FPGA.

The LLRF systems interfaces with the timing and EPICS systems from AOT-IC, the fast protect and run permit systems from AOT-OPS and water and tuner systems from AOT-MDE.

In Fig. 2, the blue outline represents the entire LLRF system, and the purple outline represents the LLRF Control System.

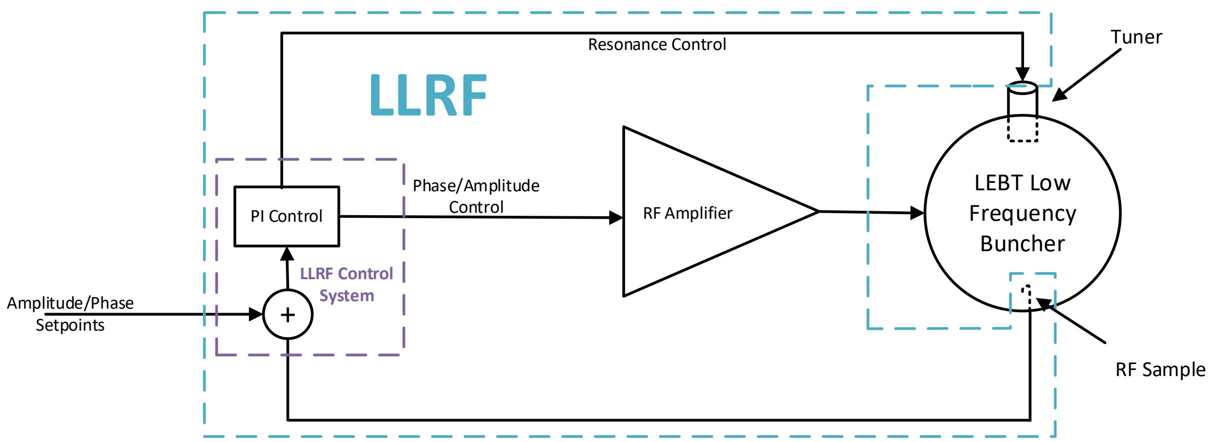

Figure 2: LLRF LEBT Buncher System Block Diagram

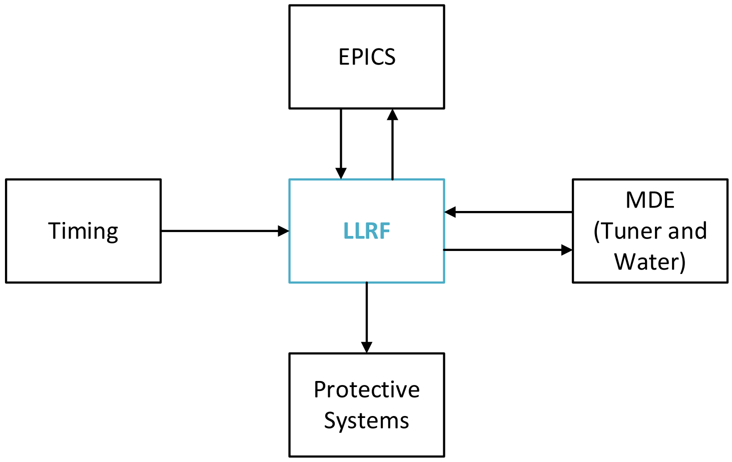

Figure 3: LLRF LEBT Buncher System interaction with other systems

Table 3. Parameters of LLRF LEBT Low Frequency Buncher RF systems.

Parameter	**Value, units**	**Comment**
Cavity operating frequency	16.7708 MHz	201.25 MHz. / 12 [1]
Peak amplitude error	± 0.1%	
Peak phase error	± 0.2°	
Amplitude control margin	15% min	
Phase control margin	± 45°	
RF Peak power (Maximum)	2 kW	
Peak Operational Resonance Error	± 10 kHz from 16.7708 MHz	

The LAMP LEBT Low Frequency Buncher LLRF system will be developed from the current digital LLRF systems to a new digital system with the upgrades needed for LAMP. The hardware will be upgraded from cPCI systems as the current cPCI systems are obsolete and parts can no longer be obtained. A VPX-based direct RF system will need to be developed.

