

# PREPARATORY INVESTIGATIONS FOR A LOW FREQUENCY PREBUNCHER AT REA\*

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## Abstract

The reaccelerator facility (ReA) at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) will provide a unique capability to study reactions with low-energy beams of rare isotopes. A beam from the coupled cyclotron facility is stopped in a gas stopping system, charge bred in an Electron Beam Ion Trap (EBIT), and then reaccelerated in a compact superconducting LINAC. At present the beam repetition rate at the ReA targets is the same as the LINAC RF frequency of 80.5 MHz. A lower frequency would be desirable for many types of experiments using time of flight data acquisitions. This paper reports the results of preliminary design studies of such a low frequency prebuncher designed to increase the pulse separation and minimize bunch lengths at the detector.

## INTRODUCTION

Figure 1 shows the layout of the ReA facility [1]. The 80.5 MHz frequency of the ReA RFQ and LINAC has a period of 12.4ns. This means that the time-of-flight (tof) measured at a detector is ambiguous by an integer multiple of that period. In order to reduce that ambiguity, a longer period between bunches is desired for tof experiments. Due to the low intensities of the rare isotope beams far from stability, any solution to this issue must attempt to conserve as many particles as possible. This rules out, for example, simply building a chopper to discard 4 out of 5 bunches.

## MULTIHARMONIC BUNCHING

### *Principles of Multiharmonic Bunching*

A common way to transform a macropulse into a bunched beam for acceleration is through the use of a Multiharmonic Buncher (MHB) [2]. The ReA EBIT will produce macropulses of 10 to 100 microseconds. For each RF period of the buncher, an MHB applies a decelerating potential to the leading particles and an accelerating potential to lagging particles. This causes the overall bunch to converge to a narrow time spread in the focal length of the device, at the cost of increasing the energy spread of the bunch.

The ideal waveform for the buncher voltage would be a perfect sawtooth wave with zero transition time from high to low. In practice, this waveform is approximated with its first 2-4 Fourier components. Each additional component increases the amount of time over which the waveform is

approximately linear, and thus the fraction of the beam that can be successfully bunched.

The present ReA accelerator has an 80.5 MHz MHB [3] which bunches particles at the fundamental frequency of the accelerator. In order to increase the bunch spacing to 62ns, a second buncher at the 5th subharmonic of the accelerator, 16.1 MHz is being designed. The preliminary studies have shown that for the low frequency regime, the 80 MHz buncher does not improve the capture efficiency. Therefore only one of the two bunchers would be operated at a time, based on the requirements of each experiment. Since bunchers increase bunch energy spread to decrease time spread, and this effect goes inversely with frequency, the energy acceptance of the accelerator is a critical parameter that needs to be considered for the design of the new buncher. To this effect, the energy acceptance of the ReA RFQ was measured, and the results are discussed elsewhere in these proceedings [4]. The acceptance was found to be on the order of +/- 5%, which appears to be adequate for 16.1 MHz bunching.

### *Buncher Parameters*

Once the frequency of a buncher is set, there are only two primary input and two output parameters to be optimized for the device. The input parameters are the focal length and peak voltage of the sawtooth wave, and the output parameters are the energy and time spread at the focus. The closer the buncher is placed to the focal point, the greater the bunching efficiency, but the higher the voltage required to bring the beam to a time focus in that distance [5]. Bunching efficiency is defined as the fraction of initial particles than can be brought to a time focus by the device. As focal length decreases, bunching efficiency increases linearly, but voltage increases quadratically. In practice, this means that the maximum achievable bunching voltage is the controlling parameter which sets the optimum location and maximum possible efficiency of the device. (Other physical considerations, such as available space on the beamline, can of course also play a role.) The resulting beam energy spread is directly proportional to the peak voltage.

Figure 2 shows a simulated plot of required peak voltage vs. position for a 16.1 MHz MHB. This plot was generated for a beam charge to mass ratio (Q/A) of 0.25. As the Q/A decreases, the line of optimum voltage shifts to the right, so voltages and focal lengths must be selected to accommodate the minimum anticipated Q/A, in this case 0.2. Another parameter which affects the final efficiency of the buncher is the initial energy spread of the beam. The greater the energy spread of the input beam, the worse the achievable time focus will be at the focus of the buncher. The initial

