II. OPERATION AND DEVELOPMENT OF ATLAS

OVERVIEW

Highlights of the operation of the Argonne Tandem Linear Accelerator System (ATLAS), a DOE national user facility, and related accelerator physics R&D projects are described in this chapter. ATLAS is funded to provide heavy-ion beams for basic research in nuclear physics but also serves other areas of research and development, including material science. In addition ATLAS has a rich program in developing the tools of accelerator mass spectroscopy (AMS) applied to wide ranging research programs such as oceanography, nuclear physics, astrophysics and geology. Over half of the beam time is allocated to experiments for which the spokesperson is an outside user. Recent ATLAS operating performance and related development projects are described in the next section. ATLAS personnel are also involved in developing technology in support of a future advanced facility, based on ATLAS technologies, for beams of short-lived nuclei. Projects related to the Rare Isotope Accelerator (RIA) Facility are described in the third section below.

For the first half of Fiscal Year 2004, ATLAS operated at maximum efficiency: running 7-days per week, 24-hours a day. But in May 2004 ATLAS was required to returned to 5.3 day operation with some limited 7-day operation in the summer. This schedule was initially precipitated by operator resignations, and the need to train new operators, but has now been continued to the present and immediate future due to significant budget constraints. For Fiscal Year 2004 ATLAS provided 28 beams of different isotopes to users. A total of 5559 hours of beam time was provided for the research program; that total rises to 6202 hours when setup time is included.

Since Fiscal Year 1995, ATLAS has made beams of short-lived rare isotopes (RIBs) available for nuclear physics research. A total of 15 different radioactive beams have been developed to date and are generally available for use. Further development of RIBs is planned as required by the nuclear physics and nuclear astrophysics programs at ATLAS. During Fiscal Year 2004, beams of ^{6}He, ^{8}Li, ^{16}N, and ^{21}Na were provided. Construction of a new cryostat and resonators for a major energy upgrade of the facility, that will increase the overall voltage of ATLAS by 25%, continues. First "offline" tests, with two prototype resonators, are expected by the end of the 2005 calendar year. The final six resonators are now under construction. This project is made possible by AIP funds provided in Fiscal Year 2001 – 2005.

A new Cf-fission source project that will allow ATLAS to provide unique neutron-rich radioactive beams for research has been proposed and is undergoing review by DOE. A three-year funding profile is proposed. The detailed proposal was submitted to DOE in February 2005.

Gammasphere has operated on its own dedicated beamline since late May 2004. This has allowed the FMA to undertake experiments requiring higher beam currents and more intense radiation fields than would have been possible with Gammasphere surrounding the FMA target.

Table II-1. Summary of ATLAS experiments and user statistics.

	FY2004 (actual)	FY2005 (actual)	FY2006 (pred.)	FY2007 (pred.)
Beam Use for Research (hr)				
Nuclear Physics	5402	4570	3610	4550
Accelerator R & D (RIA & ATLAS)	47	92	70	100
Accelerator Mass Spectroscopy	110	0	150	150
Other	0	24	50	100
Total	5559	4686	3880	4900
Number of Experiments Receiving Beam	47	43	40	48
Number of Scientists Participating in Research	169	187	170	200
Institutions Represented				
Universities (U.S.A.)	20	25	25	26
DOE National Laboratories	3	4	5	5
Other	25	18	25	27
Usage of Beam Time (%)				
In-House Staff	43	45	45	35
Universities (U.S.A.)	36	35	35	35
Other DOE National Laboratories	3	5	5	15
Other Institutions	18	15	15	15
Total	100	100	100	100

A. OPERATION OF THE ACCELERATOR

a.1. Operations Summary (R. C. Pardo, D. Barnett, J. Bogaty, L. Carlquist, A. Deriy, G. Devane, G. Gribbon, R. Jenkins, A. Krupa, E. Lindert, A. McCormick, S. McDonald, F. H. Munson, Jr., D. R. Phillips, M. Power, D. Quock, A. Ruthenberg, R. H. Scott, S. Sharamentov, J. R. Specht, P. Strickhorn, R. C. Vondrasek, L. Weber, and G. P. Zinkann)

ATLAS provided a total of 28 different isotopes for research in Fiscal Year 2004. The distribution of species is shown in Fig. II-1. The calcium isotopes were, again, the most popular beams for Fiscal Year 2004 and only 13% of all beam time was for isotopes heavier than the nickel isotopes.

The replacement of the corona voltage distribution system with a resistor voltage-divider system in the tandem injector was undertaken last year. The first experiments with the rebuilt accelerator were conducted this year and the tandem performed very well. Conditioning to 8.8 MV terminal voltage went well and experiments were run with terminal voltages as high as 8.3 MV. The tandem was used for a variety of experiments this year, providing beams for approximately 27% of the total beam time. The new tandem terminal communication process installed last year was improved with the addition of software that provides a history of tandem terminal stripping foil usage. The operator can now enter the type of foil and “time stamp” the time of insertion into the beam path. The hours of usage can then be tracked for each foil.

In addition to the tandem repair, improvements at the tandem ion source system were also undertaken. As part of those studies, the transmission from the source to the tandem was improved significantly. Approximately a factor of two improvement in transmission was realized by realignment and by the removal of a HV vertical steering element that was found to be causing significant degradation to the beam emittance. This improvement is most important for the long-lived radioactive beam program and for tandem-based AMS experiments.

The switching magnet that delivers beam to the FMA or stand-alone Gammasphere beamlines was replaced this year with a magnet able to bend beams of much higher rigidity. This was required because of the improved performance of the ECR sources for the heaviest beams eliminating the need to strip the beam at an intermediate point to achieve Coulomb-barrier energies. By eliminating this stripping, approximately a factor of 5 higher beam intensities are available but the increased beam rigidity requires a more robust magnet. The magnet installed was obtained from the decommissioned nuclear structure laboratory at the University of Rochester. Extensive modification to the support structure and vacuum chamber was required for use at ATLAS.

