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# CONTROLS FOR OPERATING AND PROCESSING THE MIT-LNS LINAC*

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## Summary

The Central Control Room for the MIT Linac is designed for simplicity of operation (one man) with an eye on future use of a computer to set the desired operating parameters. A natural summing of local controls around the five RF driver/dual-modulators and the injector/master oscillator control room allows one to switch to the display and control of the six areas one at a time with a trunk line. The distributed parameters (magnetics, radiation and RF phase monitoring) are mostly monitored and controlled directly from CCR with pushbutton selection of each parameter. Also mentioned are the detailed results of RF processing the 7m, S-band accelerator sections with 15μs, 4MW pulses at repetition rates exceeding 1000 $s^{-1}$ and phase tuning the rectangular waveguide networks using a combination of the SLAC method and beam loading maximization.

## Introduction

The final design for the central control room (CCR) of the Bates Linear Accelerator was formulated recently after examining our pocketbook, our construction schedule, available surplus instruments and cable, an airplane cockpit and SLAC's touch panel controls. Simple, direct, one-man control of the gun, RF power, RF phasing, triggering and beam centerline magnetics was deemed essential. To accomplish this the primary controls are located within arm's reach on a few panels in front of the operator. Secondary metering functions (vacuum) are easily viewed by turning one's head. The control console consists of fourteen, 2m high relay racks arranged in a bulging L configuration. (Fig. 1) It is probable that the accelerator, the beam switchyard and the experimental areas will have their controls somewhat amassed together in an amorphous control room, so only 50% of the rack space was initially allocated for the accelerator controls. In general the panels are laid out from right to left which is the beam direction from the operator's viewpoint. Cable trays emanate out from the top and toward the back of the console to run the length of the RF gallery, down into the accelerator and beam switchyard vaults over the machine and to various points associated with the experimental areas. Future interfacing of monitoring and control functions to a PDP 11/45 computer, for instance, either for reasons of better optimizing the beam into our spectrometer or for more automated control, should be eased considerably by the general use of switched motor-driven controls and switched digital metering (selected as desired by a combination of several pushbuttons).

## Control Console

From numerous panel discussions and the above potpourri of considerations emerged a functional layout for the control console panels (Figs. 2 and 3) that approximates the one-man, one-digital voltmeter principal. That is to say, the operator's focal point is a single digital voltmeter (DPM), surrounded by function indicating lights, pushbutton selector switches and several control switches (increase/decrease, up/down and right/left). The Lone Ranger (DPM) has his sidekick, Tonto, on his right in the form of a digital display for monitoring the RF frequency and the trigger generator pulse width, delay and repetition rate. Supplementary monitoring is provided around the periphery by: 1.) oscilloscope displays of the beam pulse, the RF power to the accelerator loads, and the pulsed cathode currents of the ten high power klystrons, 2.) an FET-multiplexed oscilloscope display of 30, Compton battery, radiation detectors[1] located along the machine and into the switchyard for machine protection and to aid steering control, 3.) a bank of 32 edgemeters for simultaneous display alternately of horizontal or vertical steering coil currents, 4.) a digital temperature meter that monitors accelerator section, rectangular waveguide and cooling water temperatures using standard thermistors accurate to better than 0.1°C, 5.) individual current metering of the vacion pump power supply[2] currents, 6.) metering of beam shut-off ionization chambers and residual radiation detectors, and 7.) several status light panels indicating the operational states of the transmitters, beam, steering detectors, panic circuit and search network.

