Improved RF System for Aladdin*

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Abstract

A new 50.58 MHz RF system has been installed in the Aladdin synchrotron light source at the University of Wisconsin – Madison. A more compact aluminum RF cavity was constructed to make the original RF straight section available for a future insertion device. The original grounded cathode 4CW100000E power amplifier was also modified to improve its stability and control system. The new system delivers enough power to run the cavity at maximum gradient while supporting large beam currents. New low level RF electronics were constructed, including low level RF feedback. Feedback allows the use of a smaller RF bucket at injection to improve beam capture and eliminates operational difficulties with the Robinson instability. Operational results with the new system are presented.

I. INTRODUCTION

The original Aladdin RF system consisted of an aluminum quarter wave coaxial resonator and a grounded cathode 4CW100000E power amplifier[1]. Stability problems with the PA prompted the acquisition of a surplus Collins 20 kW amplifier that had previously seen service on SPEAR. The ring has been running with the Collins unit since commissioning. The original cavity was installed in a long straight section that is now desired for future use by an insertion device. The need for higher gradients during 1 GeV operation also prompted the construction of a new cavity. The only place available for a new cavity was a short section at the beginning of a quadrant of bending magnet cells. A much smaller aluminum cavity[2] was designed which had approximately the same Q and shunt impedance as the original cavity. This gave an opportunity to address the problems of the original power amplifier. The 4CW100000E amplifier was modified to correct its problems. New low level electronics were built and the system tested with the new cavity insuring that it performed properly before installation.

II. POWER AMPLIFIER

A. Modifications

Improvements made to the power amplifier (Fig. 1) consisted of the addition of a 50 ohm grid damping resistor and simplification of the neutralization circuit. The neutralization cable is now connected to the grid end of the input circuit in parallel with the RF drive.

The amplifier is operated at rather low bias levels for a tube of this type. This is because the tube's full output capability is not needed and a low anode load impedance is desirable for stability. A section of 3 1/8 inch rigid coax one half wavelength long connects the PA to the cavity. Impedance matching at the amplifier is through a tap on the coaxial anode resonator. A coaxial rotatable joint at the cavity end allows the adjustment of the cavity coupling coefficient.

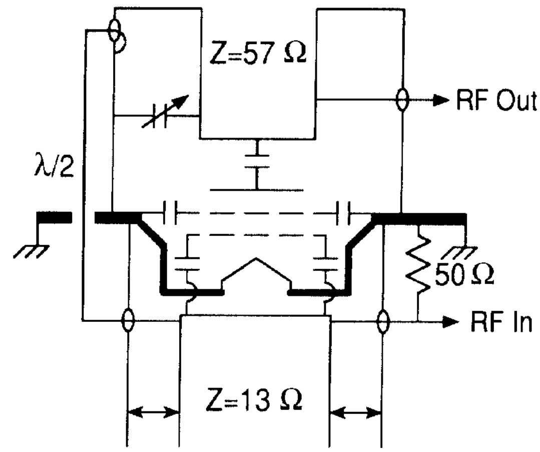

Figure 1. 4CW100000E Amplifier Circuit

Anode Voltage	9 kV
Screen Voltage	1.1 kV
Grid Voltage	-215 V
Load Impedance	550Ω
Power Gain	23 dB
Anode Bias Current	2.8 A
Power Output	35 kW

Table 1. Power Amplifier Operating Parameters

B. Instability Cures

Operation of the power amplifier into a high Q cavity load presents some problems. The interaction of the anode resonator tap with the feedline and coupling loop results in a pair of resonances in the plate circuit about 5 MHz above and below the operating frequency. These unloaded resonances present a very high impedance to the tube anode. In addition the bandwidth of the neutralization circuit is limited due to the λ/2 phase inversion line. The combination of these effects causes a stability problem that is not evident unless operating with a narrowband resonant load.

The solution to the problem is to provide damping for the off frequency resonances without dissipating too much power at the operating frequency. To accomplish this both the power amplifier and cavity are overcoupled by a factor of three. The resulting standing wave on the λ/2 connecting feedline has a voltage minimum at the center when the cavity is resonant and a voltage maximum when off resonance. The addition of shunt resistive loading at the center of the line produces the required damping while dissipating only a small percentage of the RF power. Figure 2 is the output from a SPICE simulation showing the effect of a 250Ω damping resistance at the center of the feedline on the anode load impedance as a function of frequency. The damping reduces the impedance of the undesirable resonances to approximately the level seen by the anode at cavity resonance.

