# A MODULAR RF CONTROL SYSTEM AT TRIUMF

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## Summary

New rf systems planned for installation at TRIUMF in the near future include a third harmonic flat-topping system, a fourth harmonic booster cavity and an rf extraction deflector operating at the 11.5 MHz subharmonic of the main frequency. A new modular rf control concept is being adopted to develop the basic building blocks for each of the required rf control systems. One of the main design considerations is that all parameters are to be accessible and controllable by an external central computer. This will permit the computer to utilize expert systems and adaptive control techniques for remote debugging and loop parameter optimization. In order to carry out diagnostics on individual rf systems it is necessary that the control system be totally operational in a local manual mode, independent of the central computer with smooth transitions between computer and local control. This paper discusses the design of the new control system and its application to a full power flat-topping rf model cavity.

## Introduction

The resonator for the main TRIUMF rf system consists of two quarter-wave flattened coaxial stubs facing the dee gap as in a conventional two-dee cyclotron and is contained within a large vacuum vessel. At present the resonant cavity is excited at a power level of approximately 1 MW to achieve a dee-to-dee voltage of 200 kV at its fundamental TEM mode resonant frequency of 23 MHz. The amplitude is regulated to four parts in $10^4$ and there is no phase regulation. Proposed rf improvements for TRIUMF include flat-topping the the main rf waveform by means of simultaneous excitation of the main resonant cavity at its third TEM mode resonant frequency. Several new rf systems are also to be installed in the vacuum chamber in a region external to the main rf resonator. These include high power booster cavities operating at the fourth harmonic of the main fundamental frequency and an rf extraction deflector operating at half the fundamental frequency. The most demanding from the control point of view is the rf flat-topping system where the amplitudes and phases of both the main and third harmonic frequencies must be controlled to a high degree of precision.

A new modular rf control concept is being employed at TRIUMF to develop the basic building blocks for each of the required rf control systems.[1] The modular approach offers the advantage of reduced development time and allows easy upgrading since the components are readily interchanged. Because of the inherent flexibility of the modular approach, adapting the control system for the different rf requirements requires little change in the basic design. Essentially only the rf components (detectors, filters and modulators) as well as the transfer function of the regulation amplifiers need to be changed. This makes serviceability easier and quicker as most components are common between the systems. The unique problems associated with each of these rf systems, such as heating, multipactoring, amplifier stability, etc. are usually difficult to anticipate. Moreover, the overall system transfer function can in most cases only be estimated. A local manual mode of operation that is simple to use and that provides the system status information in a readily understandable form is therefore essential. It should have direct control of rf parameters such as drive levels, limit set points and pulsed/cw operation. Open and closed loop operation should be easy to implement and it is desirable to have control of the gains and time constants of the regulation amplifiers.

Traditionally, computer control of rf systems has been limited to supervisory tasks, and control of set points as wide bandwidth regulation and stabilization could only be achieved with analog circuitry. It is not desirable, however to be limited to a static control system. Hence in the present design the computer will be able to access control the internal parameters of the rf control system. This will allow the computer to compensate for unknown effects such as aging vacuum tubes and drifting cavity Q's. Where several rf control systems are involved, the different systems may be coupled by effects such as beam loading. These problems can be more readily evaluated and resolved through the use of expert systems and adaptive control techniques. Such a control system system needs two distinct and completely functional modes of operation: a local/manual mode and a remote/computer mode. Changes between modes must not introduce discontinuities in any of the internal parameters. This paper discusses the general design of the new control system and how a smooth transition between the local and remote control modes of operation is realized.

## Control System

To achieve the goal of straightforward operation and to provide the status in a readily understandable form it was decided to incorporate the SIN[1] philosophy for front panel design. The front panel layout that will be used for the new TRIUMF rf control system is shown in Fig. 1.

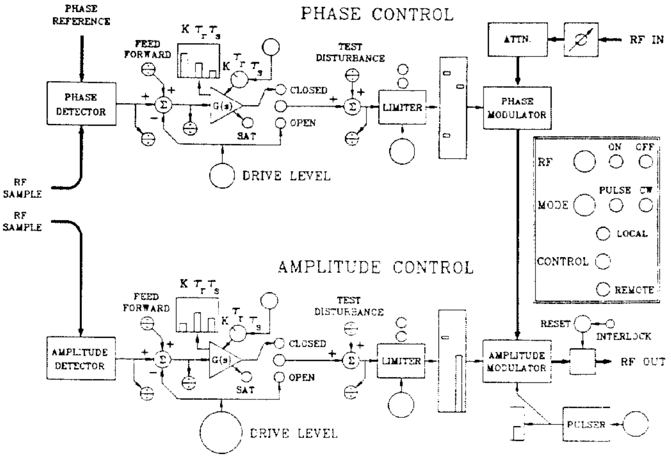

Fig.1. Front panel of control system.