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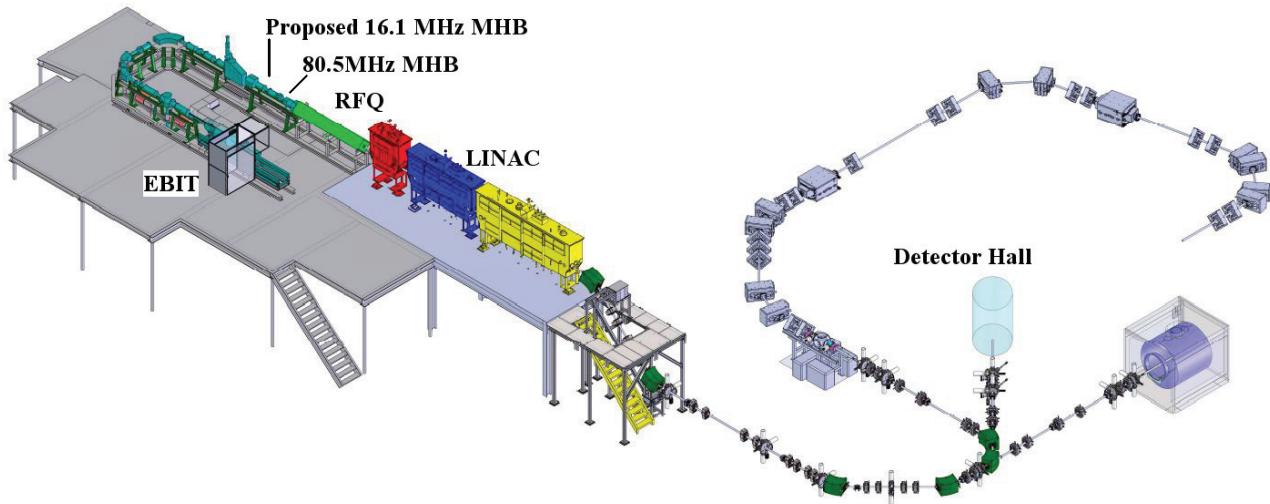


Figure 1: Layout of the NSCL ReAccelerator, including the location of the proposed 16.1 MHz MHB.

energy spread does not change the optimum focal length or voltage, only the overall efficiency. The predicted efficiency for a buncher 1.7m from the RFQ ranges from 12% for a 2% initial energy spread to 77% for a beam with no energy spread.

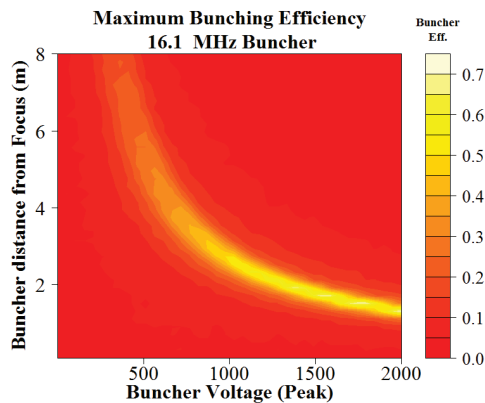


Figure 2: Bunching efficiency plotted as a function of position and peak voltage for  $Q/A$  of 0.25 and an initial energy spread of 0.2%.

## BEAM OPTICS

### Beamline Redesign

To accommodate the new buncher, the beamline prior to the RFQ will need to be reconfigured to make space for the new device. To that end, the beam optics were recalculated with three conditions: a waist at the new buncher location, a waist at the existing 80.5 MHz MHB, and appropriate matching conditions into the RFQ. The optics were fit using COSY [6], and a reasonable fit was found by moving only one quadrupole doublet. The longitudinal properties of the new optics were confirmed using TRACK [7] as shown in Fig 3.

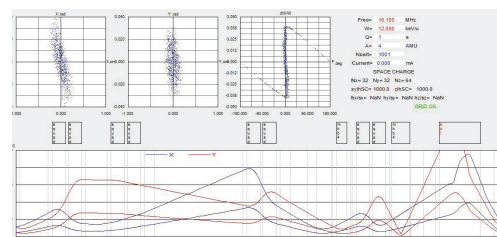


Figure 3: ReA LEBT optics fit for waists at both bunchers.

### Effects of 16.1 MHz Buncher

In order to determine the effect of the buncher on beam quality at the detectors, it is necessary to simulate the entire beamline from the ion source to the detector. Since this line includes low energy electrostatic elements, medium energy magnetic elements, accelerating cavities, and an RFQ, the optics code Dynac [8] was selected for its ability to easily include all of these elements in a single simulation run.

A large number of simulations were run at various beam energy levels and  $Q/A$  ratios to determine the minimum achievable energy spread and time spread at the experiments. A further consideration is the planned addition of one or two rebunching cavities after the LINAC at a future date.

Some results of these simulations are shown in Table 1. The minimum achievable time spread improves with higher beam energy and  $Q/A$ . The minimum energy spread also improves at higher energies, but is relatively insensitive to  $Q/A$ .

