TRIUMF CYCLOTRON RF SYSTEM IMPROVEMENTS

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ABSTRACT

The 1.8 MW, 23 MHz RF system for the TRIUMF cyclotron has been in operation since 1974. In order to improve reliability, ease maintenance, and increase efficiency of the power amplifiers, a program of upgrading some system components and retuning the four amplifier, three combiner system has been undertaken. Measurements were made on the amplifier input/output circuits and combiner circuits to understand their theory of operation and to determine the modifications and retuning required. Analysis of these measurements, modifications incorporated and future modifications required are reported.

1. INTRODUCTION

The TRIUMF cyclotron RF system has undergone many improvements over the original system supplied by Continental Electronics[1] in the early seventies. This system has been described in many papers[2], but many of the modifications have not been reported. Many of these changes have come about as a result of fault diagnosis, and some have evolved from a need to more easily tune, service and repair the RF system.

A simplified diagram of the system is shown in Fig. 1. The RF system consists of a solid state preamp driving a two stage intermediate power amplifier up to the 30 kW level. This power is then split four ways through a pi network phasing circuit to drive four power amplifiers. The 250kW outputs of these amplifiers are then recombined using three 4-port hybrid combiners.

Tuning the amplifier input circuits, output circuits and combiners has been very difficult due to a lack of diagnostic signals and a less than full understanding of the circuitry. Diagnostics have been installed and extensive measurements taken to ease this difficulty.

2. PA INPUT CIRCUIT

The power amplifier input circuit consists of a pi network

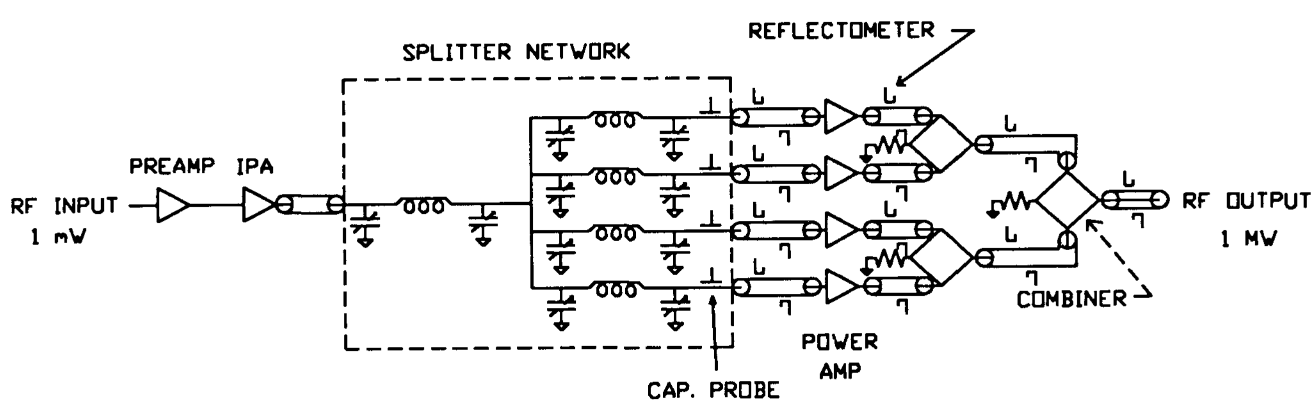

Figure 1. RF System Diagram

with a toroidal transformer to match the 50 ohm input to the push pull grounded grid tubes. Although simple in principle, the circuit is much more complex in practice.

Signal level measurements and tuning revealed many resonances and some unpredicted behavior. In order to tune the input circuit at signal level, it is necessary to place external loads between the grids and cathodes of the tubes to simulate the dynamic operating impedance of the tubes. Since one cannot physically place the calculated dynamic load impedance inside the tube, it must be transformed through the various structures to the point where the external load can physically be connected. However, determining what this external dynamic load should be was the result of many hours of measurements and computer modeling. Network analyser and vector impedance measurements were taken in order to develop a model of the input circuit[3]. A computer program was written to simulate the response of the circuit, and predict the external dynamic load values. The simulation proved to be very close to the measured parameters, and yielded a value of 22 ohms in series with 80pF for the needed external dynamic load.

3. REFLECTOMETERS & PROBES

In order to balance the outputs of the four power amplifiers and tune the combiners, reflectometers were installed in all of the 9 inch transmission lines, as shown in Fig. 1. These reflectometers allow precise adjustment of the amplitude and phase of the RF at each port of the amplifier-combiner system and the input impedance of the combiners to 50 ohms.

Each reflectometer signal is brought to a patch panel via identical cable lengths so that phase accuracy is maintained. In addition, capacitive probes located at the splitter outputs, PA cathodes, and PA anodes provide additional signals at the patch panel. A permanently mounted vector voltmeter and an oscilloscope adjacent to the patch panel allow easy measurement of power level, phase at any point in the system, the VSWR on any line, the phase shift through any components, and the power level at dirrerent points along the amplifier chain.

4. COMBINERS

A schematic of the four port combiner is shown in Fig. 2. The capacitance is provided by Jennings vacuum capacitors and the inductance by 1.5 inch diameter copper pipe, which makes the connections between the ports requiring an inductive path. Not shown in the schematic are 4 parasitic mode dampers which are required because of the arrangement of the components in a large volume housing.