The major components of both the phase and amplitude control loops are shown on the front panel along with the display of status. Bar graph displays are used to show drive signals and limit values. Manual control of the drive and limit set points for the rf amplitude and phase and the gains and time constants of the regulation amplifiers is accomplished using 'soft knob' digital shaft encoders. To facilitate system maintenance and development strategic points within the control loops are accessible on the front panel. This provides flexibility for system development. For example, measurement of open loop transfer functions can be accomplished by providing a swept frequency signal at the test disturbance input. Inputs are available for feedforward compensation. This can be used to compensate for known, periodic beam loading effects or for other schemes to decouple the phase and amplitude control loops.

A block diagram of the internal layout of the control system is shown in Fig. 2. There are two basic sections: the rf section consisting of the phase and amplitude detectors and modulators and the low frequency section consisting of the control and regulation electronics. The low frequency section interfaces to the front panel and the

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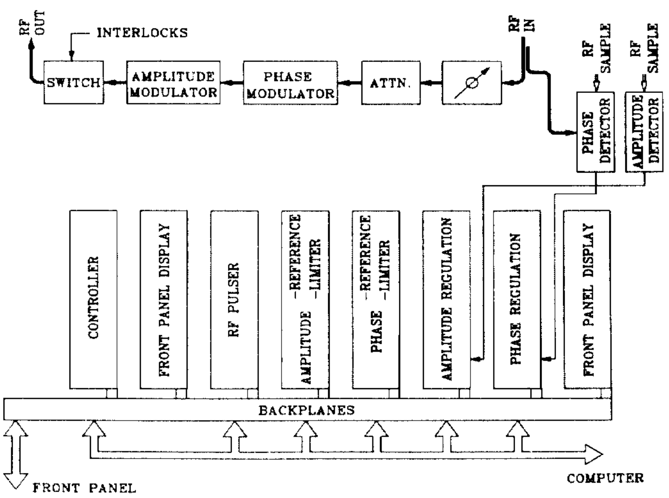

Fig. 2. Block diagram of control system.

computer. Considerable attention was given to designing the system in a manner that would minimize rf interference and ground loop problems. All of the rf components are constructed in separate, well shielded boxes. All signals that originate externally, either from the front panel or the computer, are electrically isolated from the internal electronics of the control system. This is accomplished through the use of opto-isolators for digital signals and wideband isolation amplifiers for analog signals.

The low frequency section consists of eight boards of VME physical dimensions that are interconnected through dual backplanes. There are two boards for controlling the front panel displays, an rf pulser board for pulsing the rf with variable duty cycle from 0 to 100%, phase and amplitude reference/limiter boards which control the amplitude and limit set points, and the phase and amplitude regulation boards. A block diagram of the amplitude regulation board is shown in Fig. 3. The upper section contains the circuitry for interfacing to local control from the front panel or remote computer control. This section is also common to the phase and amplitude reference/limiter boards and the pulser boards. The local/remote mode is selected through the remote enable line. The value for any control or rf parameter is held in the up/down counter and can be changed incrementally when the mode is in local and in a parallel fashion when the mode is in remote. The quadrature outputs from the shaft encoders are decoded and the resulting signal increments or decrements the selected up/down counter. This ensures a smooth transition when the mode is changed from remote to local. The central computer communicates with the up/down counters through external input and output registers. Thus the controller can be used with any computer bus architecture.

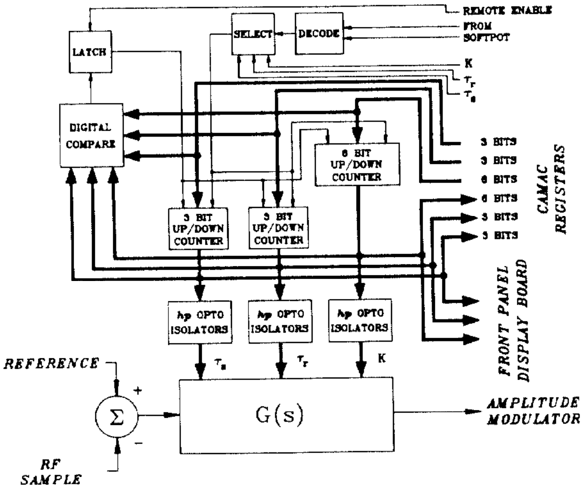

Fig. 3. Amplitude regulation board.

A single board computer with 32-bit input and output registers is used as a programmable logic unit to implement such functions as rf on/off, rf pulsed/cw, and opening and closing regulators as indicated by the front panel. The device performs supervisory functions only and is not located within any control loop. Since computer speed is not critical it can be programmed in a high level language to reduce the software development time.

## RF Test Facility

Testing of the new rf control system design will be done in the TRIUMF rf test facility[2] shown in cross section in Fig. 4. The rf test facility consists of two TRIUMF resonator segments positioned one above the other, fluxguides and a shorting plane at the dee tip to form a simple coaxial $\lambda/4$ resonant cavity. The electrical characteristics are equivalent to those of TRIUMF.

