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ORIC RF SYSTEM - PREPARATION FOR HHIRF

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Abstract

The integration of the Oak Ridge Isochronous Cyclotron (ORIC) into the Holifield Heavy Ion Research Facility (HHIRF) requires several RF system modifications to permit injection of ion beams from the 25 MV tandem electrostatic accelerator into ORIC. A new dee eliminates structural interference with the injected beam path and provides an opportunity to improve the mechanical stability of the resonator and to reduce RF voltage gradients in areas susceptible to sparking. Space for structural improvements is realized by reducing the ion beam aperture from 4.8 cm to 2.4 cm. The complexity of the original ORIC RF power system has been substantially reduced. A new broadband solid state driver amplifier between the frequency synthesizer and the main power amplifier eliminates most circuit tuning and permits the use of a new simplified dee RF voltage regulator loop. Most of the remaining instrumentation and control circuitry is TTL compatible and will eventually tie to the ORIC computer control system through a CAMAC interface.

Introduction

The Oak Ridge Isochronous Cyclotron (ORIC) will soon be an integral part of the Holifield Heavy Ion Research Facility (HHIRF).[1] After a long productive career as a multiparticle AVF cyclotron, ORIC is undergoing a variety of alterations which will make it compatible with HHIRF. Most notably, ORIC must accommodate ion beam injection from the 25MV Tandem Electrostatic Accelerator as illustrated in the trajectory diagram in Fig. 1. The beam passes through the RF resonator dee stem and through areas occupied by the dee periphery and the upper tuning capacitor or trimmer. A large steering magnet and other ion optics components will be located inside the dee stem. Other changes including a new broadband RF driver amplifier and a new RF voltage regulator loop with transient protection circuitry are primarily intended for improvements in ORIC's performance and reliability, but HHIRF will especially benefit from the resultant simplification in ORIC's control system.

The New Dee

ORIC's original dee featured a fairly thin walled structure with substantial bracing in the peripheral areas. Since the points at which the injected beam penetrates the periphery are subject to variation as a function of momentum and mass/charge ratio, the cuts required to accommodate all beams would have destroyed the structure. Consequently, a new dee was fabricated with its periphery entirely open except for 2 small corner braces. Past experience with ORIC indicates that its original dee aperture was larger than necessary and that its maximum RF voltage limitations were determined by dee edge geometry rather than by dee to ground clearance. Therefore, the new dee has more structural support in its walls with resultant increase in wall thickness from 1.4 cm to 3.8 cm. While the new dee lacks peripheral structure, it is considerably stiffer than the original.

*Operated by Union Carbide Corp. for U.S. ERDA.

Some dimensions and characteristics of ORIC's original and new dees are listed in Table 1. The reduced dee to ground clearance adds some capacitive loading which lowers the minimum frequency of the RF tuning range. This increases the number of heavy ion beams which can be accelerated in fundamental mode rather than in 3rd harmonic mode. Since the added capacitance is centered toward the dee stem, it does not affect the upper end of the RF tuning range although it causes a 10% increase in excitation power. Allowable clearances are based upon Cranberg's[2] criteria for voltage breakdown threshold. Surface conditioning should permit considerably higher voltages than the threshold levels. ORIC typically operates with its dee voltage at about 75 kv. The increased dee tip radii should permit somewhat higher dee voltage or smoother operation at voltage levels used in the past.

Considerable effort went into achieving improved cooling so as to prevent dimensional variation with respect to RF power level. The maximum temperature differential from the copper surface to the coolant water will be less than 11°C. In addition to the usual array of copper lines which are brazed to the inside surfaces of the dee walls, the dee edges are formed from heavy walled copper tubing (2.54 cm dia.) which is also part of the coolant loop.