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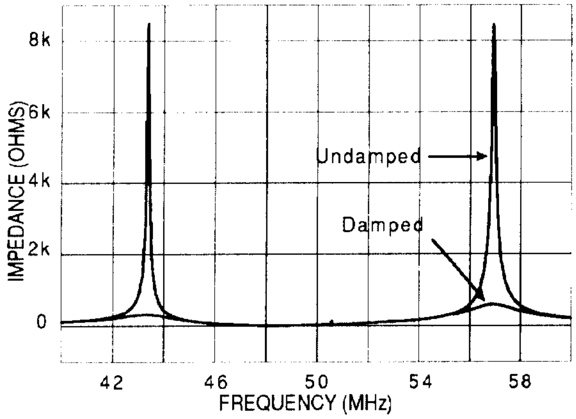

Figure 2. SPICE output showing off resonance behavior

IV. LOW LEVEL RF CIRCUITRY

A. Circuitry

The low level RF stages (Fig. 3) are conventional in design. A modular approach was adopted to allow easy servicing and modification. Amplitude and phase control are performed by a double balanced mixer acting as a current controlled attenuator and a phase shifter using a quadrature hybrid loaded with varactor tuned series LC circuits. The amplitude control loop uses a compensated schottky diode detector to measure the cavity field. A phase loop locks the phase of the beam signal generated by a pickup to the master oscillator phase. Both of these loops have modest bandwidths (<500 Hz) because the RF feedback already reduces any low frequency noise in the system. An ENI 5100L amplifier is presently used to drive the power amplifier. If high current operation at 1 GeV is desired this amplifier will be inadequate and a 300 W MOSFET amplifier module will be constructed to replace it.

V. RF FEEDBACK

The injection scheme of Aladdin imposes some unusual requirements on the RF system. An unbunched beam is injected from a 100 MeV microtron at a rate that is much faster than the radiation damping time. This makes injection and stacking more critical than usual. The energy loss per turn is only 4 eV at injection so most of the beam will be captured if it can be held within the machine aperture. To capture efficiently it is necessary to keep the RF voltage low so as to limit the amplitude of the energy oscillation. However, the voltage must be kept high enough to stabilize the beam against phase instability as the beam loading is inversely proportional to V/R_S. An effective feedback mechanism is the solution to meeting these conflicting requirements.

There are several approaches to solving the beam loading problem[3]. Wideband amplitude and phase control loops are not suitable for this purpose due to the very large beam loading factor. Feedforward compensation is a possibility but the sensitive amplitude and phase adjustments are a discouragement. Baseband feedback processing using in-phase and quadrature components[4] would be practical but complicated. Clearly in our case the simplest and most effective solution is the use of direct proportional RF feedback to lower the effective shunt impedance of the cavity as seem by the beam thereby reducing beam loading.

An RF feedback loop is implemented at low level with a summer and amplifier module that can be switched into the signal path at the output of the low level RF stages. A pair of SPDT PIN diode switches allows the feedback to be turned on and off under remote control. The signal from a cavity pickup is adjusted in amplitude to match the drive signal amplitude without feedback and is summed out of phase with the drive signal. The difference signal is amplified and fed to the driver amplifier. The loop gain is 20 dB increasing the effective cavity bandwidth to about 50 kHz and lowering the effective shunt impedance to below 100 kΩ.

During commissioning it was found that the Robinson instability was affecting the beam even with the feedback operating. This problem was more severe at high energy. Inspection revealed a phase error in the feedback loop that resulted in the system being tuned to the unstable side of resonance. Although it is not immediately obvious, a phase error in the feedback signal will result in a shift in resonant frequency of the system when the feedback is turned on. This effect is clearly shown in Figure 4. The phase of the RF feedback was advanced 10 degrees from the out of phase condition. This shifted the system resonance to about 10 kHz below the RF frequency, providing Robinson damping and eliminating the problem. This shows that the use of classical Robinson damping must still be considered when using RF feedback, especially with modest loop gains such as employed here.

