# Conceptual Design of the 26.7 MHz RF System for RHIC*

J.Rose, D.P.Deng, R.McKenzie-Wilson, W.Pirkl, A.Ratti
Relativistic Heavy Ion Collider
Brookhaven National Laboratory
Upton, N.Y. 11973

*Abstract*

The 26.7 MHz (harmonic # h=342) RF system will be used to capture the injected bunched beam from the AGS and accelerate it to a kinetic energy of up to 250 GeV for protons; 100 GeV/u for gold ions. All ions except protons cross transition, and are finally transferred to a storage RF system working at 196 MHz. Each RHIC ring will be provided with two single-ended capacitively loaded quarter-wave cavities; each of these can be dynamically tuned by 100 kHz to compensate for the change in speed of the beam, and can deliver at least 200 kV voltage. A 100 kW tetrode amplifier with local RF feedback is directly coupled to the cavity to minimize phase delay. Prototypes of cavity and amplifier have been built and first test results are presented.

## I. INTRODUCTION

The Relativistic Heavy Ion Collider at Brookhaven consists of two counter-rotating beams of ions ranging from protons to gold colliding at up to six interaction regions. The machine consists of superconducting magnets with room temperature RF systems located in warm sections of the ring. Major machine parameters are given in Table I.

The accelerating RF system must capture the injected beam from the AGS, accelerate to top energy and transfer (rebucket) to the 196 MHz storage system. Table II shows the relevant bunch parameters at injection and top energies.

**Table I** Machine Parameters

| | |
|---|---|
| Circumference | 3833.852 m |
| Rotation Freq | 78.196 kHz |
| $\gamma_{tr}$ | 22.8 |
| B-$\rho$ inj/top | 96.7/839T-m |
| Average Radius | 610 m |
| Horizontal Tune | 28.19 |
| Vertical Tune | 29.18 |

* Work performed under the auspices of the Department of Energy

**Table II** Bunch Parameters

| | Protons Inj./Top | Au Inj./Top |
|---|---|---|
| Energy ($\gamma$) | 31.2/268.2 | 12.6/108.4 |
| Full Bunch Length (ns) | 6.5/4.0 | 13.5/7.5 |
| Synch. Freq (Hz) | 45/25 | 90/27 |
| Z, A/Z | 1/1 | 79/197 |
| $\Delta P/p$ ($10^{-4}$) | 10/1.7 | 8.3/3.4 |
| Bunch Area (eV-s/u) | 0.30/0.33 | 0.2/0.4 |
| # bunches/ring | 57(114) | 57 (114) |
| # ions/bunch | $10^{11}$ | $10^{9}$ |
| Norm. Emittance ($\pi$ mm-mrad, 95%) | 20/20 | 10/15 |

## II. SYSTEM DESCRIPTION

The 26 MHz system consists of a capacitively loaded quarter wave cavity with a close-coupled tetrode amplifier. The cavity is two meters long and 0.84 meters in diameter with the amplifier situated directly underneath. A prototype system has been constructed and is shown in Figure 1. This prototype will be used to study methods of tuning, HOM suppression, feedback design and susceptibility to multipacting. The prototype cavity is of copper plated steel construction. Provisions for vacuum pumping and water cooling have been made to allow full power testing. It is designed to allow amplifier coupling at either end of the cavity, it is currently configured with coupling to the capacitor electrode at the high voltage end. Numerous ports have been included for field probes, HOM damping tests and access for titanium nitride coating in the development program.

The codes SUPERFISH and URMEL were used to calculate the Higher Order Modes (HOM) of the structure.[1] This data was then used to calculate the growth rates of longitudinal coupled bunch instabilities using the Sacherer formalism.[2] The HOM frequencies, shunt impedances, Q's, and the coupled bunch mode growth rates are given in Table III. Analysis of transverse coupled bunch modes is in progress.

0-7803-1203-1/93$03.00 © 1993 IEEE

The first two HOM's are associated with coupled bunch modes with particularly fast growth rates of 6.7 $s^{-1}$ and 3.9 $s^{-1}$ respectively. Because of the low frequencies involved classical mode damper designs (waveguides above cutoff, quarter wave notch filters) are excessively large. The transverse waveguide dimension can be greatly reduced by capacitive loading, but in general the length cannot. In order to transmit the 67 MHz mode a cutoff frequency of about 50 MHz is required. The fundamental would then be attenuated in the guide below cutoff as

$$V=V_0 e^{j\beta z}$$

where z is in meters and $\beta$ is the propagation constant in rad/s and is defined as

$$\beta=\sqrt{\frac{\omega^2}{c^2}-\frac{\pi^2}{a^2}}$$

with a being the waveguide width. Below cutoff $\beta$ is imaginary and the above exponential becomes negative and real. It would then require over 2 meters of waveguide length just to reduce the fundamental voltage by a factor of 10. Likewise a quarter wave notch filter would require a length of 2.8 m, 1.4m even if folded back in half. Therefore there was an incentive to develop a lumped element mode damper. The approach being developed is a lumped L-C notch consisting of a parallel arrangement of a high voltage vacuum capacitor and a short coil in series with the load resistor. Work is continuing on this and alternate dampers.