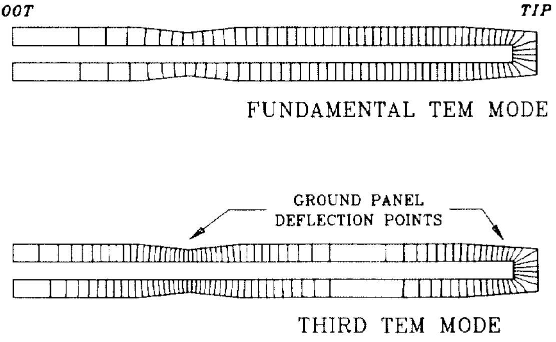

Fig. 4. Cross section of test facility.

The cavity can be excited simultaneously at its fundamental and third TEM mode resonant frequencies through individual coupling loops requiring two control systems to provide a stable flattopped rf waveform at high power. Tuning of the cavity to obtain and maintain a precise ratio of three between the resonant frequencies is accomplished through deflections of the ground arm panels as indicated in Fig. 4. Successful flat-topping tests have been carried out at voltages near the present TRIUMF operating levels (86 kV) using prototype feedback modules. These tests demonstrated the feasibility of simultaneous excitation of a single cavity at high power to achieve a controlled flattopped rf waveform. The next step in the program is to increase the flattopped voltage level to 100 kV as this will be the value required at TRIUMF. The fundamental power amplifier has been upgraded to make this possible.

## Central Control

An important feature of the present system is the ability to carry out control and diagnostic functions from either the local (hardwired) console or from a remote computer terminal. As shown in Fig. 3., the values of all set point and readbacks are buffered out to external parallel registers (in this case to the TRIUMF central CAMAC system). This provides the capability for the central control system to observe and track the behaviour of rf parameters during manual adjustment and operation. For write operations, a potential problem arises when the transition is made from local to remote control. If the value in the output register does not correspond to that in the up/down counter a jump will result when the transition is made. This problem is resolved by a digital comparator which does not permit remote control until the computer has matched the values in the output registers to those of the the up/down counters. The central computer must take care of the queueing of multiple requests to change parameters of the control system to ensure the integrity of the bits, since the bits are written in parallel.

A block diagram of the fundamental and third harmonic rf systems and central computer link required for the test stand is shown in Fig. 5. Operators in the central control room interact with the rf control systems through the existing console. Although all rf internal parameters are accessible by the central computer, the most common usage by the accelerator operators is for setting rf amplitudes, frequencies and relative phases, to compensate for such effects as beam loading. Using interactive graphic tools developed at TRIUMF,[3] graphic displays emulating the local console are being developed for use on standard color graphics terminals which may be located anywhere on or off site. This permits the rf expert to carry out diagnostics from any location, even from his home. Software packages are written as required for new and unanticipated situations, and to automate routine sequences for spark recovery and cavity tuning once they have been tested by the expert.

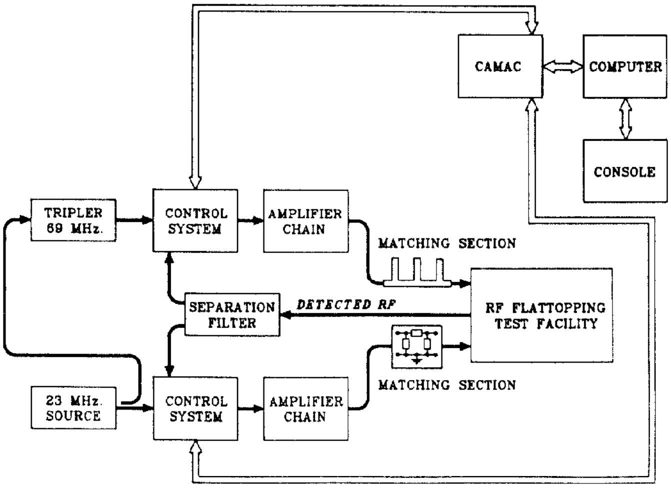

Fig. 5. Control systems for rf flat-topping in the test facility.

## Conclusions

A modular rf control system design is described, with simple but flexible access to a central control system. The system is easily configured and adapted to suit the specific requirements of different rf systems. Replacement of individual modules due to component failure or to introduce improvements is straightforward. Access to a central computer will enhance troubleshooting and permit the use of adaptive control techniques.

## References

[1] P.Sigg, TRIUMF Design Note TRI-DN-85-27

[2] T. Enegren, L. Durieu, D. Michelson, and R. E. Worsham, "Development of Flat-Topped Voltage for TRIUMF," IEEE Trans. on Nucl. Sci. NS-32

[3] C. Kost, M. Mouat, and D. A. Dohan, "Applications of High Level Programs in a Control Environment", in these proceedings.