The program to high-pressure water rinse resonators in ATLAS in order to restore their performance continued this year with four resonators in the first Booster linac cryostat rinsed. The technique continues to show significant gains in resonator performance, but the cryostat design which employs a common vacuum for the beam and resonator interior with the thermal isolation vacuum means that fields deteriorate over time as dirt re-deposits on resonator surfaces. Even so, the technique has produced significant gains in field performance.

ATLAS has for many years relied on a time-of-flight (TOF) resonant pick-up system that continuously monitors the beam energy delivered to experiments. A new software application has been developed that runs continuously, logging the TOF (Time Of Fight) energy measurement data into a permanent file identified by date, beam type and accelerator parameters sufficient for unique identification. Energy measurements are made every 30 seconds and the results are archived in these permanent files. This application is capable of storing trend type data files where the file name consists of the ion source and injector being used, the atomic number and mass, and the date the file was created, thereby associating a trend file with an experiment. These files can be made available to the user, upon their request. After selecting the archived trend file, the user can view the plotted data "online" using a Vsystem utility, or export the data to a non-Vsystem utility such as MS Excel.

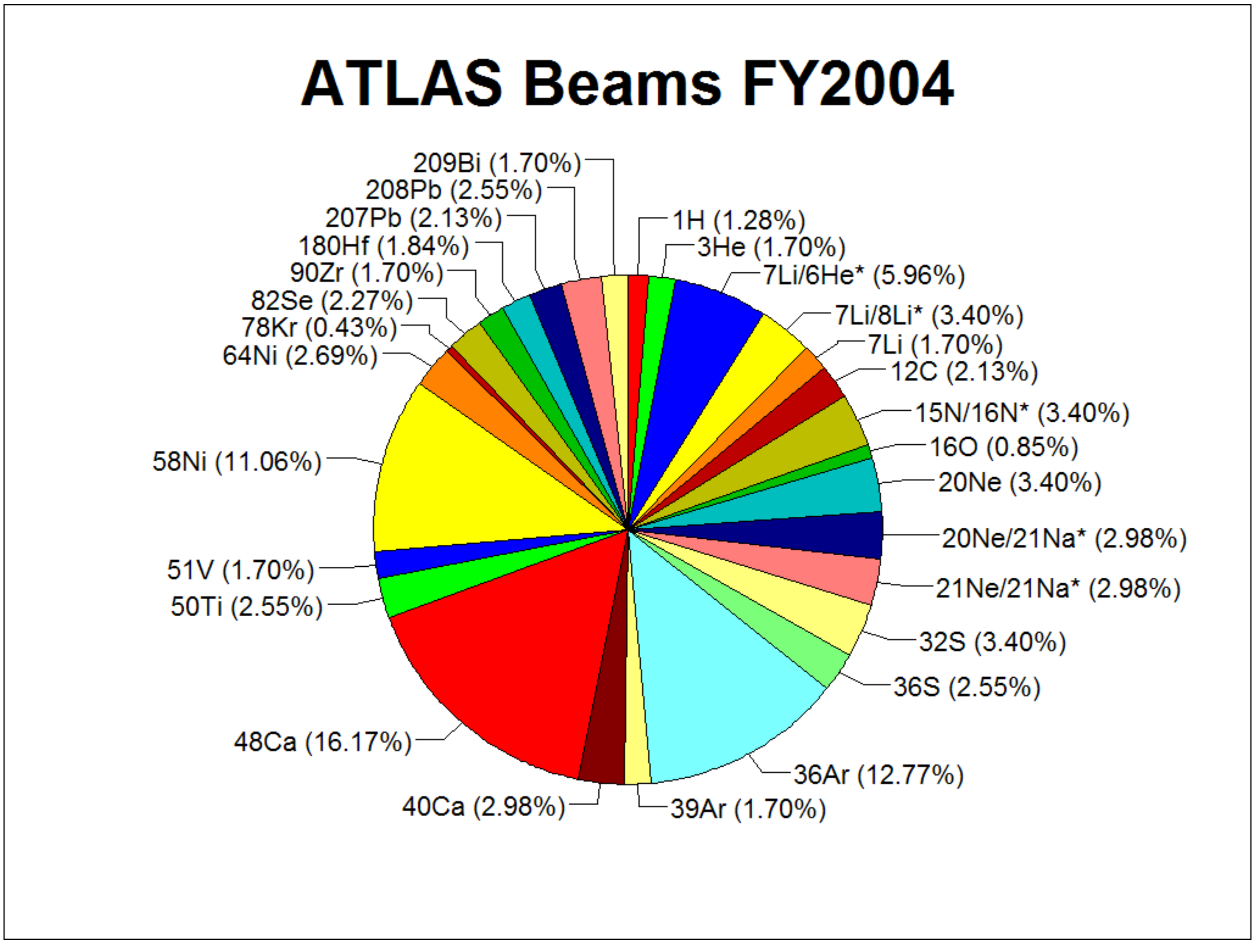

Fig. II-1. Distribution of beam time by isotope provided by ATLAS in Fiscal Year 2004. A total of 28 different isotopes were provided to the research program. Radioactive beams (indicated by an asterisk) comprised 18.7% (1040 hours) of all beam time in Fiscal Year 2004.

B. DEVELOPMENTS RELATED TO ATLAS

b.1. Status of the ECR Ion Sources (R. C. Vondrasek and R. H. Scott)

b.1.1. Hexapole and Plasma Chamber Re-Design

The ECR2 hexapole design was modified in 2003 resulting in significantly improved source performance. However, the cooling of the permanent magnet hexapole continued to be an issue with damage occurring to three of the hexapole bars. A new hexapole chamber design was adopted which directs the cooling water along the hexapole pole tips, where the majority of the heat from the plasma is deposited, rather than along the sides of the magnets as in the previous design. This change also allowed an increase in the number of radial ports (from three to six) available for solid material introduction and improved pumping to the central region of the plasma chamber (Fig. II-2).

