A NEW RF SYSTEM FOR THE ORIC*

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Summary

The Oak Ridge Isochronous Cyclotron RF system has been converted from an RCA 6949 power amplifier to an RCA 4648 power amplifier. The primary incentive was to reduce tube replacement cost; however, improved system performance and reliability were also realized. Existing servo-tuned driver amplifier stages and RF voltage regulator loops were retained. Typical accelerating potential noise levels are about 0.05% to 0.1% peak to peak noise per peak RF voltage.

Introduction

The Oak Ridge Isochronous Cyclotron (ORIC), has been in operation since 1963. An active accelerator improvement program keeps ORIC up with the state-of-the-art and permits an ever expanding range of capabilities. ORIC's MOPA RF system orginally featured a 6949 power amplifier (PA), 4 intermediate tuned amplifier stages between the master oscillator and the PA, RF voltage regulator loops, and automatic tuning servos.[1,2] Nevertheless, there has been a constant demand for improved stability, improved reliability, and simplification of operation and maintenance procedures. Significant changes over the years include replacement of the master oscillator by a frequency synthesizer, replacement of two intermediate amplifier stages by a transistor distributed amplifier,[3] improvements in the regulator loops, and the addition of heavy filtering to most of the dc power supplies. Most recently, the 6949 triode PA tube was replaced by an RCA 4648 tetrode.

Objectives

The primary incentives for replacing the 6949 are cost (price quotation in January 1972 was $29,000) and installation time required for the 6949 at ORIC (3 days minimum shutdown). It was necessary to withdraw the entire RF system from the cyclotron magnet and to lower the resonator assembly from the support crane in order to be able to insert or withdraw a PA tube through the only access hole in the top of the PA enclosure. The 4648 cost about 1/4 as much as a 4649, its power rating is equal to the 6949, and it is relatively compact. It should be possible to change 4648 tubes through an access hole under the PA enclosure in a period of a few hours without disturbing the cyclotron vacuum system or electrical wiring.

The high gain characteristics of the 4648 are especially attractive since it is hoped that some form of broadband solid state amplifier will eventually replace the remaining tuned RF circuitry between the synthesizer and the PA Superior RF characteristics should lead to improved PA performance and eliminate neutralization problems formerly experienced with the 6949, which required reneutralization each time that ORIC's frequency was changed.

The Conversion

The PA conversion program was planned such as to accomplish its objectives at minimum cost (less than the cost of a new 6949) and with minimum cyclotron shutdown time. Except for a new tube socket and related hardware, the original PA enclosure and resonant RF circuits were retained, thereby precluding preinstallation testing of the 4648. On Oct. 11, 1972, ORIC was shut down and the conversion commenced with irreversable committment to successful operation of the 4648. About 4 weeks (40 man days of craftsmen time) was required for PA enclosure alterations. Equipment installation and reassembly of the cyclotron were completed on Nov. 8. An additional week was required for checking out electrical circuitry and cooling system plumbing. On Nov. 16, ORIC was back "on the air", a bit shaky, but nevertheless, circulating an ion beam.

Alterations to the PA enclosure included cutting holes to accommodate the new tube socket and to provide a route for inserting tubes from an easily accessible area below the PA. A ringed array of 4 each 1000 pF vacuum capacitors which formerly served as the plate blocker was replaced by a ring of 12 each ceramic capacitors (Fig. 1), whose values are alternately 100 pF and 250 pF. Capacitance values were selected such as to avoid parallel resonances within the PA's 7.3 to 22.5 MHz tuning range. A new PA grid contact adaptor (Fig. 2) was necessary to complete connections from the existing grid tank to the 4648 grid. Relatively minor power supply changes included adding a filter choke to the dc filament power supply, the former 6949 bias power supply now serves as the 4648 screen power supply, and a new grid bias power supply was added.

Two components vital for PA stability are the low impedance "screen bypass" capacitor and the low impedance "grid swamping" resistance. The screen bypass is shown in the first of 3 stages of development in Fig. 3. A sandwich structure is formed by separating the screen contact disc from the flat upper surface of the tube socket by a 3 mil kapton film. The 100 in^2 electrode surface area yields a capacitance of about 25,000 pF. PA stability with this configuration was marginal. Consequently, a second ground electrode with another 3 mil kapton film was added on top of the screen contact disc thereby increasing the capacitance to about 40,000 pF and reducing inductance slightly. PA stability is now acceptable, but a third version of the screen bypass now being fabricated will reduce inductance further and simplify assembly procedure. Stability is further enhanced by 4 each 50 ohm, 1 kW, water cooled swamping resistors which shunt the PA grid circuit. The Q of the grid pi network is now so low that automatic tuning is unnecessary.

Inclusion of a neutralization network may be noted in Fig. 4. The network was retained from the 6949 PA as a back-up in case of oscillation with the 4648. It appears that neutralization is still desirable, although the optimum setting for C_n is very small (<1 pF). Also note a 50Ω, 50 kW water cooled load resistor which is coupled to the PA plate tank via a 15 pF capacitor. It loads the PA plate resonator whenever the main resonator is detuned. Otherwise very high RF voltage and circulating current are developed which may initiate PA oscillation and/or RF voltage break down in the plate tuning capacitors or on the resonator drive capacitor. Power loss in the shunt resistor is only a few kW for normal RF voltage levels in the plate tank.