A 50 ohm resistive load , refered to as a waster load is required at the port opposite the output port to provide a dissipative load for unbalanced currents and in the event of a failure in one of the input amplifiers. The waster loads which were supplied with the original RF equipment are a

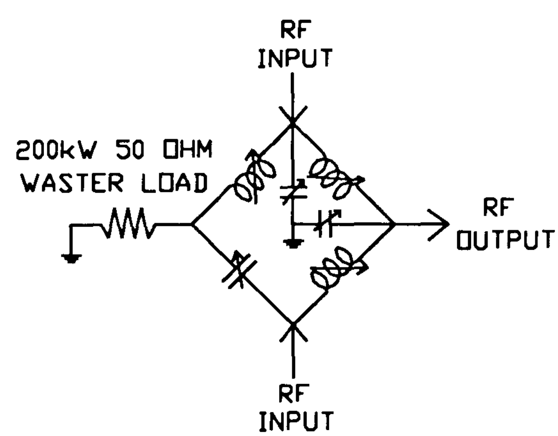

Figure 2. Combiner Schematic

circulating column of water doped with sodium nitride to provide a 50 ohm impedance. When the combiner is properly tuned and terminated the input ports should provide a 50 ohm load for the amplifiers and minimun power should be dissipated into the waster load.

Initial measurements with the reflectometers clearly indicated that the input impedances were not 50 ohms and that the combiners needed retuning. Because of the mechanical design of the combiners, terminating the ports with 50 ohms was not possible without dismantling and moving around long lengths of nine inch transmission line. A scheme was developed where the soldered-in transitions from the nine inch lines to the combiner circuit were replaced with removable brass cones using finger stock contacts. These allowed the easy termination of any of the combiner ports, the termination of the power amplifiers, and the ability to disconnect the output transmission line to the cyclotron for resonator measurements. Special fixtures were fabricated to allow easy connection of BNC cables and 50 ohm loads to the combiners.

Extensive measurements were then taken using an HP network analyzer and vector impedance meter. A 50 ohm matching point at the input ports of the combiners could not be attained because the inductances in the phasing and matching networks were too large. A new mechanical design of the combiner is being developed to reduce this inductance as well as hopefully reducing some of the parasitic modes also present in the combiners. However the above modifications enabled the matching at the input ports to be greatly improved from the initial values.

The impedance of the sodium nitrite waster loads used as the load for each combiner is very sensitive to temperature variations, and consequently they would not present a 50 ohm load to the combiner under all operating conditions, especially when trying to tune at signal levels. These waster loads have been replaced with Altronics 57200 BE6 water cooled 200 kW resistor loads, which are not only extremely clean and simple, but also present 50 ohms to the combiner at all times.

The original waster loads were designed for up to 600 kW of power dissipation, while the new loads are only rated for 200 kW. In order to protect these loads, interlocked water flow meters are installed in the cooling lines, as well as power level sensing and trip circuits which disable the RF drive if too much power is fed to the loads.

With the aid of the new reflectometers, the amplifier system can be tuned so that there is less than 1 kW dissipated in each load during normal operation.

5. PLATE CIRCUIT

The power amplifier plate circuit was difficult to tune due to lack of a reliable method of measuring the plate impedance of the amplifier, and an easy way of terminating the amplifier with a 50 ohm load.

The plate circuit output transformer primary is attached to the anode of the tube at one point only, causing anode current to flow asymmetrically on the anode ring. As a result the impedance measured at the anode varied substantially at different points around the anode ring. A jig was fabricated to ensure that the HP vector impedance meter probe was held at a particular position on the tube's anode for all measurements so that consistent measurements could be taken. The plate circuits were tuned for 600 ohms plate to ground at 23 MHz, to correspond to the value calculated from the characteristics of the tube and the tube's operating currents. This resulted in an amplifier efficiency increase from 50% to 62%.

Mechanical modification to the combiners with quick disconnect connectors has made terminating the amplifier with 50 ohms much easier.

6. OTHER IMPROVEMENTS

There have also been several other small but significant improvements made to the RF system. The tube sockets were completely overhauled, and were reassembled using Dow Corning DC4 silicone on all Kapton bypass capacitor surfaces. In addition Dow Corning 3140 RTV silicone was used on all external edges and bolt holes in an effort to waterproof the sockets. These measures have proven very successful and have eliminated the need to overhaul a socket in the event of a water leak on to the socket.

An intermittent parasitic oscillation in the screen circuits of the amplifiers, which would usually damage the screen power supply and choke, was damped successfully with two Ferroxcube 3C8 torroids placed over the screen series resistor.

The RF controls were modified so that the RF drive was cut off when a resonator spark was detected. This was supposed to be how the original controls were designed, but the circuit did not work properly, and tried to increase drive in closed loop to regulate the resonator voltage. The result was often a crowbar in the high voltage plate power supply, but sometimes a spark and water leak in an amplifier would also occur. Since this repair, no similar sparks or leaks have occurred.

7. CONCLUSIONS

The modifications described have proven extremely useful in both diagnosing RF system faults and reducing beam off time due to RF failures. It is now possible to easily measure many system parameters which were difficult or impossible before, thereby making tuning a straightforward task. Amplifier efficiency has improved, components run cooler and last longer. Measurements have shown a need to redesign the combiners, and this task is now proceeding. For further improved reliability, two power amplifier operation with two amplifiers on standby is also being investigated.

8. ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Norman Carlson, Vojta Pacak and Robert Worsham to the work described.

9. REFERENCES

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