The magnet bars which showed damage due to excessive heating were repaired and then encased in stainless steel cans to prevent corrosion of the permanent magnet material. The cans were fabricated on site and then laser welded once the magnet bars were in place. The source is presently being reassembled and operations will resume in early 2005.

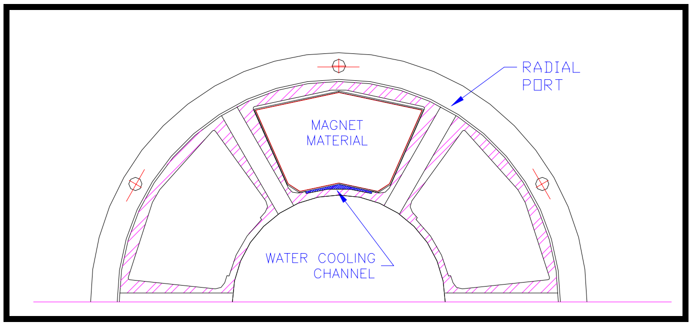

Fig. II-2. ECR2 hexapole showing half of the hexapole and the aluminum plasma chamber. The pole tip cooling channel is highlighted and one of the six radial ports is indicated.

b.1.2. Special Helium Source for AMS

Accelerator Mass Spectroscopy (AMS) continues to be an active area for ECR development. The techniques used to measure ^{3}He concentrations in ultra-pure ^{4}He samples have been refined. The performance of the mini-quartz source used for these studies was improved by a modification to the internal waveguide configuration. Instead of broadcasting the RF into the full plasma chamber and allowing the waves to propagate to the quartz source, the waveguide was extended within the source chamber and the launching point was established next to the quartz. This has greatly simplified source operation and has improved the source performance.

b.1.3. Plasma Potential Measurements and Ion Lifetime

In collaboration with the University of Jyväskylä ECR group, a device was constructed to measure the source plasma potential. The device was installed on ECR2 and a series of measurements were performed in both single and two-frequency heating modes. In addition the production times of various charge states of lead were monitored using a fast pulsed sputter sample.

The injection microwave power using two frequencies creates two concentric ECR surfaces for electron heating which leads to an increased electron density and population thereby extending the ion confinement time.

The ECR surfaces must be closed to produce stable electron heating, and the choice of a large frequency separation creates discrete ECR surfaces (i.e. - 11 and 14 GHz). An electrostatic potential structure is established via the confinement and loss mechanisms of the electrons and ions within the plasma. The structure consists of a central plasma potential (~4-10 V) with a central dip of a smaller magnitude which serves to confine the ions (Fig. II-3.).

Observed increases in the beam intensities and decreases in the production times of lead charge states indicate that the electron density and population are increasing when two frequency heating is used. The peak of the charge state distribution (CSD) also shifts higher when in two frequency mode indicating a longer confinement time within the plasma. However, measurements with O^{7+} showed that while the beam intensity increased (31 eμA to 68 eμA) with two frequency heating, the plasma potential remained constant at 4.6 V. Additional tests which involved altering the magnitude of the gap between the two frequencies showed that while a larger gap favored higher charge state production and decreased the production times, the overall beam output decreased. This would indicate a decrease in the electron population, while at the same time the electron density and the confinement time are increasing in order to produce the higher charge states.

To provide a consistent model for these opposing observations, a multiple potential structure for two-frequency heating has been proposed (Fig. II-3). A "core plasma" defined by the inner resonance is created by the superposition of the two electrostatic potential structures. The core plasma maintains a higher density than the surrounding plasma and is responsible for the production of the highly charged ions by deepening the electrostatic potential well. The outer resonance supplies "warm" electrons and ions to the inner resonance.

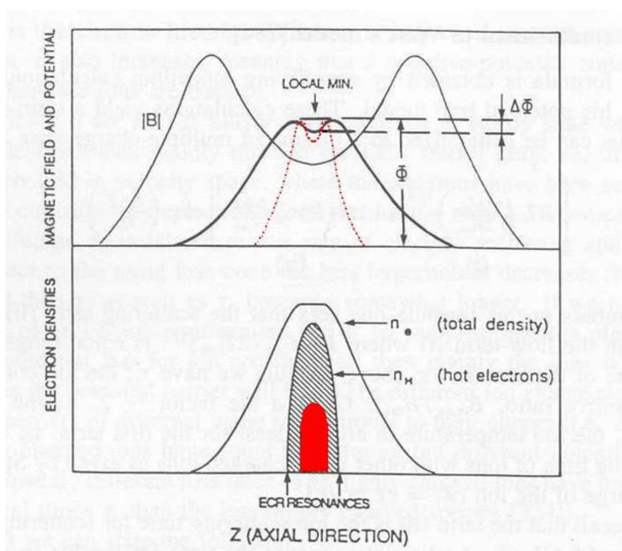

Fig. II-3. The proposed plasma potential structure for two frequency heating. The main plasma potential (~4-10 V) regulates the electron loss term while the inner potential dip regulates the ion loss term. The potential structure of the second resonance, in red in the upper frame, is within the primary potential structure and has a higher electron density, denoted in red in the lower frame.

b.1.4. Other ECR Source Improvements

Several small but significant improvements in equipment were made on the sources. The 14 GHz transmitter which was purchased in 2003 was installed on ECR1. This enables ECR1 to operate in two-frequency mode and provides more of an overlap between ECR1 and ECR2 in beam production capabilities. New high frequency switching power supplies were installed on one coil of ECR1. This allows for higher magnetic field levels and hence improved source performance. And the oil pumps on ECR1 were eliminated and replaced with dry pumps. This has eliminated a major source of carbon contamination and has improved source performance.

b.2. ECR Source High-Voltage Monitoring and Control (J. M. Bogaty)