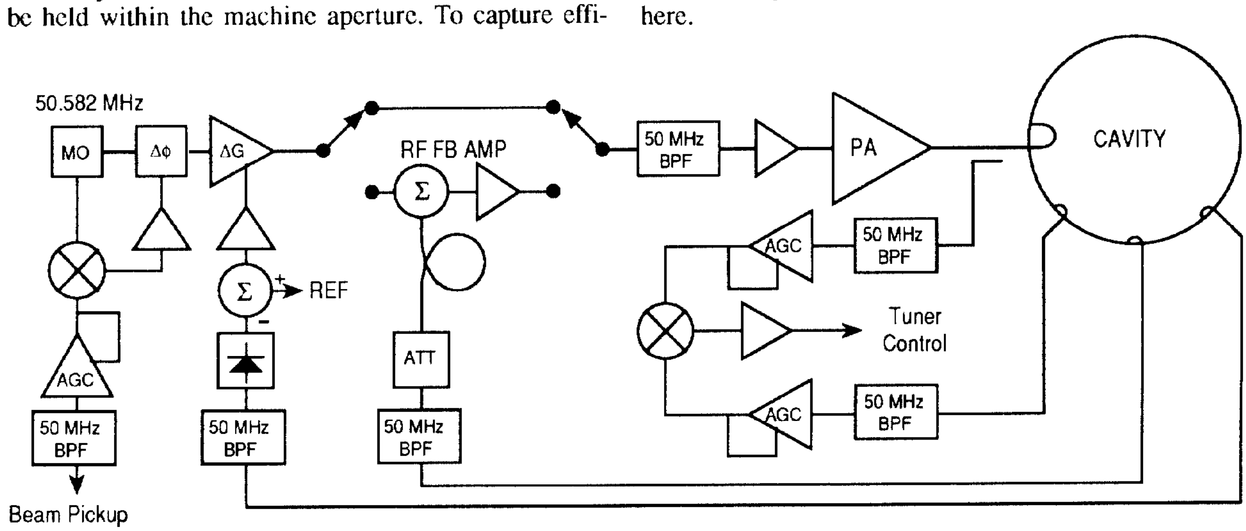

Figure 3. Aladdin RF System Block Diagram

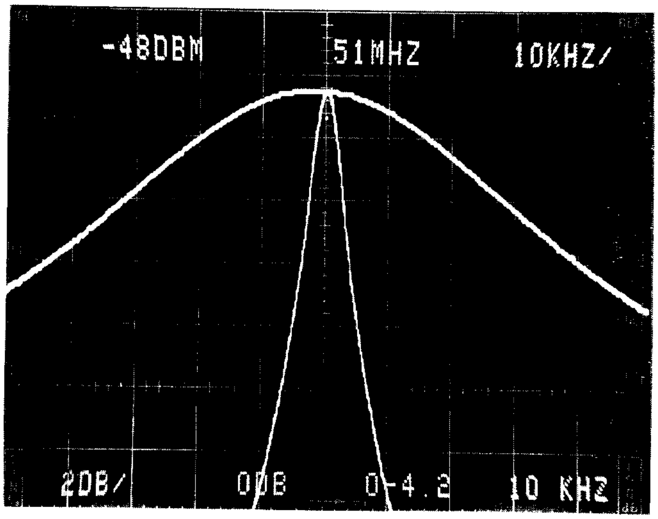

Figure 4. Effect of RF feedback on system frequency response

The reactive impedance required to obtain Robinson damping is better obtained by misphasing the RF feedback instead of detuning the cavity. The effect of cavity detuning is reduced by the feedback loop gain. The result is that the power amplifier is required to drive a very reactive load, which contradicts one of the original reasons for using RF feedback. Slightly misphasing the feedback also shifts the resonance of the system, altering the impedance seen by the beam. This provides Robinson damping without introducing a large reactive component in the load impedance, allowing efficient operation of the power amplifier.

V. PERFORMANCE

The performance of the new system has been quite satisfactory. Injection is much improved due to the elimination of a HOM problem in the old cavity that caused periodic debunching of the beam at high current, severely impairing stacking above 150 mA. The lower number of low frequency HOM's in the new cavity design and the damping of modes that are present has resulted in a reduction of the equilibrium bunch length at injection by about 30 percent. Tests using RF feedback at injection have verified that the dependence of the Robinson instability on cavity tuning has be eliminated. With feedback it is also possible to lower the cavity voltage by 50% from the level required without feedback without causing instability. This is enough to improve beam capture and stacking significantly. The result of this is that typical stored beam currents are increased by about 15 percent over the no feedback case. The low current stacking rate is nearly doubled.

Operation at 800 MeV is reasonably good. There are several coupled bunch modes that appear to be generated by high frequency HOM's in the cavity but they do not impair machine operation. Initial tests using RF feedback revealed additional instabilities. The bunch modulation resulting from these instabilities interfered with beam position measurements. This problem was traced to HOM transmission through the RF feedback loop. An additional bandpass filter inserted before the driver amplifier eliminated the problem.

Since the high energy coupled bunch problems appear to be caused by one or two modes at about 1 GHz, There is a particularly simple damping method that will be investigated as soon as machine time is available. Preliminary experiments have shown that a section partially loaded with microwave absorber inserted into the feedline will damp the offending HOM's by means of the cavity coupling loop. The frequency dependent loss of the material will possibly allow the use of enough material to significantly damp the 1 GHz HOM's while simultaneously providing the much smaller attenuation required to damp the feedline resonances at 50 MHz. The feedline damping network could then be replaced by the absorber section resulting in a much simpler arrangement.

VI. REFERENCES

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