The choice of VPX as the primary system architecture is based on the experience over the last two decades of using compact PCI based system and the experiences at other accelerator facilities. Two telecommunication standards, Advanced TCA and MicroTCA, are viable alternative to VPX and are used at many accelerator facilities around the world and have the appropriate features we require in a system architecture. VPX was chosen by DOD as their system standard with the expectation that it would have a service lifetime of 35 to 50 years in support of DOD systems. Both telecommunication standards are expected to have a viable lifetime of 8-12 years. VPX offers a system lifetime and extension that meets the long-term requirements of LANSCE.

Feed Forward.

To reduce the cavity field transients due to the beam entering the cavity, a feed forward system is implemented. The feed forward systems sense the peak current amplitude of the beam and generates a proportional signal for distribution to the accelerator RF control systems, see Fig. 4. Because LANSCE can generate multiple beam types, the feed forward system needs to sense and generate the appropriate signal based on the exact type of beam being transported in each section of the accelerator (LBEG, H-GX, etc.). The system consists of current sensors and amplifiers for both H^+ and H^- beams, signal generation circuitry for both RFQ/DTL sections and CCL sections of the accelerator, and signal distribution system throughout the accelerator (Sectors J to H). H^+ and H^- are independently measured and the appropriate signal is delivered to each sector based on the beam species transported (including simultaneous H^+ and H^-). The beam feed forward rack is in Sector J and all signals are distributed from this rack. Beam feed forward sensing is not utilized for the LEBT bunchers but will but utilized for the MEBT bunchers.