ATLAS ion sources ECR-I and ECR-II now have precision monitoring of platform and extractor voltage levels. New, carefully characterized, high voltage divider stacks were installed at both ion sources. Voltage coefficients of the divider stack resistors were measured from which first order correction equations were determined. Resistor voltage coefficients contribute most of the error when accurate measurements are desired over a large range of voltages. Temperature effects can contribute significant errors but this is being controlled through design considerations. Each ECR has a correction equation that allows mutual calibration with the other ECR's platform voltage as well as restoration of past operating voltages to high precision. One ECR can be shutdown and the other ECR's platform voltage set for the same value. Computerized correction will insure that the transfer error will be within 40 ppm.

b.3. An Improved Pneumatic Frequency Control for Superconducting Cavities (G. P. Zinkann and S. Sharamentov)

The ATLAS (Argonne Tandem Linear Accelerator System) superconducting cavities use a pneumatic system to maintain the average cavity eigenfrequency at the master oscillator frequency. The present pneumatic slow tuner control has a limitation in the tuning slew rates. In some cases, the frequency slew rate is as low as 30 Hz/sec. The total tuning range for ATLAS cavities varies from 60 kHz to as high as 450 kHz depending on the cavity type. With the present system, if a cavity is at the extreme end of its tuning range, it may take an unacceptable length of time to reach the master oscillator frequency. We have designed a new slow tuner control system that increases the frequency slew rates by a factor of three hundred in the most extreme case. This improved system is directly applicable for use on the RIA (Rare Isotope Accelerator) cavities (see Fig. II-4 for plots of the old and new slew rates).

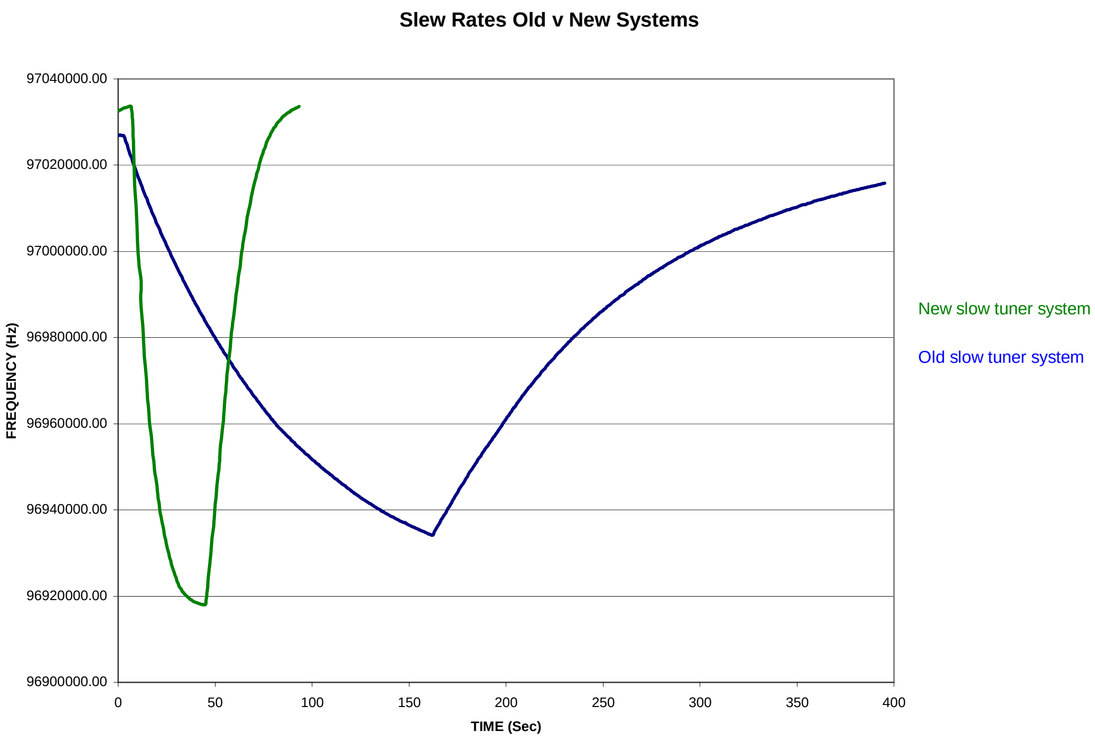

Fig. II-4. A comparison of the slew rates between the old resonator slow tuner system and the new system.

b.4. New Harmonic Buncher RF Control System (S. I. Sharamentov)

The block diagram of the PII harmonic buncher RF control system is shown in Fig. II-5 and the photograph of the electronic rack is shown in Fig. II-6. The system includes a four-harmonic resonant structure, two-channel RF power amplifier, RF amplifier power supply, new harmonic buncher RF control chassis and the original phase shifter, located in the master oscillator rack. Power supply, RF amplifier and RF control chassis are mounted in the RR214 rack close to the four-harmonic resonant structure.