Since the 16.1 MHz buncher would be operating at the fifth subharmonic of the RFQ, simulation indicates there will be some remaining unbunched particles in the four satellite RF buckets. These satellites are estimated to contain, in total, 8% of the particles reaching the final detector. Investigations are currently ongoing to determine the best means of removing these satellite bunches by deflecting them either transversely using a beam chopper, or longitudinally using a

Table 1: Predicted minimum time and energy spread at target for beam energies from 0.3-3 MeV and 0.25-0.5 Q/A

Beam Energy [MeV/u]	0.3 MeV	3 MeV	0.3 MeV	3 MeV	
<b>Freq.[MHz]</b>	<b>dt[ns] (<math>\pm 3\sigma</math>)</b>		<b>dE/E (<math>\pm 3\sigma</math>)</b>		
16.1	yes	6.8	0.6	0.5%	0.2%
	no	12.8	1.7	0.9%	0.3%
80.5	yes	3.2	0.5	0.2%	0.06%
	no	8.3	1.3	0.4%	0.2%

cavity with a frequency at an integer ratio (i.e. 6:5) to the LINAC frequency.

## BUNCHER DESIGN

### Electrode Design

To apply a longitudinal kick to a beam requires a pair of electrodes with the conflicting requirements that the aperture be large enough to allow for beam steering but small enough to minimize the radial field gradient. They must be close enough together to minimize the longitudinal field gradient while far enough apart to avoid excessive capacitive coupling. Finally, they must be as transparent as possible to beam particles.

Various approaches have been taken to electrode geometries to achieve these goals. The original ReA MHB electrodes had wide (5cm diameter) gridded apertures [3], and have since been replaced with electrodes with narrower (1cm diameter) apertures with thin bars rather than grids. The ANL-ATLAS buncher uses electrodes with no grids and a 2cm diameter aperture [9], while the MHB constructed for FRIB uses a similar gridless design with a 1cm aperture [10].

Once an electrode design is selected, the actual voltage which must be applied to each mode can be calculated. One method is to generate a field map of the electric field for each electrode geometry to be tested. Given the beam energy gain produced by each mode of an idealized buncher, the voltage is adjusted on each mode in simulation to produce the same energy gain. The voltages can also be calculated purely analytically using the transit time factor for each electrode geometry.

### RF Design

For the present 80.5 MHz MHB at ReA, an initial design was selected using the fundamental frequency and two harmonics: 80.5, 161, and 241.5 MHz. At these frequencies, the most effective way to achieve the RF voltage on the buncher electrodes is with resonant coaxial structures. [3] For the frequencies anticipated for the new buncher (16.1, 32.2, 48.3, and possibly 64.4 MHz) the length of coaxial structures would be prohibitive, however in these frequency ranges, a tank circuit structure with lumped elements such as the one used at ATLAS (ANL) is quite satisfactory.

For efficiency and cost reasons, it would be desirable to use only one low level RF controller and amplifier. In order to prevent distortion of the higher modes, the harmonics of the lower modes must be suppressed. Bench tests have

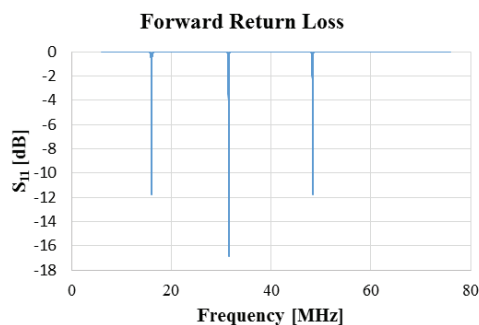


Figure 4: Simulated return loss of tank circuit.

been performed on an available LLRF controller, and it has proven capable of providing the necessary frequency isolation. The 100W amplifier used for testing also generates harmonics, measured at around -12dBc at 50W output power. The LLRF controller can also suppress the individual amplifier harmonics in open loop mode, however, closed loop mode will be necessary in operation to suppress all harmonics simultaneously. A preliminary tank circuit design has been simulated in Ansoft Designer, as shown in in Fig. 4 and used to show that the first three harmonics can be driven from one input port. A second port may be necessary if a four-harmonic design is chosen.

## CONCLUSION

Preliminary simulations indicate that a 16.1 MHz buncher is feasible for ReA at NSCL. The resulting beam would provide a 62.1 ns bunch spacing at the detectors, a minimum relative energy spread under  $\pm 5\%$  and a minimum time spread under 2 ns at the RFQ entrance. RF design for the device is nearing completion, and mechanical design is underway. The problem of cleaning the remaining particles in the satellite bunches is currently under investigation.

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