*Research sponsored by the U. S. Atomic Energy Commission under contract with Union Carbide Corp.

Table I. Some operating parameters for the 4648 PA.

Plate dc voltage	15 kV
Plate dc current	15 A
Screen voltage	1000 V
Conduction angle	140°
Plate RF voltage	11 kV peak
Output power	142 kW
Efficiency	63%
Grid bias	-176 V
Grid RF voltage	170 V peak

Conclusion

A 4648 tetrode has replaced the 6949 triode in the PA. ORIC's performance is equal to or better than that previously experienced. The PA neutralization procedure was eliminated from the set-up routine. A neutralization circuit is still in use, but the value of C_n is fixed and suitable for all operating conditions over the entire tuning range. Automatic tuning of the PA grid circuit is now only used during "set-up". Noise levels observed with the 4648 PA are typically in the range of 5 to 10 pp 10^4 (p-p)/p which is about the same that was typical for the 6949. Most of the noise structure is 60 Hz and 360 Hz ripple which can be reduced through further improvement in power supply filtering. Although the p-p noise/peak RF level is unchanged, the noise structure has improved. Some high frequency components in the 10 KHz to 100 KHz range are considerably smaller than that which was typical with the 6949.

References

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2. S. W. Mosko, N. F. Ziegler, "Improvement in the ORIC RF System", IEEE Trans. on Nucl. Sci., NS-12, June 1965.

3. Electronuclear Div. Annual Progress Report, 1969, ORNL-4534.

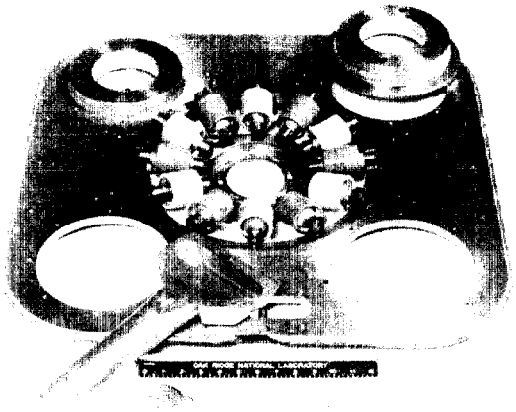

Fig. 1. The "PA plate blocking capacitor". The center ring mates with the 4648 plate. The large holes in corners and associated fittings mate with variable vacuum tuning capacitors. The RF power output connector is shown at lower left.

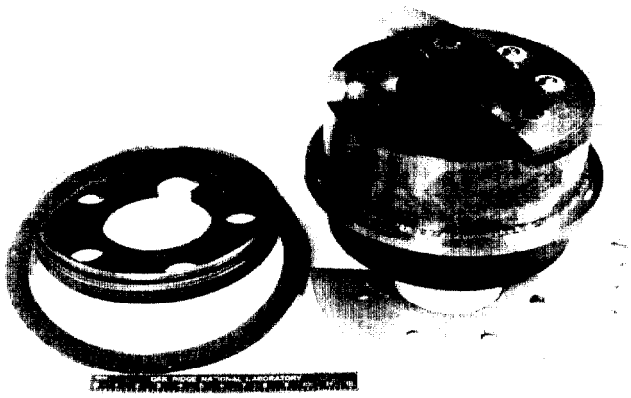

Fig. 3. The "PA tube socket". The 4648 is inserted from below. The plate and screen terminals protrude from the hole in top center. The partially assembled screen bypass capacitor is on top. Socket was fabricated from a double layer of steel for magnetic shielding with copper clad surfaces for RF current conduction. The bottom cover on left completes the magnetic shield after tube installation.

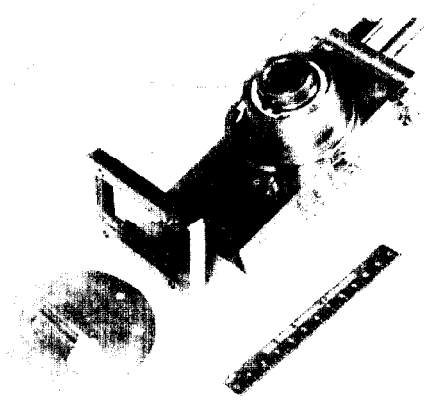

Fig. 2. The "PA grid contact adaptor". The circular contact areas mate with the 4648 input flanges. The flat inner conductor or grid lead mates with the grid pi network via the adaptor at lower left.

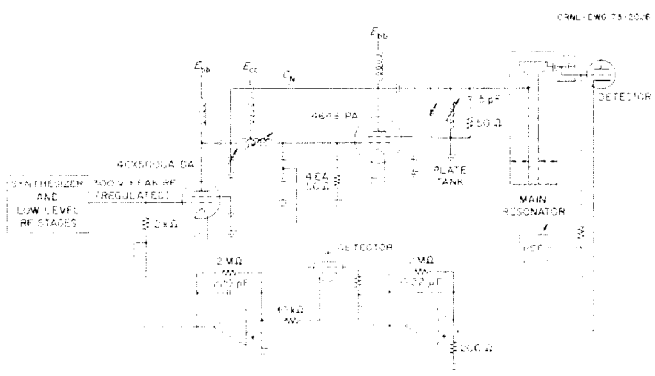

Fig. 4. A simplified schematic of the PA circuit including the driver amplifier stages, the main RF resonator, and the dee RF voltage regulator loop.