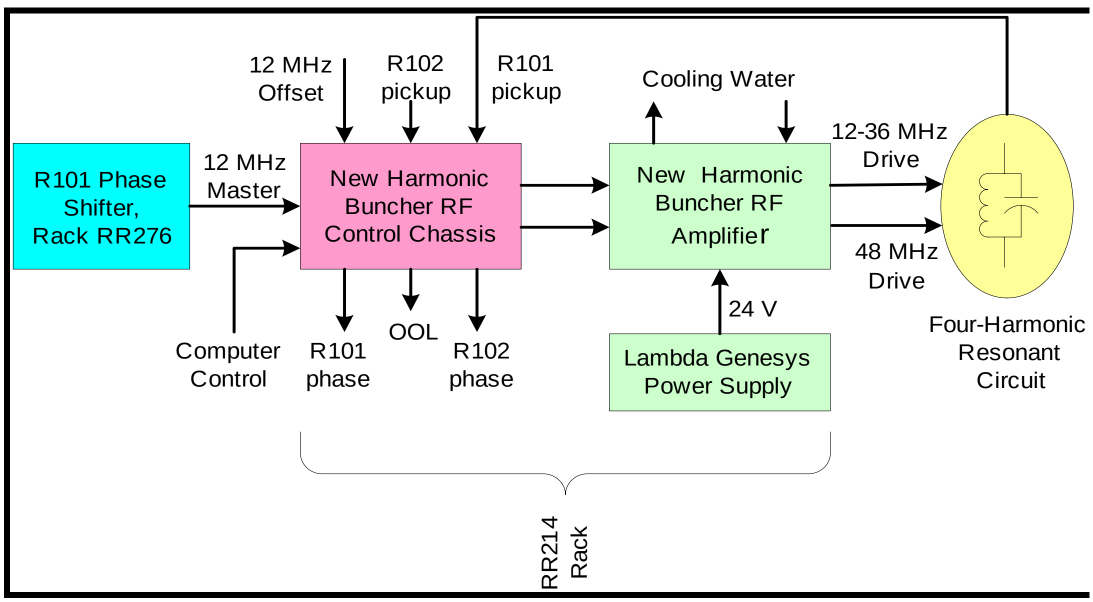

Fig. II-5. R101 Harmonic Buncher RF Control System Block Diagram.

Fig. II-6. RR214 rack view showing the harmonic buncher control chassis and associated power supplies.

b.4.1. RF Power Amplifier

The two-channel RF power amplifier block diagram is shown in Fig. II-7 and the photograph of the front and rear panels is shown in Fig. II-8. In addition to adding a 48-MHz channel, the amplifier has a feature which is new for the ATLAS RF amplifiers. It is a built-in protection and metering board, which provides measurement and indication of the output RF power for forward/and reflected waves, as well as 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. All the trips can be reset by the reset button on the amplifier front panel.

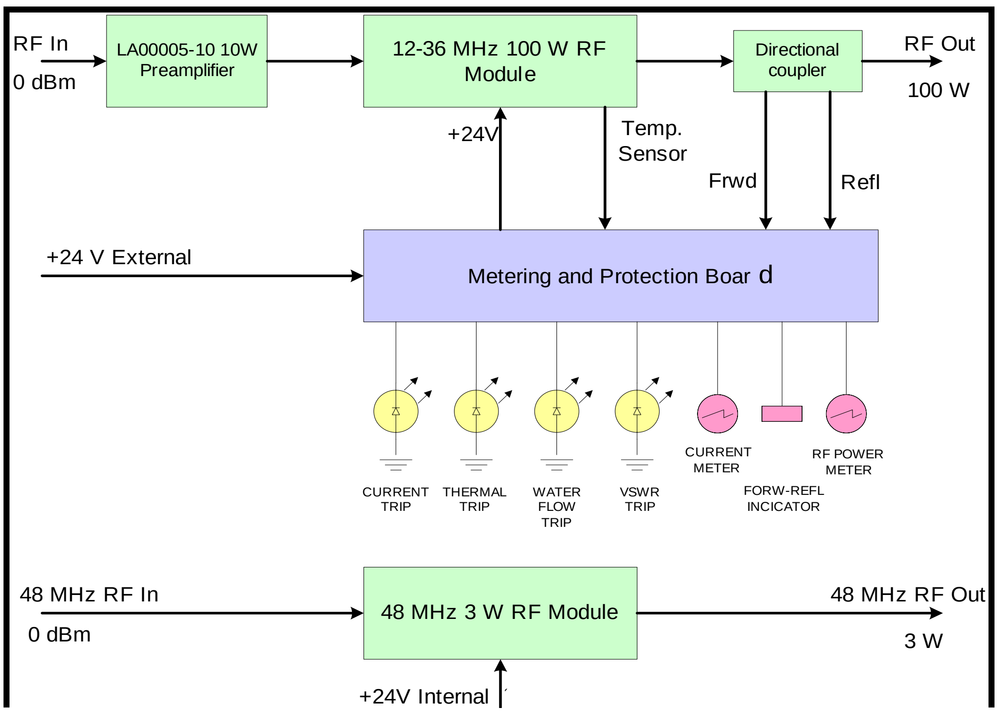

Fig. II-7. Two-channel RF power amplifier block diagram.

Fig. II-8. Front panel and rear panel amplifier view.

b.4.2. Harmonic Buncher RF Control Chassis

The new harmonic buncher RF control chassis is a four-channel **I** and **Q** type RF feedback controller. Each channel controls a single harmonic of a composite four-harmonic RF field in the buncher grid space, at the fundamental frequency of 12.125 MHz.

RF feedback control systems of **I** and **Q** type are becoming more and more popular these days. Unlike conventional systems which represent an RF vector in a polar system of coordinate, i.e. with phase and amplitude, **I** and **Q** system does that in rectangular system of coordinate, i.e. by **I**n-phase (or sine) and **Q**uadrature (or cosine) components.

