# *THE AGS BOOSTER HIGH FREQUENCY RF SYSTEM**

*R. Sanders, P. Cameron, R. Damn, M. Goldman, E. Jablonski, J. Keane, A. McNerney, M. Meth, M. Plotkin, M. Puglisi, A. Ratti*

*Brookhaven National Laboratory*
*Associated Universities, Inc.*
*Upton, New York 11973*

## Abstract

A high level RF system, including a power amplifier and cavity has been designed for the AGS Booster. It covers a frequency range of 2.4 to 4.2 Mhz. and will be used to accelerate high intensity proton, and low intensity polarized proton beams to 1.5 GeV and heavy ions to 0.35 Gev per nucleon. A total accelerating voltage of up to 90kV will be provided by two cavities, each having two gaps. The internally cross-coupled, pushpull cavities are driven by an adjacently located power amplifier. In order to accommodate the high beam intensity, up to $0.75 \times 10^{13}$ protons per bunch, a low plate resistance power tetrode is used. The tube anode is magnetically coupled to one of the cavity's two paralleled cells. The amplifier is a grounded cathode configuration driven by a remotely located solid state amplifier.

## Introduction

The AGS Booster will have RF systems covering three frequency ranges from 178.5kHz to 4.2MHz. The two low frequency ranges, 178.5 to 675kHz and 675kHz to 2.4MHz, will be used only for heavy ions. The highest frequency range, 2.4 to 4.2 MHz, will be used to accelerate heavy ions, polarized and nonpolarized protons.

The high frequency system, also designated Band III, will be required to function with widely different gap voltage ranges and from essentially no beam loading to proton beam intensities as high as $0.50 \times 10^{13}$ protons per bunch.

This paper will describe the Band III high level RF system including both the cavity and power amplifier.

## RF System Configuration and Parameters.

The system requirements for high intensity proton beams determine, for the most part, the system configuration and parameters. The requirements are tabulated in Table 1.

Table 1.

| | p | $S^{+14}$ | $Au^{+33}$ |
|---|---|---|---|
| RF Amplitude | | | |
| Injection | 41kV | | |
| ejection | 53kV | ≤17kV | ≤17kV |
| at max. accel. | 90kV | ≤17kv | ≤17kV |
| Harmonic Number | 3 | 3 | 3 |
| RF Frequency | | | |
| Injection | 2.5 MHz | 2.5MHz | 2.5MHz |
| ejection | 4.11MHz | 3.89MHz | 3.06MHz |
| Phase Space Area/A | 1.5 eV-s | 0.0707eV-s | 0.0707eV-s |
| Intensity (per bunch) | $0.5 \times 10^{13}$ | $5 \times 10^{9}$ | $1.1 \times 10^{9}$ |
| Total Gap Impedance ($f_{rf}$=4.1MHz) | ≤24kΩ | - | - |
| Acceleration Time | 62ms | ≤3.5T/s | ≤0.7s |
| Maximum $\dot{B}$ | 9.5T/s | ≤0.15T/s | ≤3.5T/s |
| $\dot{B}_{inj}$ | 1.5T/s | | ≤0.15T/S |

To achieve the above requirements, a practical set of parameters were developed. These parameters take into consideration such aspects as beam loading, realizable high voltage designs, limited selection of commercially available electron tubes and high power components, and the limited space available in the Booster tunnel. Furthermore, to insure a conservative design, the system will be sized to handle beam intensities to $0.75 \times 10^{13}$ protons per bunch and the shunt impedance will satisfy the Robinson Criterion for open loop operation[3]. The system parameters are tabulated in Table 2.

Table 2.

| | |
|---|---|
| Number of RF cavities | 2 |
| Number of accelerating gaps | 4 |
| Peak RF voltage per gap | 22.5 kV |
| Peak RF power per cavity (180 kW rms nom.) | 264 kW peak |
| Frequency range | 2.4 to 4.2 MHz |
| Duty cycle | 50% |
| Maximum output impedance | 6kΩ |
| Number of power amplifiers | 2 |

Figure 1. shows the total RF gap voltage program for accelerating high intensity protons.

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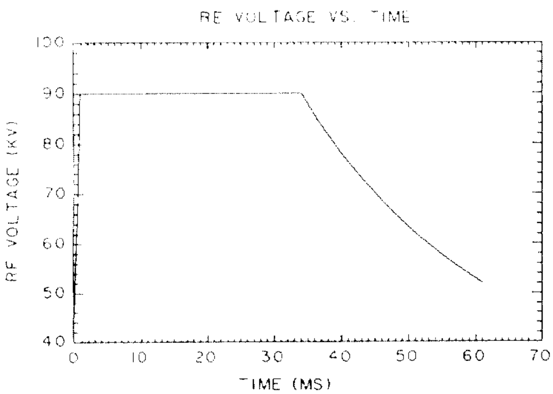


Figure 1. Total Gap Voltage vs Time

Cavity

The cavity is a pushpull, two gap, ferrite loaded accelerating cavity. It is driven single-ended but cross coupled to provide for pushpull operation. It is dc bias tuned to change frequency. It is physically located above and directly coupled to the RF power amplifier. See Figure 2.