Table 1. Dimensions and Characteristics of the Original ORIC Dee and the New Dee

	Original Dee	New Dee
Max. orbit diameter	178 cm	178 cm
Beam aperture at edges	4.8 cm	2.4 cm
Dee tip (edge) radius	0.32 cm	1.27 cm
Dee-to-ground clearance, (flat surfaces)	3.81 cm	2.54 cm
Dee-to-ground clearance, (edges)	2.54 cm	2.54 cm
RF tuning range, F min.	7.5 MHz	7.0 MHz
F max.	22.5 MHz	23 MHz
Breakdown RF voltage threshold,		
on flat surfaces	78 kV	77 kV
on edges	44 kV	66 kV

The ion beam injection trajectory passes through the upper periphery of the dee; however, for the sake of symmetry the lower periphery is also open. (Fig. 2) The fine tuning capacitors, or trimmers, will also be replaced. Since the upper trimmer is in the beam path, it too is slotted to match the periphery of the dee. Again, the lower trimmer is identical to retain symmetry.

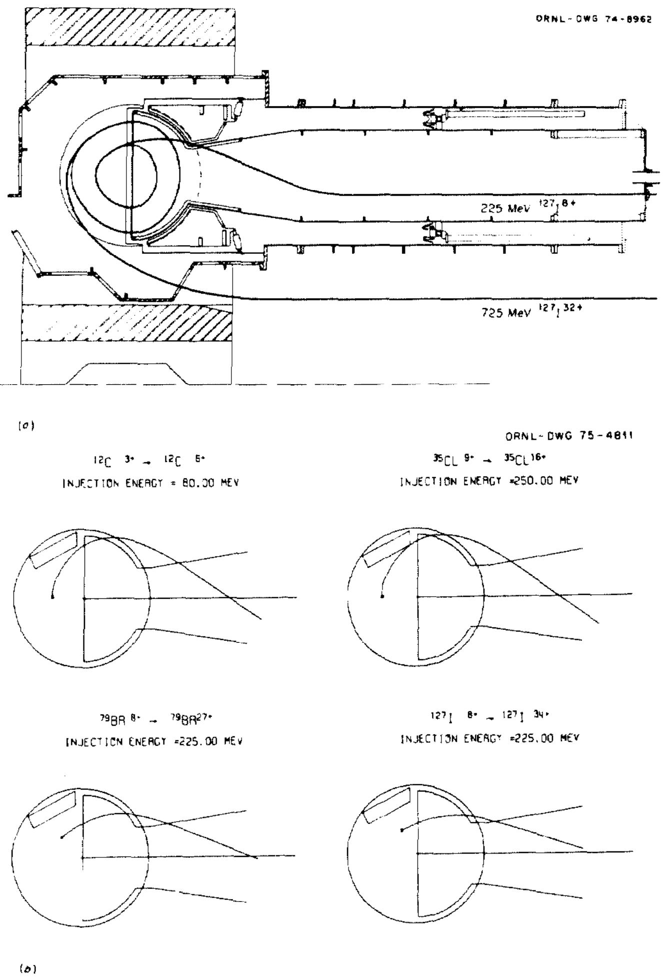

Fig. 1.(a) A profile of the ORIC RF Resonator, accelerating tank, and main magnet and the injection/extraction trajectories of an Iodine beam.
(b) Some examples of the injection trajectories of other beams in vicinity of the dee.

The Upgraded RF Drive System

The RF power system has been through many changes and improvements since ORIC first went into operation. The most recently reported improvements[3] involved replacing the RCA 6949 triode power amplifier (PA) with an RCA 4648 tetrode. At that time the existing driver stages which included a 4CX5000A tetrode and a 4CX350A tetrode were retained with their automatic servo tuned plate circuits. Such a combination is rather oversized since the 4648 reaches the typical ORIC power requirements (150 kW output) with Class AB_1 drive conditions. It was hoped that solid state broadband amplifiers might soon be available for driving the 4648 directly without the need for tuned amplifier stages. The recent introduction of commercially available broadband solid state amplifiers in the hundreds of watts size range has brought this hope to reality. An array of four amplifiers (Electronic Navigation Industries Model A-300) with a combined output rating of 1200 watts has replaced virtually everything between the RF signal synthesizer and the grid of the 4648 PA. A new RF voltage regulator loop was also required since the earlier loops were closed by modulating the grid of driver amplifier stages. (Fig. 3)

The P.A. grid matching and termination network, as shown in Fig. 4, is a bridged-tee configuration.