The tuning range required is set by the velocity change of gold between injection and top energy. The frequency shift required is given by

$$f_{rf}=\frac{hc}{C}\sqrt{1-\frac{1}{\gamma^2}}$$

Where c is the speed of light, C is the RHIC circumference and h is the harmonic number. The frequency spread is then limited at the low end by gold at injection ($\gamma$=12.6) and by protons at top energy ($\gamma$=268.2) resulting in f=26.6537 to f=27.7435 respectively.

Tuning for compensation of beam loading falls within these limits since gold is below transition and the tuning is positive while protons are above transition and the tuning is negative. The maximum tuning rate is for gold at the beginning of the acceleration cycle and is 23 kHz/sec.

Two tuner approaches have been studied in detail. The first used three discrete ferrite loaded transmission lines connected in parallel to the cavity via a large disk integral with the inner conductor to minimize the series inductance of the tuner connection.[3] The ferrite is a low loss perpendicular biased garnet, Transtech G-810. The design predicted a 180 kHz frequency shift, in excess of the required 100 kHz to allow some flexibility in operation. The second approach is to change the gap capacitance via a mechanically actuated motion of the ground electrode. The preliminary design calls for a stepper motor driven lead screw to change the gap by 1 cm to provide 100 kHz of tuning. If implemented the mechanical tuner would eliminate the need for the large low inductance tuner disk which currently dominates the cavity design.

The ferrite tuner design concept was tested on the prototype cavity by using dummy tuners constructed of 3⅛ coaxial line with a sliding short capable of providing the same input impedance as the ferrite tuners. The resulting frequency range was 220 kHz, slightly in excess of the predictions. A choice will be made on the tuner approach based on cost, reliability and risk.

The voltage requirement is set by the requirement for a bunch rotation to rebucket the bunched beam into the 196 MHz system. This requires the accelerating system to adiabatically reduce voltage from 300 kV to 45 kV to increase the bunch length and then quickly step back up to 300 kV to rotate the bunch. After a quarter of a synchrotron period when the bunch length is at a minimum the 196 MHz system voltage is raised to capture the bunch. Each system is being designed to provide 200 kV, for a total of 400 kV per ring to allow flexibility and future upgrade capability.

**Table III** 26 MHz Cavity Longitudinal HOM's and coupled bunch mode growth rates

| Freq. (MHz) | $R_{sh}$ (MΩ) | Q ($10^3$) | Growth rate $sec^{-1}$/mode# (Gold) | Growth rate $sec^{-1}$/mode# (Proton) |
|---|---|---|---|---|
| 26.8 | 0.93 | 12 | n/a | n/a |
| 64.8 | 0.038 | 15 | 2.8/34 | 6.7/31 |
| 119.3 | 0.048 | 27 | 0.1/46 | 3.9/44 |
| 205.7 | 0.009 | 36 | <<0.1 | 0.24/10 |
| 287.9 | 0.111 | 23 | <<0.1 | 0.15/34 |
| 349.4 | 0.164 | 18 | <<0.1 | 0.19/23 |
| 360.6 | 0.018 | 26 | <<0.1 | <<0.1 |
| 427.0 | 0.080 | 45 | <<0.1 | <<0.1 |
| 479.6 | 0.014 | 47 | <<0.1 | <<0.1 |

The amplifier is housed in a wheeled cabinet beneath the cavity to allow easy installation and removal. It utilizes an EIMAC 4CW150000 in a grounded cathode configuration. The tube is used in class AB_1, with a quiescent current of 3A and an anode voltage of up to 20kV. A neutralization loop provides > 60 db of isolation between anode and grid. A 4:1 input transformer is used to drive the grid more efficiently in a 200 Ω impedance. A simplified schematic is shown in Figure 2. The machine cycle mandates beam gymnastics for ions at transition crossing, and for protons and ions alike at beam

