PERFORMANCE OF THE ORIC VARIABLE RF SYSTEM

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(Presented by R.E. Worsham)

The master-oscillator power-amplifier RF system for ORIC was described previously[1]; a block diagram of the system, based on design data existing at that time is shown in Fig. 1. During the past year, most of the components were fabricated, installed, and tested. The system is now complete with the exception of some of the regulator loops.

Installation of the amplifier stages and control circuit wiring began during July 1962. Dee voltage from excitation supplied by the RCA-6949 power amplifier was first obtained on December 20, 1962. Since that time, testing and installation has continued intermittently, along with operation of the cyclotron to produce an internal beam for deflection studies. Some of the major components of the system are shown just prior to installation of the 6949, see Fig. 2.

The entire system is now controllable from the main cyclotron control room.

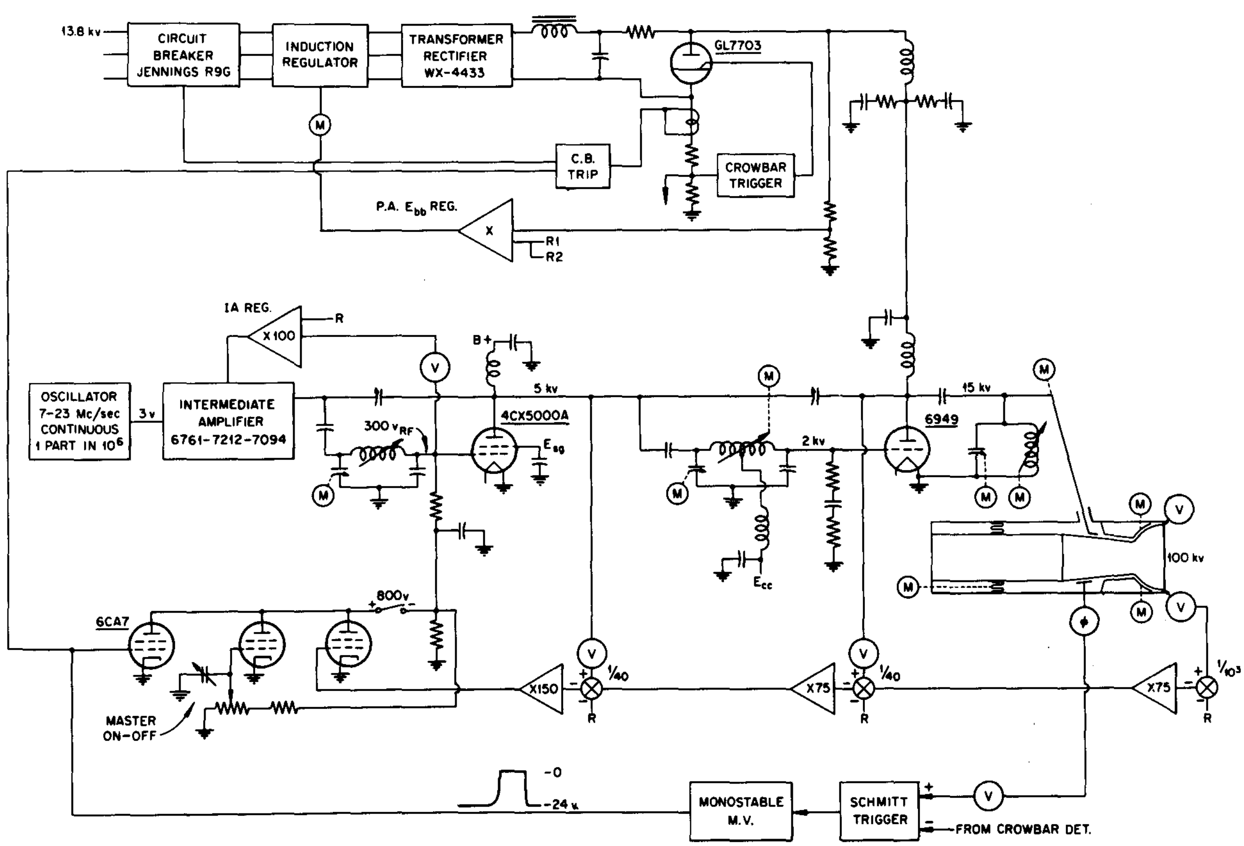

Fig. 1 Block diagram of RF amplifiers, control, and regulator circuits for ORIC.

(*) Operated for the USAEC by Union Carbide Corporation.

