UPGRADE OF THE ATLAS POSITIVE ION INJECTOR BUNCHING SYSTEM*

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Abstract

Over the last few years, significant efforts were concentrated on improving the ATLAS Positive Ion Injector (PII) RF bunching system, consisting of a four-harmonic pre-buncher, Traveling Wave Chopper (TWC) and a single-frequency sinusoidal re-buncher. The primary goal was to improve RF field stability with a redesigned RF system and to improve buncher performance for higher current beams resulting in better bunch stability and time structure at the first PII superconducting resonator. The major parts of the system were redesigned and rebuilt, including 12–48 MHz RF power amplifiers for the harmonic pre-buncher and re-buncher, RF driver rack for the TWC, and the RF control chassis for both the pre-buncher and re-buncher. The four-harmonic resonant structure of the harmonic buncher itself was modified, too, mainly for better mechanical stability and better RF matching. These improvements will be described and the performance of the new system presented.

INTRODUCTION

The ATLAS Positive Ion Injector (PII) [1] was developed in the early 1990's to provide beams of heavy-ions up to, and including, ^{238}U for the ATLAS research program in low-energy nuclear physics. The PII consists of two major components: two ECR ion sources [2,3] providing the heavy ions needed with sufficiently high charge states for injection and acceleration in a 12-MV, 18-resonator, superconducting (SC) linear accelerator. In order to maintain the highest possible beam quality, the use of an RFQ linac was avoided. Instead the ECR ion source was placed on a high-voltage platform sufficient to provide ions whose velocity was approximately 0.01c for further acceleration in the SC linac which is based on a novel quarter-wave resonator design allowing matched ion velocities at this low value.

For such a linac system to efficiently accelerate beam from a DC output source, a two-stage, three-component bunching system was developed consisting of a multi-harmonic buncher, a beam chopper to remove the unbunched portion of the beam and a second, sine-wave, buncher capable of providing approximately 200 ps bunches to the linac. The system originally implemented placed the multi-harmonic buncher on the high-voltage platform giving a large drift distance to the time waist and requiring low bunching amplitudes. It was soon realized that at high beam currents space charge effects limited the bunching ability of this geometry and resulted in poor bunch widths into the linac. This problem was studied [4] and a new buncher geometry design was implemented over the years, including the development of a traveling-wave chopper (TWC) [5] which allowed removing the tails of a poorly formed beam bunch without significant longitudinal emittance growth.

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NEW HARMONIC BUNCHER SYSTEM

Harmonic buncher system block diagram is shown below in Fig.1. The system consists of four-harmonic lumped elements resonant structure with two parallel grids, 100 W RF power amplifier with external 24 V power supply and analog **I** & **Q** type RF feedback controller chassis.

This paper describes the new electronics implemented for the harmonic buncher and TWC with improved amplitude and phase stability and the necessary power handling capacity for operation of the TWO. Overall system performance is also described.

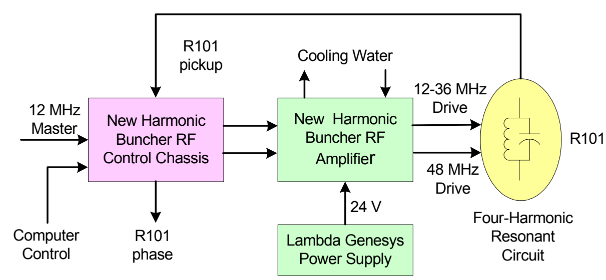

Figure 1: Four-harmonic buncher system block diagram.

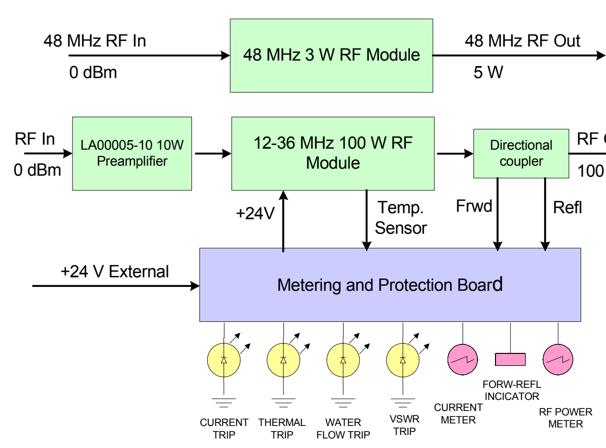

Figure 2: RF amplifier block diagram.

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The RF amplifier has two separate channels, a 12-36 MHz broadband channel and a 48 MHz single frequency channel (see Fig. 2). It has a built-in protection and metering board, which provides measurements and indication of the output RF power and forward/reflected waves, as well as a measurement of 12-36 MHz RF amplifier module supply current. The board also protects the RF module against temperature overload, supply current overload, water flow trip and VSWR trip.