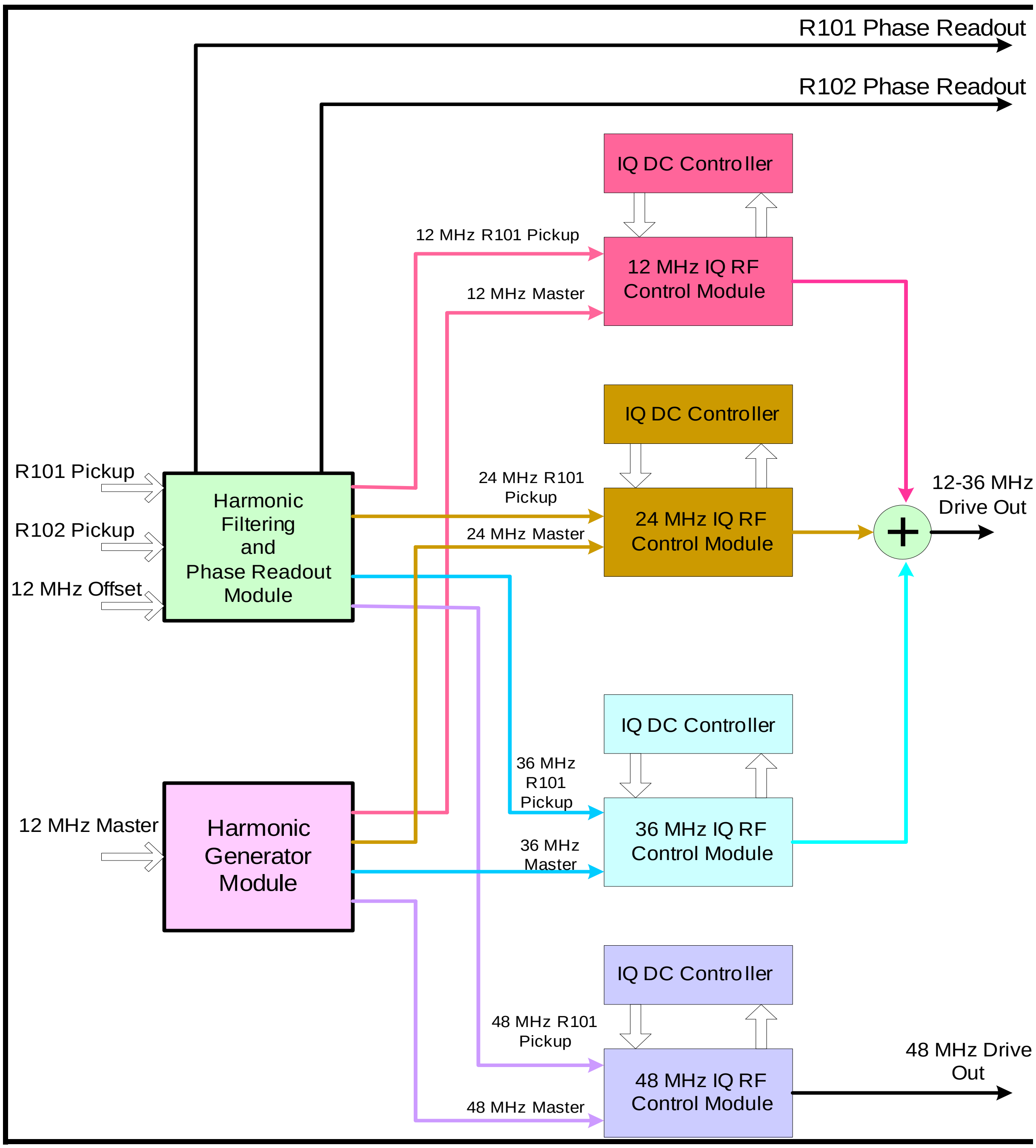

Fig. II-9. Block diagram of the new harmonic buncher RF control chassis.

A block diagram of the **I** and **Q** chassis is shown in Fig. II-9. A harmonic filtering and phase readout module filters and splits buncher composite pickup signal into four 12, 24, 36 and 48 MHz single frequency channels. It also provides phase readout outputs for the R101 harmonic buncher and R102 traveling wave chopper. The harmonic generator module uses the 12.125 MHz master oscillator signal for generation of the 24, 36 and 48 MHz master signals.

Each frequency channel is built with two modules (boards): a **I** and **Q** RF control module and a **I** and **Q** dc feedback controller. Each **I** and **Q** RF control module performs sine-cosine demodulation of the RF feedback signal and sine-cosine modulation of the RF power amplifier drive signal, as shown in Fig. II-10.

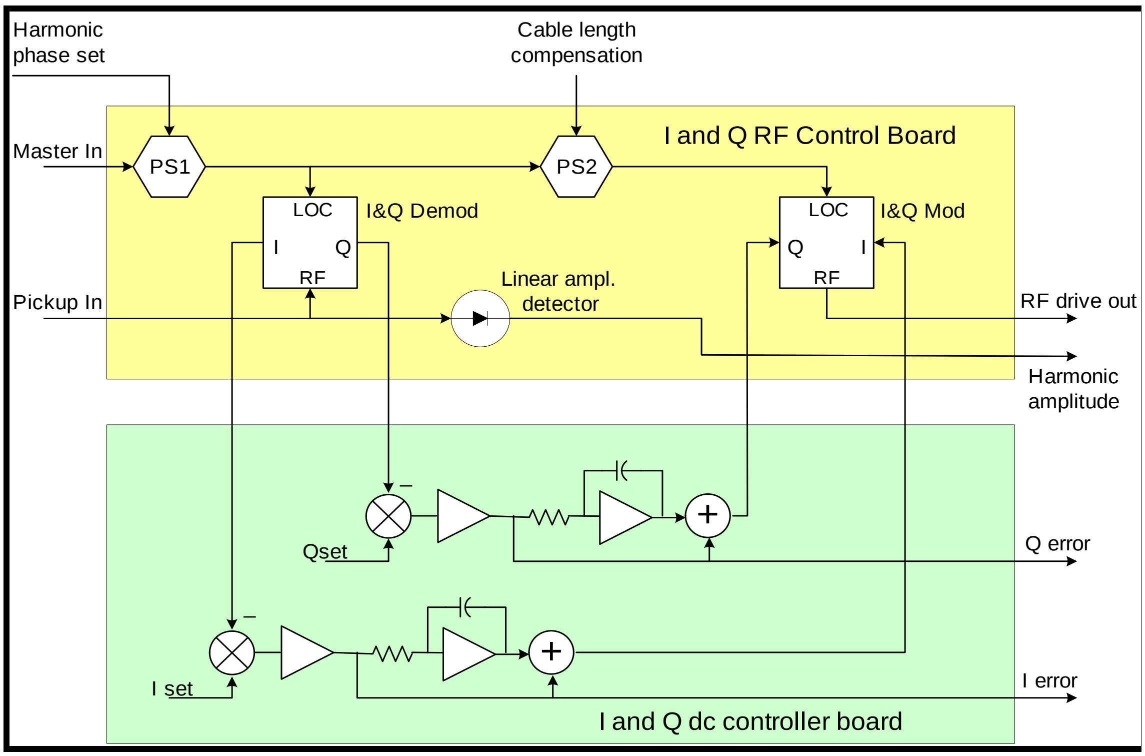

Fig. II-10. Simplified block diagram of the single frequency control channel.