Most of the system can also be operated from auxiliary controls mounted on the side of the dee-stem housing. These controls are especially useful whenever testing or trouble shooting problems require direct access to the amplifier components or to the dee and resonator. All of the power supplies, the servo amplifiers, and the regulator amplifiers are located in an area external to the cyclotron vault. Approximately 600 wires connect components in the vault with auxiliary equipment area. A similar number of wires connects the RF system with the master controls in the control room.

The RF system is continuously tunable from 7.3 to 22.1 Mc/s. Resonator characteristics are the principal limiting factors in the tuning range. Although the upper frequency limit is slightly below the original design goal of 22.5 Mc/s, the 3/1 ratio tuning range required for maximum flexibility is still available.

The three stages of the intermediate amplifier have identical output circuitry. Each stage has a π network tank circuit with two variable vacuum capacitors and a set of three inductors for multiband operation. The three bands are 7.3-11, 11-17, and 17-22 Mc/s. Tuning within the bands is controlled by a single servo amplifier. Output voltage variation due to tracking errors is corrected by the IA regulator loop which detects the output voltage and varies the grid bias of the second stage to hold the output voltage constant at 300 V.

The π network output circuit on the driver amplifier has a continuously variable inductance consisting of a pair of transmission line stubs with a shorting plane. The stubs are partially shown in Fig. 2. Dual-band operation is obtained by inserting fixed vacuum capacitors at both the driver amplifier plate and the power amplifier grid. The lower, 7.3 to 11.0 Mc, band is attained with both capacitors inserted, and the upper band, 11.0 to 22.1 Mc, is attained with the capacitors withdrawn. A variable vacuum capacitor on the driver amplifier plate is used for fine tuning. The π network is unbalanced at 5/2 ratio for impedance matching between the two amplifier stages.

The power-amplifier tank circuit uses a transmission line stub with movable shorting plane for the variable inductance, see Fig. 2. The cylindrical center conductor surrounds the plate end of the 6949. The lower end of the cylinder is shunted by four Jennings VMMHC variable vacuum capacitors. The circuit is designed to tune with a constant L/C ratio.

The 6949 power amplifier is neutralized by coupling the power-amplifier plate to the driver-amplifier plate through a variable capacitor, see Fig. 3. Since the two stages are coupled with a π network, the driver-amplifier plate should be 180° out of phase with respect to the power-amplifier grid. Apparently, some phase error is introduced by lead inductance. Consequently, the neutralization capacitor must be adjusted whenever the frequency of the system is changed.

For convenience, the neutralization capacitor is motorized, and a null indicator was added to the power-amplifier plate circuit. The neutralization procedure is as follows. A mode switch on the control console locks out the power amplifier high

Fig. 2 ORIC power amplifier. The grid tank circuit extends forward from beneath the housing of the plate tank circuit. The RCA-6949, suspended at the left, fits inside the central conductor of the variable transmission line of the plate tank circuit. One of the four variable vacuum capacitors for fine tuning of the plate tank circuit is shown on the filament transformer at the right.

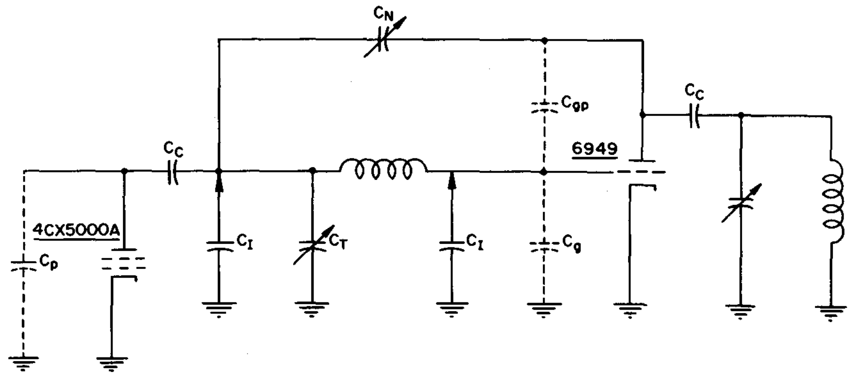

Fig. 3 Power amplifier neutralization circuit.

voltage and actuates a motor unit which inserts the null indicator voltmeter head. Then, RF excitation is applied to the power amplifier grid, and the neutralization capacitor is tuned for a null in the plate RF voltage.

The RF system has been operated over most of its tuning range. Operation below 15 Mc/s has been quite satisfactory. However, at higher frequencies, some sparking in the resonator drive line has been encountered. Installation of transient protection circuitry, and determination of optimum coupling capacitor size should help clear up the problem. Some alterations of the drive-line structure, including corona shielding for the feedthrough insulator, are under consideration.