The **I** & **Q** control chassis uses four independent feedback channels for 12, 24, 36 and 48 MHz harmonics, as shown in Fig. 3. Each frequency channel is built with

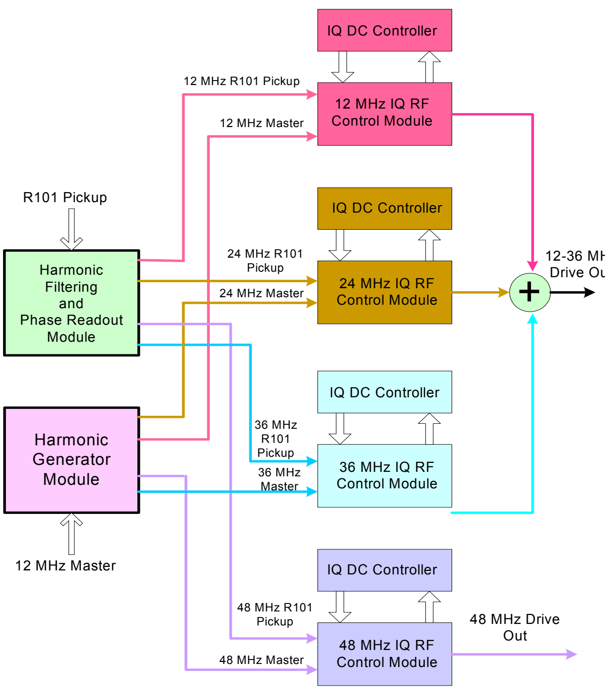


Figure 3: **I** & **Q** RF controller block diagram.

two modules (boards), an **I** & **Q** RF control module and an **I** & **Q** dc feedback controller. The RF control module performs sine-cosine demodulation of the RF feedback signal and sine-cosine modulation of the RF power amplifier drive signal (see Fig. 4). Analog phase shifters

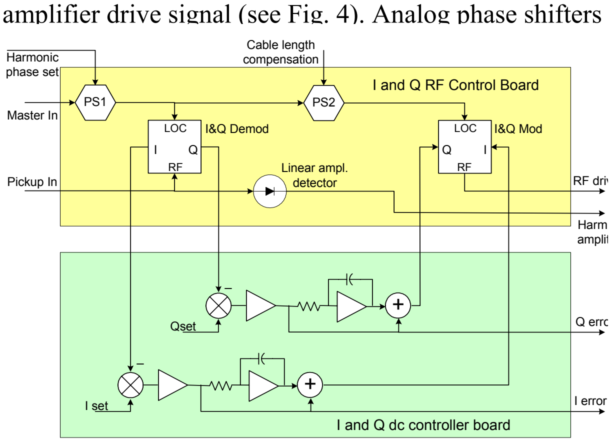


Figure 4: Simplified block diagram of the single frequency control channel.

PS1 and PS2 on the RF control board allow setting an individual harmonic phase. The amplitude and phase of each frequency is adjusted to approximate a sawtooth voltage waveform, as described by the equation below, and provide cable length compensation.

Each RF control board also has a linear RF amplitude detector, which is used to display harmonic amplitude on a front panel indicator. The DC **I** & **Q** controller board does the proportional-integral regulation of **I** & **Q** error signals, handles interlocks, and some auxiliary functions.

$$y(t)=\sin(\omega t)+0.4\sin(2\omega t+\phi_2)+0.18\sin(3\omega t+\phi_3)+0.06\sin(4\omega t+\phi_4)$$

TRAVELING WAVE CHOPPER

The TWC system block diagram is shown below in Fig. 5. The system includes a stripline type electrode assembly, RF driver, RF load and power supplies which must operate at 12 MHz in CW mode with a maximum voltage.

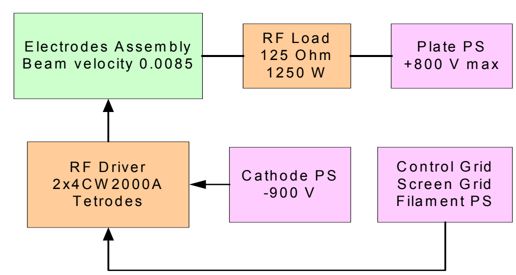
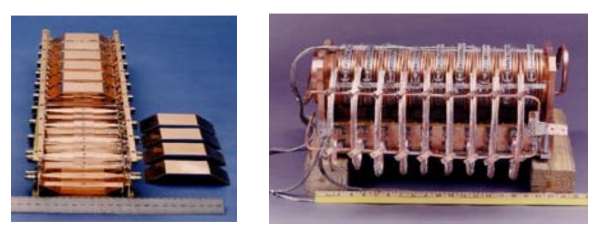


Figure 5: TWC system block diagram.

The stripline structure contains ten 1.5 cm wide, 4.5 cm spacing and a vertical gap of 3.9 cm deflection sections and nine 17.14 ns each delay lines (see Fig. 6a,b).



a b

Figure 6: a-stripline deflection section, b-delay lines.