For purposes of remote control the machine is divided into eight zones or locations (Fig. 4): injector (I), master RF oscillator-amplifier (O), the five transmitter stations (1,2,3,4,5) and all the magnetics-steering, focus solenoids, lenses, and quadrupoles-(M). Since these locations are geographically somewhat distinct and the units at the locations were designed to be largely self-contained and self-protecting (Fig. 5), they are selected one at a time for control and metering by a row of eight interlocking pushbuttons above the control console DPM. A second pushbutton must be depressed, either on the magnetics panel above, if the M button is chosen, or in the row below the DPM if one of the other seven locations is desired. A few toggle switches above appropriate buttons in the bottom row provide further subdivision or refinement of control. Electrical release solenoids on the switch banks will pop out impermissible combinations of depressed buttons. Two lights around the DPM will light up indicating which location and which function at that location is being monitored on the DPM. The control switch or switches, appropriate for the DPM, light up, and furthermore change color when operated. A cluster of four, doubly-lit, pushbutton switches are arranged in an X-Y coordinate configuration (up, down, right and left) for steering and focusing controls. Lighting of the horizontal or vertical pair of switches indicates whether a horizontal or vertical coil reading is being displayed on the DPM. Transfer of control and metering to the other axis is achieved by depressing a button in the center of the switch cluster or by depressing a switch on the desired axis. There are only two more control (increase/decrease) switches for the main part of the machine. One is to the left and below the DPM and operates in conjunction with the ten selection pushbuttons below the DPM, which control: the gun filament current, the gun high voltage, the gun current, the chopper RF phase/power, the prebuncher RF phase/power, the two RF phase shifters at the input to each pair of high power klystron amplifiers, the drive klystron voltage (gain), the modulator switch tube drive (klystron cathode current) and the modulator high voltage. The second control switch is to the right and below the frequency display. It is switched from RF frequency control to pulse width, delay and repetition rate. The trigger generator functions are completed with a toggle switch for 60 Hz line synchronization and a couple of thumbwheel switches, which allow the modulator and gun repetition rates to be divided by any power of 2 from zero to eight.

Below the DPM panel are the on/off controls and status lights for the gun and five transmitters. The gun controls are wired directly to the panel, whereas the five transmitters with identical controls are T-bar-relay switched onto a common trunk line, one at a time. Plug-in, PC board-mounted, relay trees and binary encoders are used extensively to route control to the appropriate function. Metering on a single DPM is accomplished with a combination of crossbar contact relay trees and crossbar contact pushbutton switches. Light emitting diode lamps are used in conjunction with most of the pushbutton selection switches and status lights because of their long life and soft but distinct lighting capabilities. The machine road map panel, on which the summary status of all major systems are indicated, uses standard miniature incandescent lamps to allow assignment of different colors to the vacuum, RF, video, steering, gun, search gates, et cetera, statuses.[3]

## Cabling

The linac building is small enough, as accelerator facilities go, to avoid remote multiplexing for most of the controls. The transmitters and parts of the injector control room (ICR) share two 57 conductor cables that run from CCR to ICR with five transmitter drop-offs, alternately selectable thru 96 poles of T-bar switching at each location. Additional navy surplus, armored, 57 conductor, #18 AWG wire in the form of 19 shielded triplets that are directly connected from ICR to CCR, bring the total to about one kilometer for the spinal cord for the accelerator magnetics, transmitter and injector controls and monitoring. Six kilometers of RG-59/U allows for direct connection of the vacion pumps to their power supplies in CCR and another five kilometers of RG-59/U bring steering radiation detector video signals from distributed points along the machine to CCR. Three and one-half kilometers of RG-223/U carry trigger signals to the five transmitters, PIN diode RF modulator and gun pulser and bring back on separate lines video current signals from the ten high power klystrons. Over two kilometers of Spirafil II, semi-rigid coaxial cable provide direct access to twelve RF monitoring points (mainly RF loads on the accelerator sections). Finally, two kilometers of shielded, #22 AWG, twisted triplets bring temperature information from 20 thermistors taped on to water headers.