A dee potential exceeding the 100 kV desing goal has been obtained throughout the 7.3 to 15 Mc/s tuning range. Most machine operation has been at 80 and 100 kV. Operating voltage can be reached within a few minutes after startup, unless the resonator has been recently opened to air.

Power requirements are fairly close to predicted levels. Input power to the power-amplifier plate for 100 kV on the dee ranges from 110 kW at 7.3 Mc/s to 220 kW at 16.0 Mc/s. Calorimetric measurements in the plate cooling loop indicate that the tube efficiency is approximately 60%. Allowing for some power loss in the plate tank circuit and in the drive line, the power delivered to the resonator is approximately half of the plate input power.

The four automatic tuning servos now in use have been very successful. The first loop maintains 180° phase shift across the first stage of the intermediate amplifier by tuning the π network capacitors; the second and third stages are ganged with the first.

The second automatic tuning servo hold 180° grid-to-plate phase on the driver amplifier by tuning the fine tuning capacitor on the amplifier plate. The third loop maintains 180° grid-to-plate phase on the power amplifier by tuning the four capacitors in the plate tank circuit. The fourth loop tunes the resonator trimmers to keep the dee-stem drive point voltage 90° ahead of the power-amplifier plate. A typical loop is illustrated in Fig. 4.

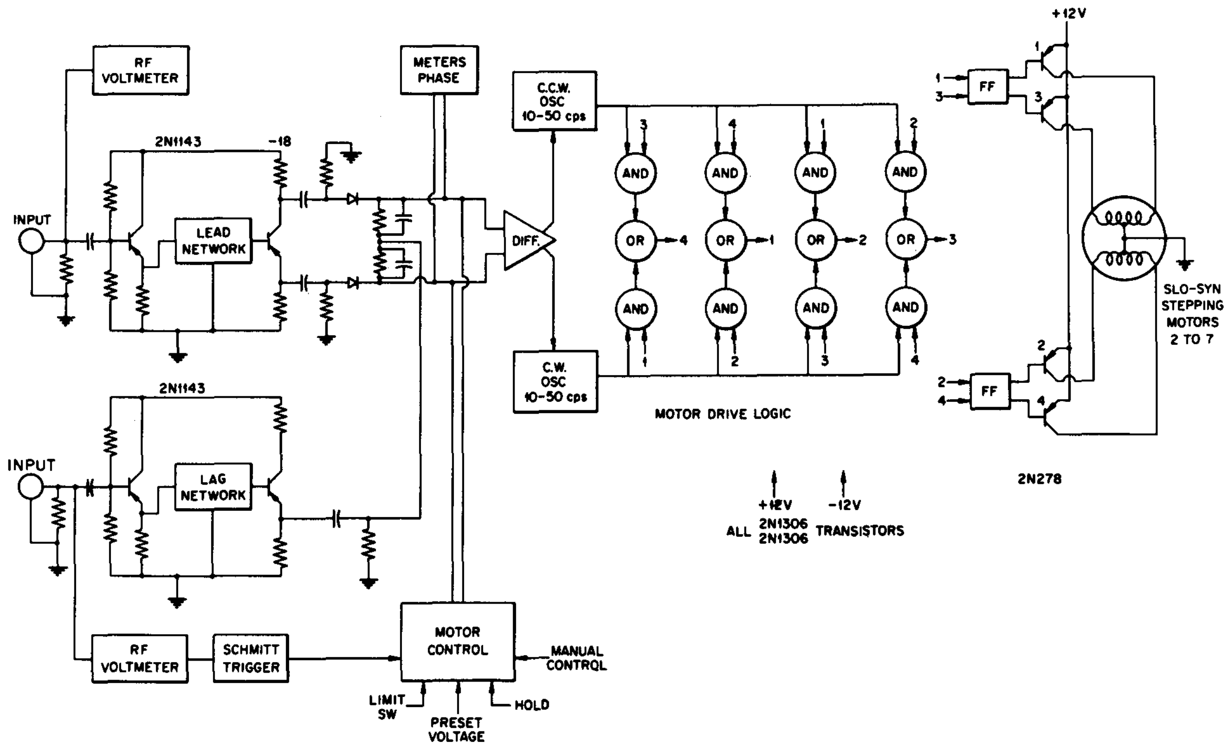

Fig. 4 Typical automatic tuning servomechanism.