Fig. 2. A side view of the new dee showing the bottom peripheral area. An identical peripheral opening on the top is traversed by injected ion beams.

Four of the illustrated units are used in parallel. The nominal 1200 PF input capacitance of the 4648 is divided four ways to obtain an equivalent shunt arm of 300 pF. The series inductance of the shunt arm is the sum of that in the grid structure and the tube connections. The shunt inductance complicates the problem of obtaining constant Z as a function of frequency; however, it tends to resonate with the grid capacitance so that the usable bandwidth for the network extends somewhat beyond that expected for a pure capacitance shunt. Some voltage standing wave ratio (VSWR) curves are shown in Fig. 5, which demonstrate the effect of small changes in the bridge capacitance. Since ORIC requires the most drive power at the upper end of its frequency range, the series capacitor is selected to produce minimum VSWR at maximum frequency.

Due to the high gain characteristics of the A-300 and the 4648 PA, relatively little signal gain is required in the dee voltage regulator. An Analog Devices 234J amplifier with a bandwidth limiting feedback capacitor is driven by ORIC's original dee tip biased detector. Bandwidth is limited by C_F to stay within the main resonator bandwidth which varies from 700 Hz at low frequency to 7 kHz at high frequency. Microcircuit relays (Teledyne 640-1) are used to switch various values of capacitance in and out of C_F so that maximum bandwidth and ripple reduction is possible at any frequency. A unity gain booster amplifier is used to match the 234J to the 50-ohm load impedance of the balanced diode mixer.

New Transient Protection

ORIC's previous RF drive systems all featured a collection of transient sparking, and overload detectors feeding a common amplitude controller which reduces or inhibits RF drive levels during the occurrence of abnormal operating conditions. The new driver stages eliminate the need for most of the previous limiter circuits, but they also require a few new ones. The transient protection system has been completely redesigned and rebuilt in a modular form. New modules are easily added and existing modules can be reassigned to new functions. Each module uses a differential input comparator circut with TTL compatible output signal. An audio alarm in the cyclotron control room warns operators of improper operating conditions. Each module also features a latching display light which remains lighted for several seconds to simplify trouble shooting. In the future, ORNL-DWG 77-5247

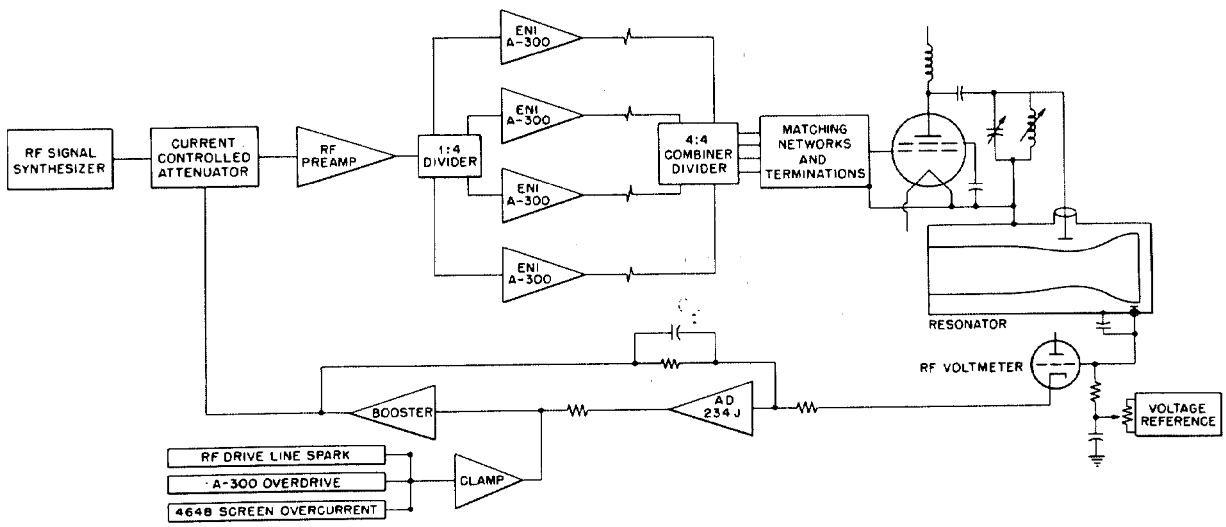

Fig. 3. A simplified schematic diagram of ORIC's RF System. The matching networks and the 4648 PA are located on top of the resonator tank. The A-300 amplifiers, the modulator, the pre amp, the regulator amplifier and the transient protection circuits are located in a utility area outside the cyclotron vault.

these signals will be fed to a CAMAC module which will link them to ORIC's control computer.