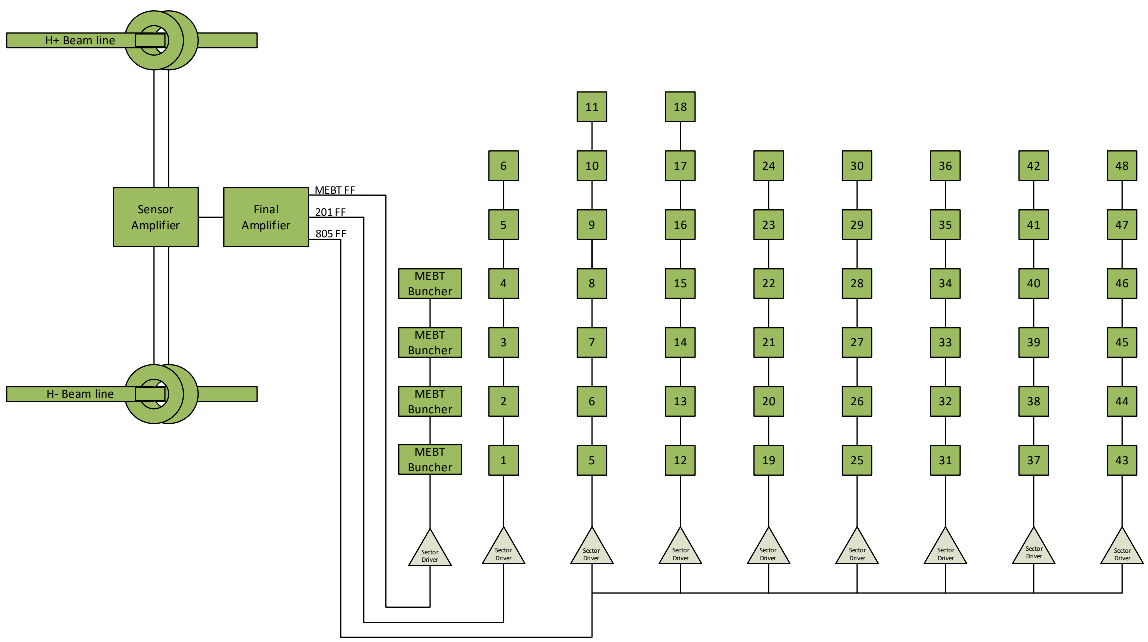

Figure 4: Feed Forward System Block Diagram

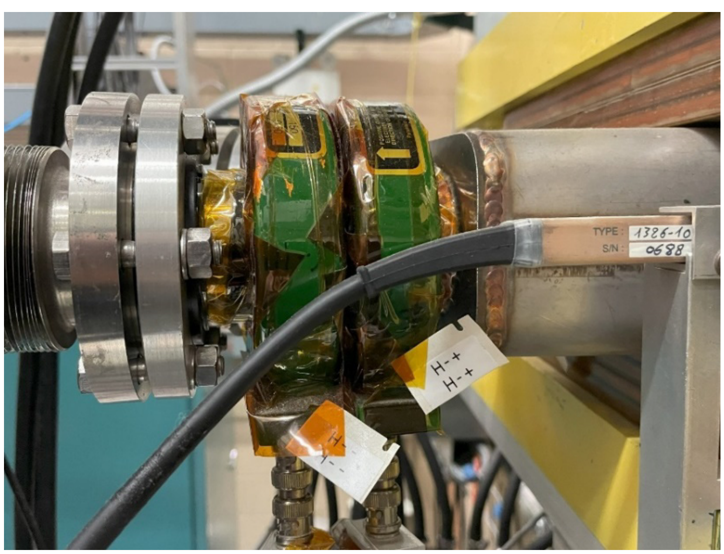

Figure 5: Toroids on beamline

Table 4. Feed Forward Signal Sensor and Generation System.

Parameter	**Value, units**	**Comment**
Beam current conversion factor	50 mV/mA peak	
Distributions system peak amplitude	5 V	
Sensor sensitivity	10 V/A	
Sensor amplifier gain	1000x	

The Feed Forward system will be based on the LLRF system developed for digital LLRF upgrades. The hardware will be upgraded from cPCI systems as the current cPCI systems are obsolete and parts can no longer be obtained. A VPX-based direct RF system will need to be developed. See above for more information on VPX.

LLRF would like to have the feed forward/frequency generation rack in the same place as it currently is, as cables that are beyond the scope of LAMP originate from this rack. This would allow the cables to remain in place and not have to be re-installed.

Toroids. There will need to be a section of the beamline where the toroids can be placed. The toroids need to be insulated from the beamline, see in Fig. 5.

Frequency Generation.

The frequency generation subsystem creates additional phase and amplitude stable signals for various systems in the accelerator: a) the frequency needed for the low frequency bunchers in the LEBT and as the master clock for the chopper pattern generator; and b) 2.8MHz for the PSR harmonic buncher, timing system and chopper pattern generator. The accelerator requires several RF signals that need to be derived from the 201.25 MHz RF phase reference for different beam line related systems including the low frequency bunches, the master clock for the LEBT beam chopper pattern generator and the circulation frequency for the Proton Storage Ring (PSR). All these systems require a phase stability equivalent to the RF phase reference for correct and consistent operational performance. The low frequency buncher and chopper pattern generator clock are derived directly from the RF phase reference using frequency dividers and the PSR circulation frequency is generated using direct digital synthesis techniques and relies on the RF phase reference as is primary clock.

Table 5. Frequency Generation System.

Parameter	**Value, units**	**Comment**
Base Frequency	100.625 MHz	
Technology		Ovenized voltage-controlled crystal oscillator
Type		Phase lock loop
Frequency Accuracy	± 0.1 ppm	
Frequency drift	< ±1 ppm/°C	
DTL Drive-line frequency	201.25 MHz	from 100.625 MHz

Technology		Harmonic multiplier
Type		Fixed
Frequency drift	± 0.5 ppm/°C	
CCL driveline frequency	805 MHz	from 201.25 MHz (4x)
Technology		Harmonic multiplier
Type		Fixed
Frequency drift	± 0.5 ppm/°C	
Master timer	100.625 MHz	
Type		Fixed
Frequency accuracy	± 0.1 ppm	
Frequency drift	< ±1 ppm/°C	
Low Frequency Buncher	16.7708 MHz	from 201.25 MHz (÷12)
Technology		Divider
Type		Fixed
Frequency accuracy	± 1 ppm	
Frequency drift	± 0.5 ppm/°C	
Proton Storage Ring (PSR) Buncher	2.795 MHz or 5.590 MHz	
Technology		Direct digital synthesis from 201.25 MHz
Frequency accuracy	± 1 ppm	
Frequency drift	± 0.5 ppm/°C	

The frequency for the LEBT bunchers may be changing and this will cause changes in the circuit design and requirements. The LAMP Frequency Generation LLRF system will be developed from the current digital LLRF systems to a new digital LLRF system with the upgrades needed for LAMP. A VPX-based direct RF system will need to be developed. See above for more information on VPX.

LLRF would like to have the feed forward/frequency generation rack in the same place as it currently is, as cables that are beyond the scope of LAMP originate from this rack. This would allow the cables to remain in place and not have to be re-installed.

Protection. See in Ref. [5].

References

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