Analog phase shifters, PS1 and PS2, on the RF control board allow setting of individual harmonic phase 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. A DC **I** and **Q** controller board does the proportional-integral regulation of the **I** and **Q** error signals and performs interlocking and some auxiliary functions.

The harmonics phase and amplitude control diagram is shown in Fig. II-11 and photographs of the electronic racks are shown in Figs. II-12 and II-13. Unlike the old control system, the new system can be fully operated in local mode, i.e. master amplitude and each harmonic phase and amplitude can be manually set by means of the front panel controls. Moreover, the local mode of harmonics phase and amplitude control (except for the master amplitude set) is considered as a primary and main control mode.

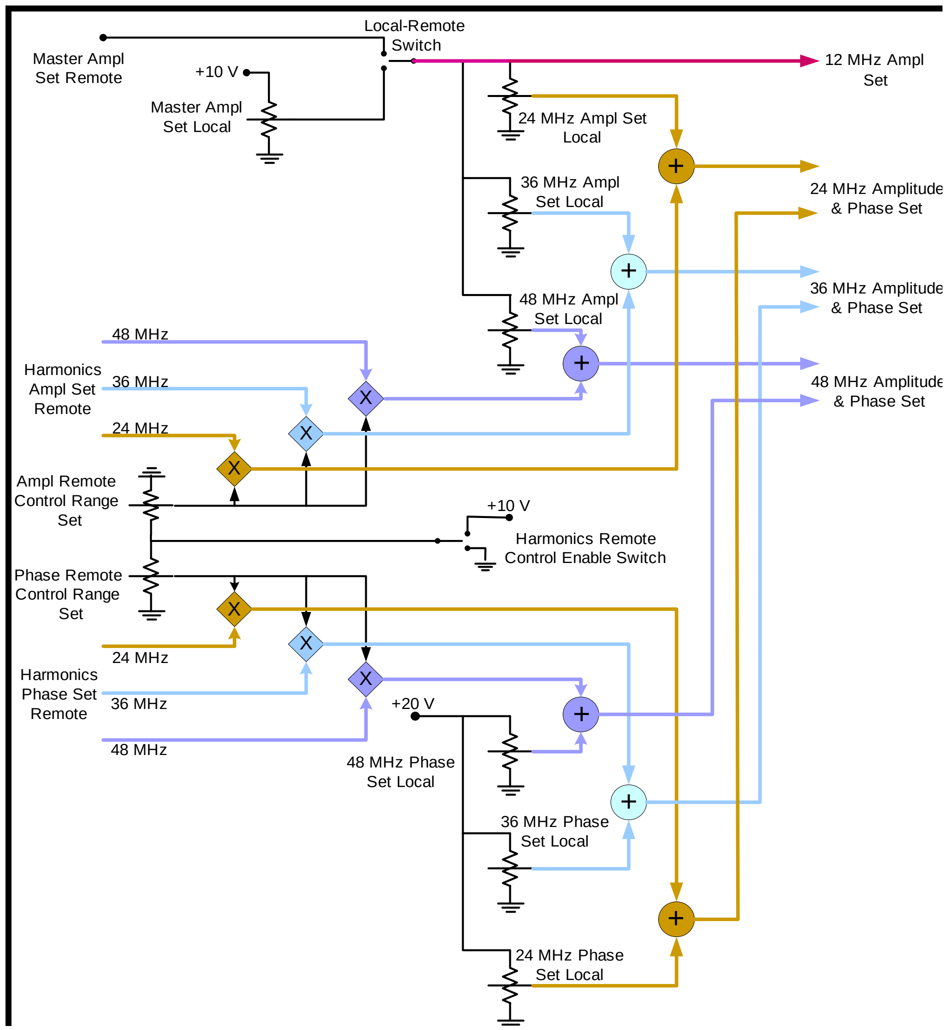

Fig. II-11. Local and Remote harmonics control diagram.

It means that the relationships between each harmonic phase and amplitude required to achieve an optimal saw-tooth waveform in four-harmonic representation (see Fig. II-14), is set locally by using the chassis front panel trim potentiometers. It is assumed that for the future routine buncher operation, normally there is no need to change these relationships.

But, if in some cases the necessity to control each harmonic amplitude and phase remotely would arise, it can be done by means of the Harmonic Remote Enable Switch (see control diagram in Fig. II-11). The range (or relative value) of the remote phase and amplitude control can be locally set with the trim potentiometers inside the chassis. It is done by multiplying each frequency remote control voltage to a constant voltage, the value of which can be set by the trim potentiometer, separately for the harmonic's amplitude and phase.

Fig. II-12. Front and rear panel of the harmonic buncher RF control chassis.

Fig. II-13. Detailed view of the individual harmonic and master amplitude controls.