Conclusion

ORIC's new dee will be excited for the first time in April or May, 1977. Our primary expectations are for greatly improved voltage stability resulting from the extremely rigid structure, improved geometry, and improved thermal characteristics.

The new RF drive system and transient protection circuitry have already been in service for several months. The most notable improvement is simplification of the vast RF system controls. ORIC's MOPA (Master Oscillator-Power Amplifier) RF system is now simpler than many self-excited RF systems. The 4648 PA no longer requires neutralization and most RF stability problems related to parasitics and fundamental self-oscillation have completely disappeared.

The A-300 amplifiers have performed fairly satisfactorily, but a warning should be noted as a result of ORIC's operating experience. While the A-300 amplifiers are rated for operation into any load (impedance) and to withstand up to 16 dB of overdrive, they cannot withstand both simultaneously. The combination of abnormally low load impedance and input overdrive causes a disastrous overload in the output transistors. At ORIC, we now use carefully tuned line terminating networks and limiter circuits on the A-300 drive signals to prevent possible overdrive.

References

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3. S. W. Mosko, IEEE Trans. Nucl. Sci. NS-20, No. 3 (1973) 416-417.

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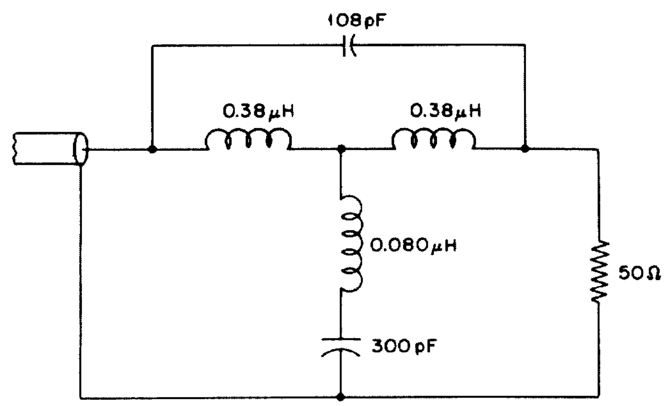

Fig. 4. The P.A. grid matching network. Four of these networks terminate the 4 respective 50 Ω lines from the A-300 amplifiers. The 300pf in the shunt arm is 1/4 of the input capacitance of the 4648 P.A.

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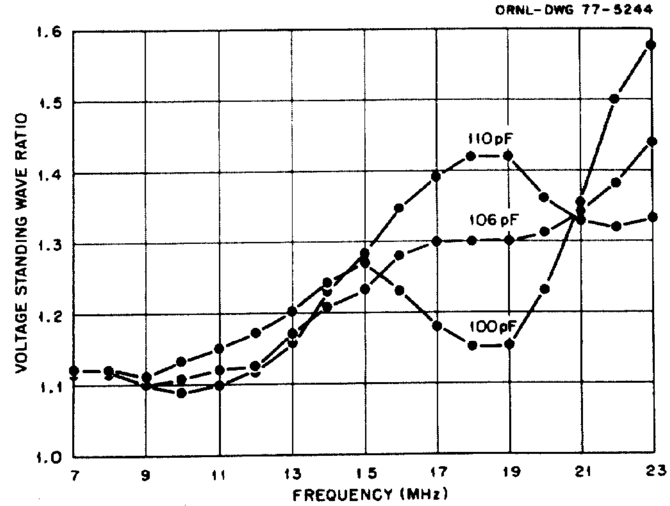

Fig. 5. Examples of the VSWR seen by the driver amplifiers as a function of frequency and bridge capacitance.