To keep the gap voltage at a reasonable level, the RF flux density, and in turn, ferrite losses manageable, the Band III cavity was designed to have two pushpull cells. The maximum RF voltage per gap is 22.5 kV peak. These cells are parallel connected. The cavity is coupled to the power amplifier in a single-ended fashion to just one cell. The two ferrite stacks in each cell are cross coupled internally with figure-of-eight windings, essentially causing the cavity to operate as a balanced 1:2 step-up transformer[1].

The design of the cavity is ultimately determined by the choice of ferrite. After a long evaluation program, in which the ferrites of a number of manufactures had been measured, it was found that the material best suited to the application would be Philips 4M2. The study of ferrite samples included the measurement of permeability, dissipation, instabilities, and other possible anomalies.

The cavity design requires 56 ferrite rings total or 14 per stack. Each ring measures 50 cm O.D. by 25 cm I.D. by 2.72 cm thick. With a gap capacitance of 395 pf per gap (chosen for a desired transient response), the permeability ranges from 115 with a dc bias of 145 amperes at 2.4 MHz, down to 37.5 with a dc bias of 900 amperes at 4.2 MHz.

The ferrite dissipation is manageable with water cooling provided by copper cooling plates between each ferrite ring. Across the passband the peak dissipation varies from 0.25 to 0.4 watts per cc, corresponding to total peak power levels of 50 t0 80 kilowatts respectively.

The Booster ring will be operated at high vacuum and thus will require that the vacuum chambers, including the cavity be baked at 200°C. The cavity beam pipes have built-in electric heating elements and thermocouples.

The ferrite stacks are dc biased from a single turn winding. The outer can, beam pipe and gap connecting bus work form the bias winding. Because the two cavity cells are effectively in series with the dc bias but parallel for the RF drive, there is cancellation of RF on the dc bias leads to the cavity.

The cavities are permanently mounted on adjustable stands. The stands are designed to allow the power amplifier (which is on wheels) to be installed directly under the cavity. The RF drive lead between the amplifier and the cavity is short and built for quick disconnect.

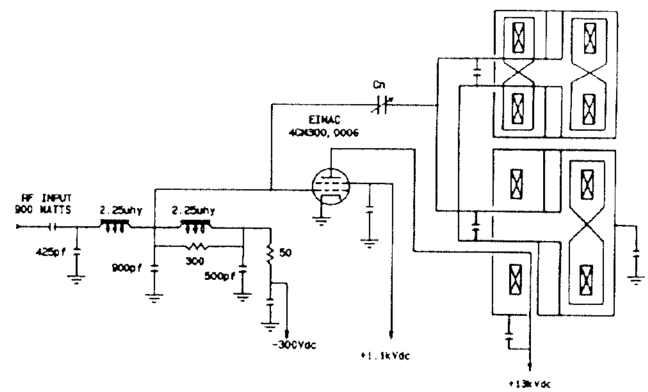


Figure 2. Band III Power Amplifier

Power Amplifier

The Band III power amplifier design was bounded by a number of constraints. Some of the more important of these include power output requirements, Robinson Criterion, and physical size[2].

At maximum acceleration, 90 kV peak, the total output power required is about 180 kW rms. The amplifier was designed to deliver over 200 kW rms.

Power tube selection and amplifier configuration required careful consideration. Since the shunt impedance required is low, the likely tube choice would be triodes. Serious thought was given to using a pair of large triodes in pushpull. However it was found that a large power tetrode (the EIMAC 4CM300,000G), could provide an average plate resistance of less than 500 ohms, providing a margin of safety. A grounded cathode tetrode also provides some simplicity to the circuit as well as being able to meet the physical space limitations.

The power tube operates Class $AB_1$. Because of the 1:2 step-up at the cavity, it is only necessary for the anode to swing 11.25 kV peak. The dc anode voltage is 13kV with a peak plate current of 65 amperes and short term average of 24 amperes. The screen voltage is 1.1 kVdc with an average current of about 0.5 amperes. The control grid bias voltage is -300 Vdc and the peak RF drive voltage is about 280 V peak.

The output circuit of the stage is simplified by bringing the anode voltage lead through the cavity for decoupling as well as RF coupling to the cavity. The need for blocking capacitors and a broadband RF choke are eliminated.

The input to the control grid is complicated by the high interelectrode capacitance, over 750 pf. A broadband low pass filter terminated in 50 pf. A broadband low pass filter terminated in 50 ohms is used to accommodate this capacitance as well as provide a standard impedance for the driver stage. A neutralizing capacitor couples the control grid to the 180 Deg. out of phase half of the cavity. The actual need for neutralization will be determined empirically.

The driver stage is a pair of ENI 500 watt solidstate broadband linear amplifiers summed with a high power broadband combiner. These amplifiers will be remotely located from the Booster ring because of possible radiation damage.

## Status

Some of the techniques and circuits are a departure from past experience. In order to confirm concepts and calculations, prototypes are being built of the cavity and amplifier. The conceptual designs have been turned into refined detailed designs. All materials and components have been ordered and machining has started on the cavity parts. The power amplifier assembly has started, using a mechanical package that will be identical to the final models with the exception of fastening methods.

Testing of the prototype system will start August 1, 1988.

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