## Accelerator RF Processing

The accelerator sections and rectangular waveguide networks were processed in place after final connection to the transmitters and evacuation. The processing was found to go most quickly if it was started with a very short RF pulse width, $\tau$, (usually 1.5μs from pulse turn on to onset of pulse decay) and a very low PRF (usually 2 $s^{-1}$). With the transmitter set for a saturated output of 1MW, the RF drive is brought on at a low level resulting in less than 100kW peak into the rectangular waveguide network (RWGN) and its one-half wavelength, rectangular window. At the above $\tau$ and PRF the peak power is brought up to its maximum (4MW) as quickly as outgassing, arcs, multipactoring and sputtering at the window and in the accelerator sections (CWG) allow. The PRF is then increased to 500 to 1000 $s^{-1}$ with $\tau$ = 1.5μs. The next step is to drop the PRF to 2 $s^{-1}$ and try to edge the $\tau$ out to 3 or 4μs, and then increase the PRF to 500 to 1000 $s^{-1}$ at the new $\tau$. The process is continued, always dropping the PRF as the width is increased. It is not unreasonable to sit at $\tau$'s of 3 to 4μs, 5 to 6μs, and 9 to 10μs on the way to the desired 18μs (15μs flat top) width. The above procedure is not the only way to process and indeed variations are often desirable or necessary. The primary effect of increased PRF is an increased rate of outgassing; however, high VSWR shut-offs will occur, too, especially due to effects at the RWGN window. During the initial stages of processing some sudden bursts of pressure can take five or more seconds to subside from, and may require temporary reduction in RF peak power and a slow return to keep the window from "sizzling" at a "poor" vacuum level for an indeterminate length of time. The high power klystron VSWR protection circuit is set conservatively to turn off video triggers to the series switchtubes for a reflected peak RF signal of 80kW (VSWR = 1.33 for 4MW peak). The vacion pump power supplies, which are interlocked to a mechanical RF switch with an 0.1 s switching time at the input to the drive klystron, are set to trip at $6 \times 10^{-7}$ Torr for the RWGN window pump and $3 \times 10^{-6}$ Torr for the CWG pumps. Provisions are usually made to monitor the reflected signal during processing in order to watch for particularly unpleasant-looking arcing. Additional processing is needed when the solenoid focus coils are turned on and not only at the maximum peak power level, but over all desired running powers. The processing time for 4MW, 18μs, 1000 pps takes at least 20 to 30 hours to reach a processing level that will allow the machine to run for a half hour between trip offs.

## RWGN Phasing

Phasing the 20 to 40m long double and quadruple output rectangular waveguide networks was done two ways. The last three quarters of the machine were phase using the SLAC method.[4] The three networks on the front end were phased, using a motor-driven, waveguide-wall squeezer while the beam was on, by monitoring the peak power in the RF loads associated with the two CWG's on a single network and operating the squeezer until the maximum beam loading dip was observed on each load for the same setting of the RF phase shifter (phase relative to the previous network). By checking $\pm 6^{o}\phi$ on both sides of the beam loading null, with an 8mA, 10μs beam and using a hot carrier diode detector signal of a few volts blown up to 5mV/cm sensitivity on an oscilloscope, phasing to within one or two degrees was possible.[5] The greatest attraction of the beam phasing method is that it can be done any time (when running) by connecting to the couplers on the desired RF loads, and also accurate, mechanical alignment in the longitudinal direction is not needed since that can be compensated for by network arm adjustment. The disadvantage is that it can not be done until the machine is running, and thus makes the initial beam threading more difficult and very time consuming, if stable operation of all RF systems has not yet been achieved.

## Acknowledgements

The design and successful completion of the CCR were very heavily dependent upon the efforts of the whole lab and in particular L. Stinson, F. Fay, J. Fish, J. Gano, J. Haimson, P. Keating, K. Rice, K. Richard and M. Riordan.

## Footnotes and References

1. This detector system was developed by F. Masse, K. Richard and M. Semo of this laboratory and is yet to be published.

2. Contrary to the general control philosophy of locating the power supplies near their loads, the vacion pump supplies were located in CCR because it was cheaper and easier to remote the pump than to remote the metering and control.

3. Not completed for the photos shown in Figs. 1 and 2, but to be installed above the bank of 32 edge meters.

4. J. Weaver and R. Alvarez, "Accurate Phase-Length Measurements of Large Microwave Networks," IEEE Trans. MTT-14, pp. 623-9, December 1966.