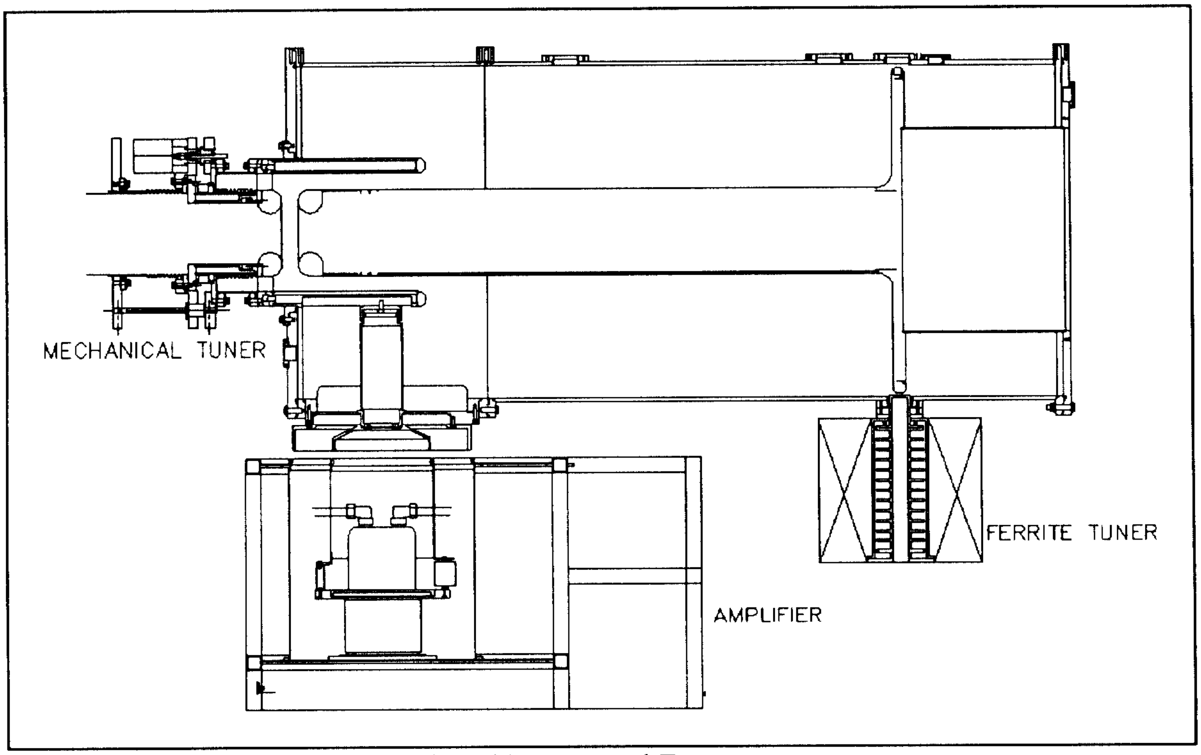


**Figure 1** Prototype Cavity and Amplifier with Conceptual Tuners.

rebucketing. Feedback performance to meet these requirements has been studied using PSPICE and a direct integration method.[4] Assumptions include a delay of 6*18.73 = 112.7 nsec, which covers a 500 W ENI drive amplifier (33 nsec) plus 2*10m of foam coaxial cable (2*36.7 nsec). Results conclude that RF feedback can be implemented with a loop gain of a least 100 which meets the requirements of the beam gymnastics.

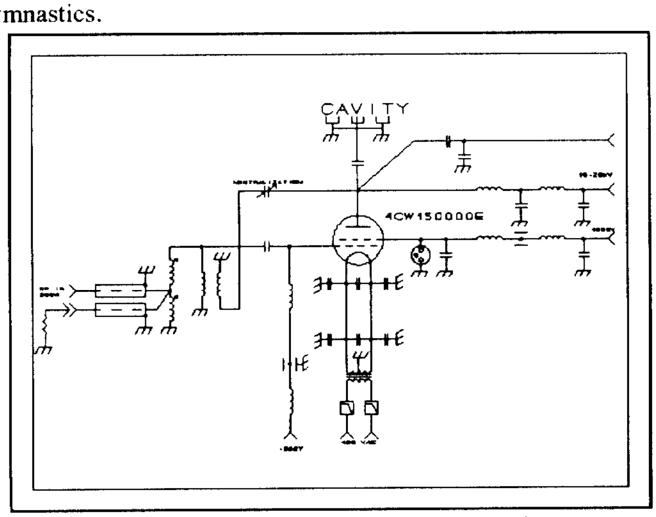


**Figure 2** Simplified Power Amplifier Schematic

III. CONCLUSIONS

A conceptual design of the accelerating system for RHIC has been completed and a prototype system fabricated. An experimental program has begun to explore in detail system performance with high power. The cavity-amplifier system has been tested to 70 Kv in air and is being readied for vacuum pumpdown. Testing of tuners and HOM dampers has begun. Future work includes cavity conditioning under vacuum, diagnosis and possible cures of multipacting, and the development of the RF driver amplifier and implementation of local feedback.

ACKNOWLEDGEMENTS

The authors wish to thank M. Blaskiewicz for performing the coupled bunch instability analysis. Special thanks go to S. Ellerd and J. Greco for their excellent technical support.

REFERENCES

1) J. Rose, Note RHIC RF-6
2) M. Blaskiewicz, Private communication
3) J. Rose, Note RHIC RD-42
4) W. Pirkl, Note RHIC RF-8