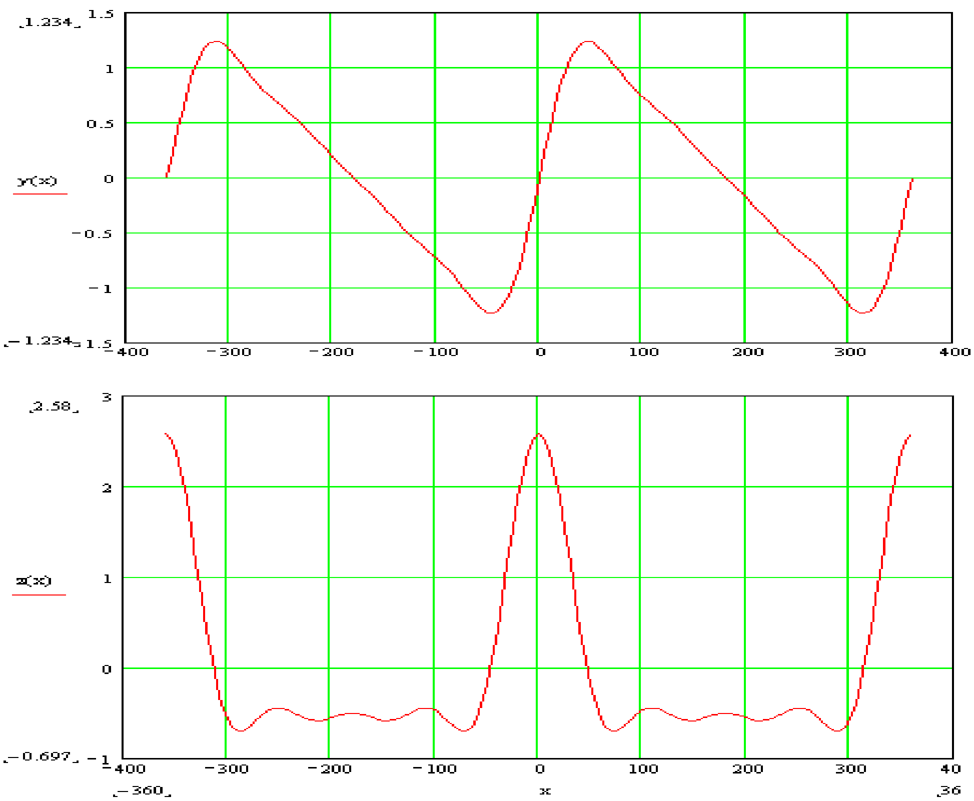

Fig. II-14. Y(x) is a four-harmonic saw-tooth waveform representation, z(x) is a waveform of the buncher pickup signal – the first derivative of the waveform.

b.5. ATLAS Control System (F. H. Munson, M. Power, D. Quock, and R. Carrier)

The ATLAS control system comprises three database management systems. Two of these systems are of a relational database design, and are used more for process initialization and data archiving. The third database is a real-time database providing a user interface for controlling accelerator associated devices, and providing moment to moment device monitoring. This real-time database system is a commercial product called Vsystem. When Vsystem was first installed as part of the control system it was only available for use on the OpenVMS operating system. More recently, this product has been made available on MS Windows, Linux, Unix, and other operating systems. It has been decided to reduce the control system's reliance on the OpenVMS operating system. Therefore, having already acquired the necessary licenses to run Vsystem on Linux, most recently licenses have been acquired to run Vsystem on MS Windows. Vsystem now runs on OpenVMS, Linux, and MS Windows platforms at ATLAS.

There has been a growing interest at ATLAS in another commercial product called LabVIEW. This product provides non-software engineers tools to develop control and data acquisition systems. Two licenses and the distribution media for this product were acquired, and the software was successfully installed on two control-system-associated PCs for initial develop-ment.

Using the software described previously, prototype software was developed that provides an interface between LabVIEW applications and the ATLAS main control system running Vsystem. This was accomplished by developing a LabVIEW application on a PC running MS Windows that also had Vsystem software installed. The LabVIEW application was able to control and monitor CAMAC (Computer Automated Measurement

And Control) connected devices that are part of the main control system via a Vsystem network connection. Two visiting researchers used this prototype software to further demonstrate the LabVIEW – Vsystem connection by successfully developing two software applications that were related to ion source projects.

The two network domains maintained by the ATLAS control system group consist of two PDCs (Primary Domain Controllers) and two BDCs (Backup Domain Controllers). The operating system software for these systems has been upgraded from MS Win 2000 Server to the latest version of this operating system, MS Win Server 2003.

Other projects include a new software application that runs continuously, and for trending purposes, logs TOF (Time Of Fight) energy measurement data. This application is capable of storing trend type data files where the file name consists of the ion source and injector being used, the atomic number and mass, and the date the file was created, thereby associating a trend file with an experiment. If any of the previously named parameters are changed, a new experiment is assumed, the current file is closed, and a new file is opened. After selecting the archived trend file, the user can view the plotted data "online" using a Vsystem utility, or export the data to a non-Vsystem utility such as MS Excel.

Another new software application that has been added provides the operator with the ability to log "online" a history of Tandem terminal foil usage. Options provided by this new application allow the operator to “time stamp” the installation date of all of the foils, and log the time when a foil is placed into service (inserted into the beam path). Additional information that is logged when a foil is time stamped is the atomic number of the beam in use and the number of hours used.

b.6. ATLAS Cryogenic System (S. W. MacDonald and R. C. Jenkins)

b.6.1. Valve Automation Project

The current means of adjusting the manual cryogenic valves located in the various ATLAS radiation areas requires the experiment to be stopped. Automation of these valves would be desirable; however the traditional means would require a redesign of the valves along with a lengthy cryogenic system shutdown. To avoid these complications, a retrofit actuator and single controller were designed, built and successfully tested on the helium supply valve to PII. A 6 valve controller was subsequently designed and built and enough parts were procured to automate 6 strategic valves in the Booster and ATLAS areas (see Fig. II-15).

With the exception of the resonator thermometry, the cryogenic display system was successfully separated from the CAMAC serial highway. This separation will provide the ability to monitor critical cryogenic parameters during the accelerator control system software maintenance and emergencies.

The cryogenic alarm system was chosen to be upgraded as a starting point for the eventual automation of critical cryogenic processes. LabVIEW real time was chosen for its ease of programming, expandability, and ability to interface with a broad range of devices. A system architecture was designed and enough hardware was acquired to double the number of alarms and allow for a redesign of the current dewar level control system. This system will also enable the remote operation of the new alarm system along with future cryogenic control processes.

Fig. II-15. A cryogenic valve control chassis to be used to control six helium distribution valves in the ATLAS and Booster accelerating sections.