Each tuning network must be pre-tuned to some point where the RF output exceeds noise level before the automatic tuning servos begin to operate. A recently installed pre-set tuning system adjusts all tunable components and band switches within 0.1 Mc/s of the intended frequency of operation. The system is actuated by a pair of rotary switches on the control console; they are calibrated in megacycles and tenths of megacycles. A typical pre-set loop is shown in Fig. 5. Six of these loops are now in service for pretuning IA capacitors, DA capacitors, DA inductance, PA capacitors, PA inductance, and resonator trimmers. Two additional loops will be added later for the drive capacitor and the resonator shorting plane.

The startup of the RF system now has the following sequence : pretuning; neutralization of power amplifier; and application of RF excitation to resonator. While excitation is being applied, the trimmers are adjusted for resonance, at which point dee voltage appears. For an alternate approach, the master signal generator may be tuned to the resonator frequency. With the latter case, the automatic tuning servos keep the amplifier chain tracking along with the drive frequency. During the tuning process, the power-amplifier plate RF voltage is usually set at approximately 4 kV. This level is sufficient to keep the tuning servos operating; and it will cause significant dee voltage to appear as resonance is approached.

There are four RF voltage regulator loops and one d.c. voltage loop, shown in Fig. 1. Currently, only two loops are in service. The other three will be installed as soon as machine time becomes conveniently available. Of the loops in service, the

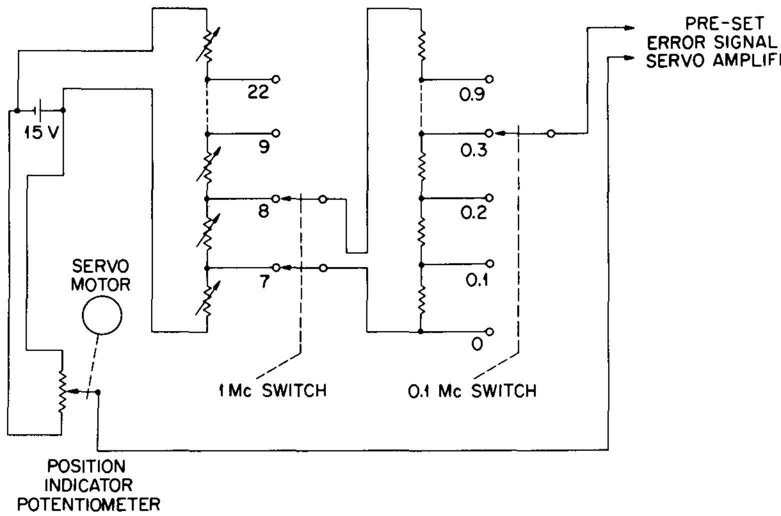

Fig. 5 Typical tuning servo pre-set control.

intermediate amplifier unit has already been mentioned. The second loop is being used as an RF voltage limiter on the power-amplifier plate, to prevent excessive voltages from occurring on the resonator drive line. The plate and drive line RF voltage tend to rise whenever the resonator is detuned by a spark or other disturbance. A voltmeter on the power-amplifier plate senses the RF voltage level and provides an error signal for controlling the driver-amplifier grid bias.

The resonator spark-detection circuit, shown in Fig. 1, generates a 20 ms pulse to cut off the RF excitation whenever a spark occurs, as indicated by a drop in dee voltage and/or an increase in power-amplifier plate current. Since this circuit tends to be inadequate, additional loops are being designed. One loop will be triggered by a photoelectric device which senses sparks on the drive line. Temporarily, a photoelectric spark detector is being used in an alarm circuit.

The GL-7703 crowbar circuit, described elsewhere[2] is working satisfactorily. The circuit is set to trigger at 100 A and fires only a few times during a typical day of operation. The circuit was tested by placing a sheet of 4-mil copper foil on the HV bus and touching the foil with a grounding hook. With 25 kV bus voltage, the resulting spark melts a 1/16 in. dia hole in the foil. The quantity of copper melted indicates that less than 1 joule of energy, out of some 2,000 joule of stored energy, is dissipated in a spark.

The ORIC RF system has operated quite satisfactorily over the lower portion of its frequency range. The stability, the simplicity of operation, and the dee-voltage capability exceed design expectations. Operating at higher frequencies will be attempted in the near future, when the necessary additional transient-protection circuitry becomes operational.

References

1. R.J. Jones et al., Nucl. Instr. and Meth. 18-19, 46 (1962).
2. N.F. Ziegler, Nucl. Instr. and Meth. 18-19, 197 (1962).

DISCUSSION

WATERTON : Could you simply explain the reason for the 90° phase difference between anode voltage and the dee voltage?

WORSHAM : The coupling system between the anode and the dee is equivalent to a quarter-wave transformer.