Both stripline sections and delay lines have 125Ω characteristic impedance, as does the RF load. The higher value of characteristic impedance allows lower of RF power dissipation into the RF load and reduced current requirements for the RF driver. The complete deflection assembly is placed in a 0.5 m diameter vacuum enclosure.

Chopping is accomplished by biasing the stripline deflectors to voltage. A zero deflection voltage pulse (or zero deflection time window) of ~30 ns is propagated in synchronism with ion bunch down the deflector array to transmit desired bunch. Only ions with velocities of 0.0085c will be efficiently transmitted.

The deflection structure is driven by an RF driver, consisting of two 4CW2000A tetrodes connected in parallel and control grid FET push-pull driver. A simplified driver diagram is presented in Fig. 7 (only one tetrode is shown). Each FET driver board is triggered by

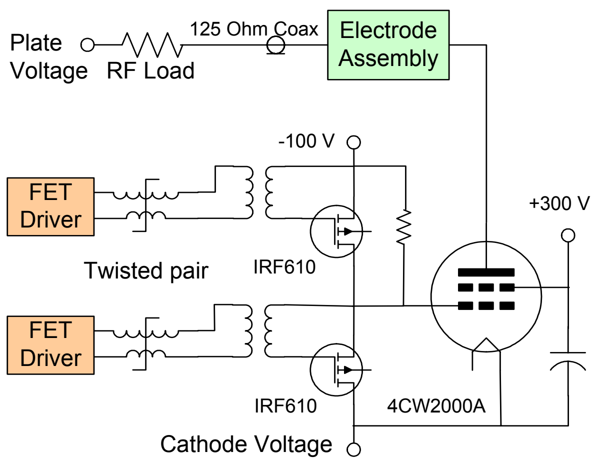
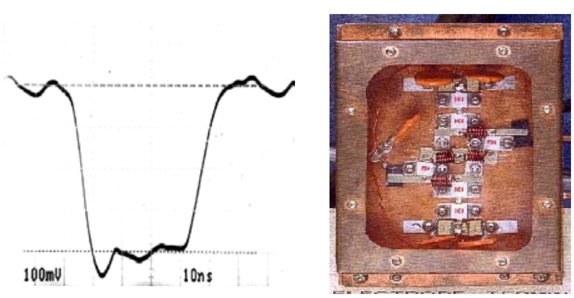


Figure 7: Simplified diagram of the RF driver. FET driver boards are DEI FPS-3N series fast power switch.

its own 12.125 MHz pulse train; changing the delay between pulse trains allowing adjustment of the output pulse width. Fig. 8a shows an example of 400 V 30 ns wide output pulse.

Because a high power RF load with characteristic impedance of 125 Ohm was not available commercially, we designed our own 350 MHz bandwidth 1250 W RF load, which is shown in Fig. 8b. The load is built of



a b

Figure 8: a-experimental waveform of 400 V 30 ns wide output pulse; b- 1250 W 125 Ohm RF load.

two parallel branches of 250 Ohm resistors which in turn consist of three 100, 100 and 50 Ohm high power KDI resistors connected in series. To compensate for the resistor capacitance, a series inductances were added.

REBUNCHER

A second 24.25 MHz sine-wave spiral rebuncher [6] located ~1.5 m from the first accelerating structure allows achieving of 200-300 ps bunch width. Rebuncher RF system is simply a 15 W 24 MHz power amplifier and RF feedback controller, the block diagram of which is shown in Fig. 9.

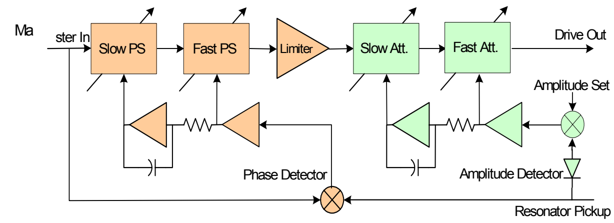


Figure 9: Simplified block diagram of 24.25 MHz rebuncher.

The controller is a ‘traditional’ type controller with separate amplitude and phase feedback loops. The specific feature of both phase and amplitude feedback loops is that that they have proportional-integral feedback regulation with separate controlling devices for proportional and integral parts of the feedback loop. In Fig.9, they are designated as ‘slow’ and ‘fast’ phase shifters and attenuators. This solution allows greatly increase system dynamic range and provides wide frequency range of feedback regulation, which in fact is limited by the spiral resonator bandwidth of 11-12 kHz.

CONCLUSION

The bunching system described above is now in routine operation. Improved phase and amplitude stability has been observed and significantly improved longitudinal emittance using the TWC has been measured [5] compared to sine-wave chopping. High current operation with the new bunching system has been demonstrated when over 20 eμA (1.33 pμA) of $^{84}Kr^{15+}$ through the PII with excellent beam quality.

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