5. See photo of beam loading pulse in J. Haimson's article in these same transactions.

*Work supported by U.S. Atomic Energy Commission and Massachusetts Institute of Technology.

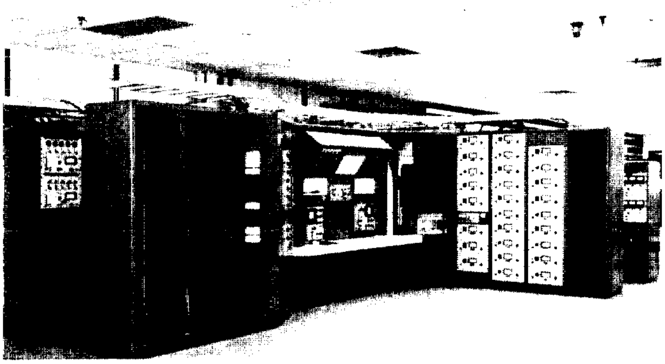

Fig. 1 - Accelerator Control Console in CCR

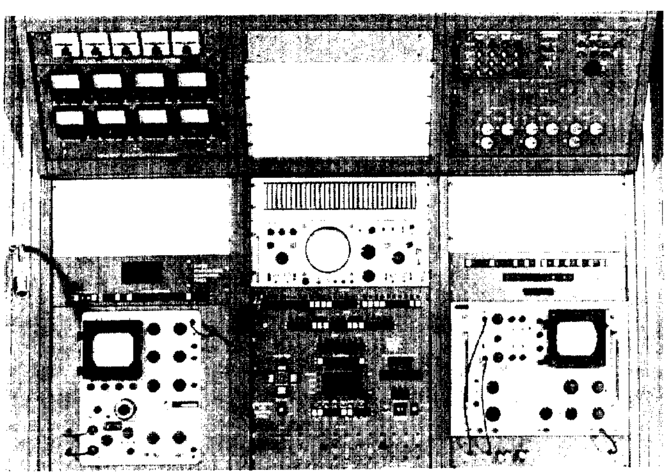

Fig. 2 - Accelerator Control Panels in CCR

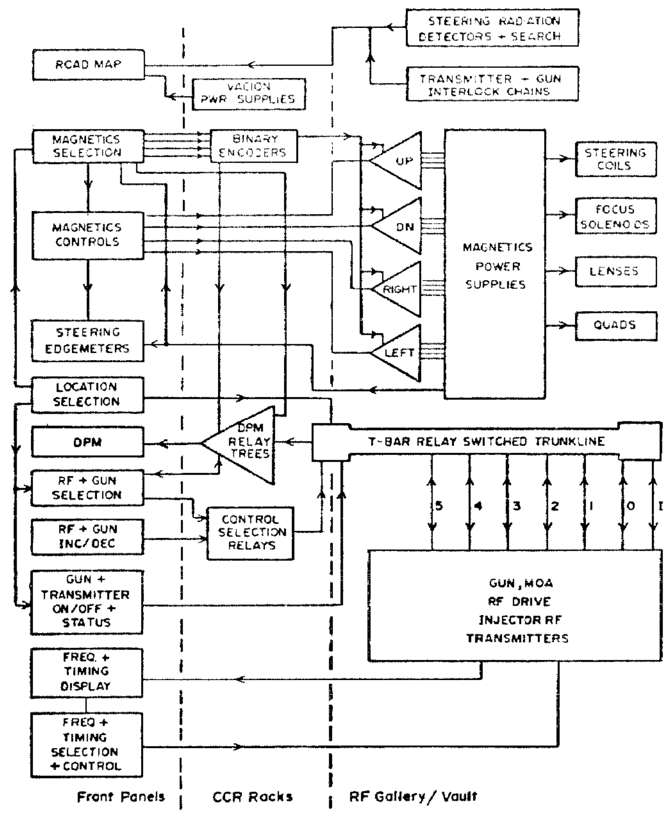


Fig. 3 - Block Diagram of Gun, Transmitter and Magnetics Controls and Metering in CCR

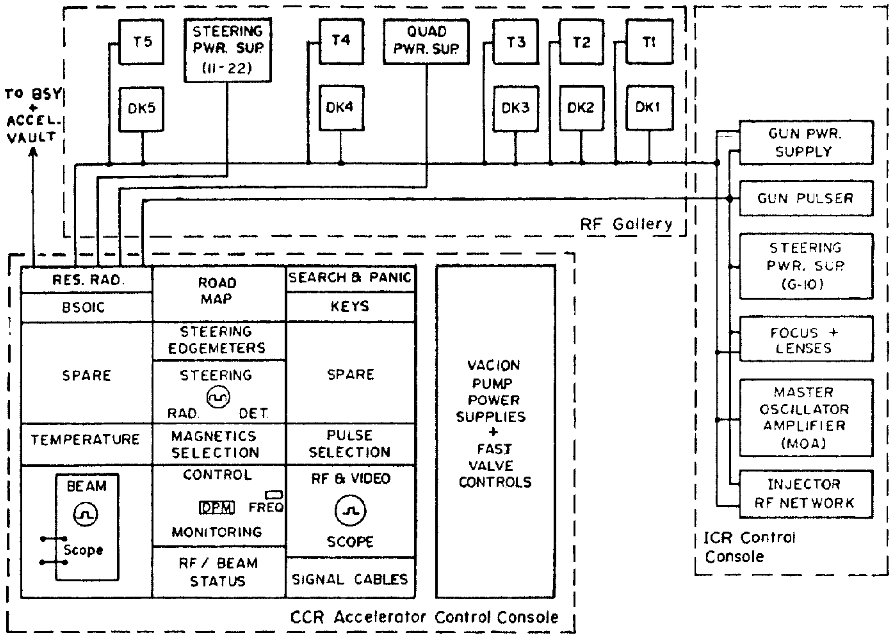


Fig. 4 - Block Diagram of Accelerator Controls

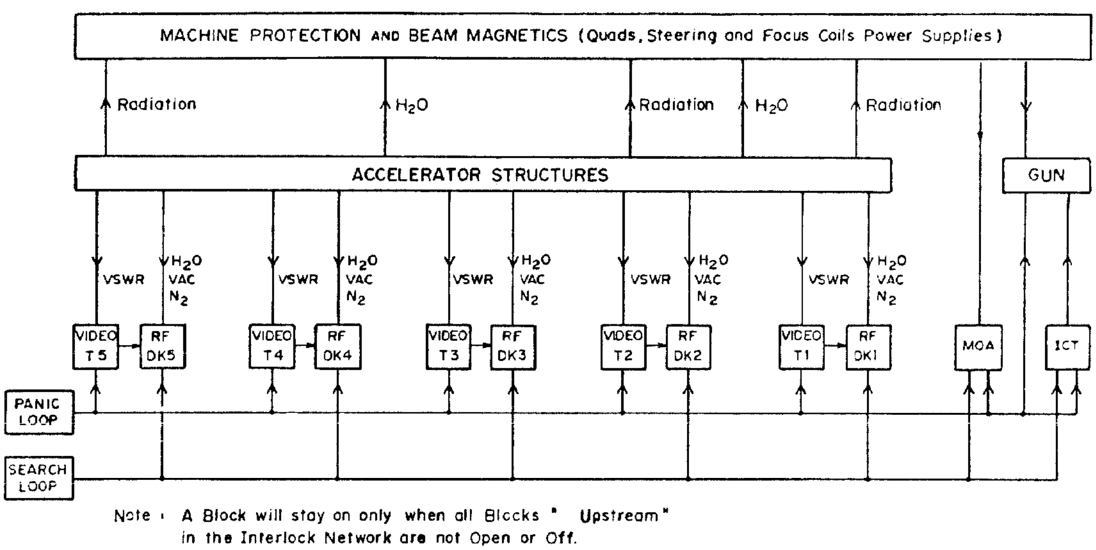


Fig. 5 - Main Accelerator Interlock Loops