RF DRIVE SYSTEM FOR THE CEBAF SUPERCONDUCTING CAVITIES

Jock A. Fugitt and Thomas L. Moore
Continuous Electron Beam Accelerator Facility (CEBAF)
12070 Jefferson Avenue
Newport News, Virginia 23606

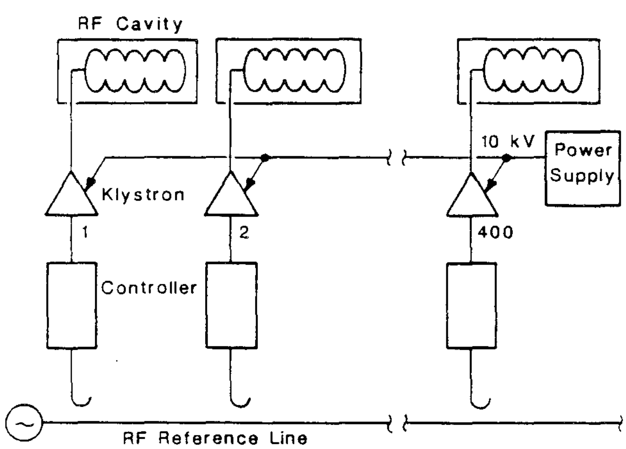
CEBAF-PR-86-006

INTRODUCTION

To obtain the maximum accelerating gradient, the CEBAF RF system uses an individually controlled RF drive chain for each superconducting cavity. This will allow us to adjust each cavity to its individual maximum field. Due to material purity and manufacturing tolerances of the cavities, we expect this maximum value to be distributed over an almost 2 to 1 gradient range. The requirement for precise individual phase and gradient control of 420 superconducting accelerating cavities, is accomplished through the use of individual fault tolerant RF drive chains and self monitoring control electronics. This might be thought of as the Phased Array* approach to accelerator RF systems.

SYSTEM OVERVIEW

The RF system consists of a stable, master oscillator with its various frequency outputs required for choppers, bunchers, accelerating cavities, and RF separators, distributed by a phase-stabilized network to each sector in the RF service buildings. The individual drive chains, one per accelerating cavity,(420 total), consists of: an RF control module, a 5Kw, highly VSWR-tolerant klystron, the waveguide feed components, including a directional coupler, a tuner, and the higher order mode (HOM) filter, and the superconducting RF accelerating cavity. The DC beam power for the klystrons is provided by several larger power supplies through a distribution network in each sector.



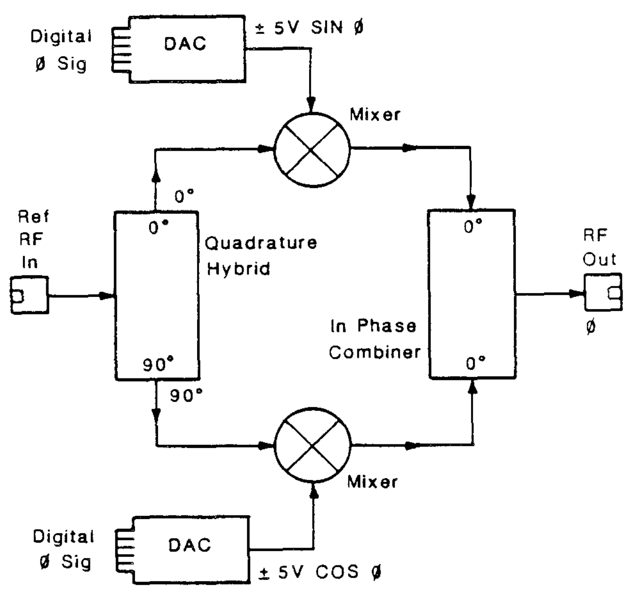
SIMPLIFIED SYSTEM BLOCK DIAGRAM

CONTROL MODULE

The key to the entire system is the RF control module, which has all circuitry required for control, regulation, and monitoring of an individual RF chain. This includes klystron control and protection, accelerating cavity monitor, tuning, and quench detection, beam permissive control (RF ready), and, of course, phase, gradient, and frequency regulation of each cavity. The controller is fabricated in a standard 3 wide CAMAC module for system standardization and ease of maintenance.

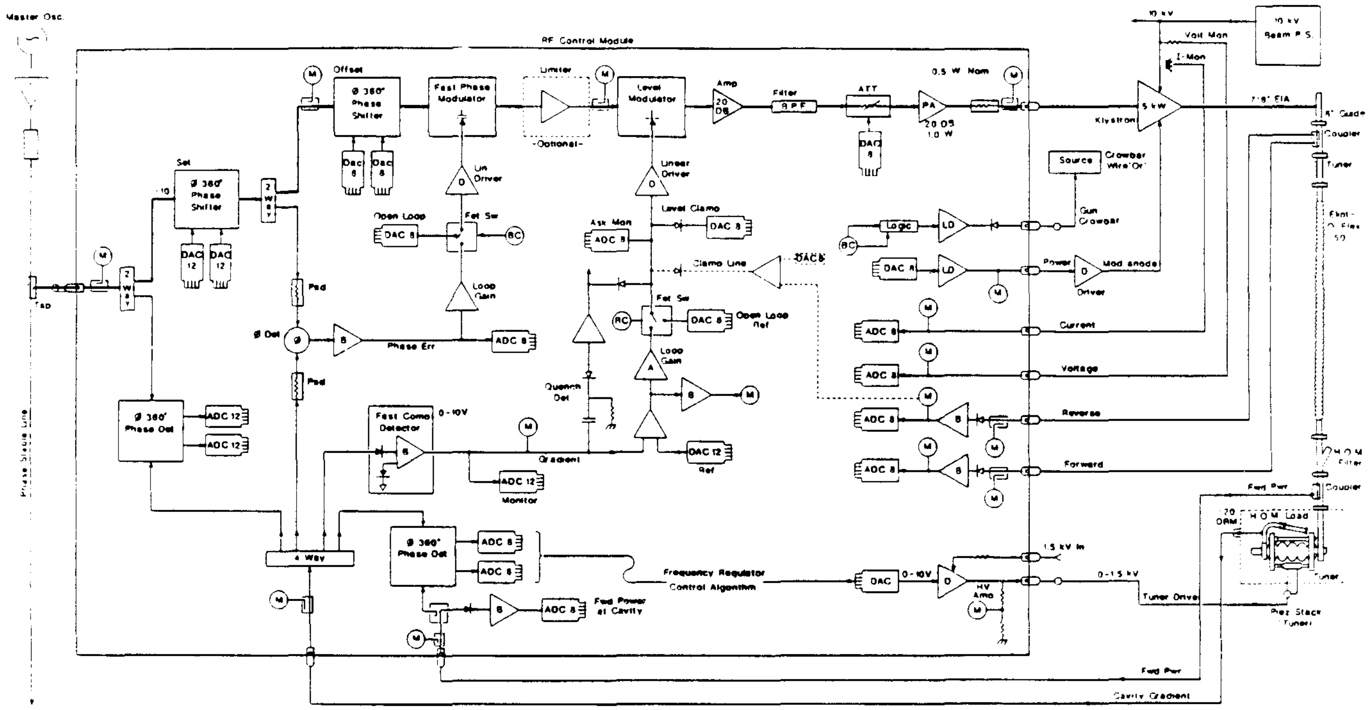
A large amount of local computing capability will be provided to reduce the programming costs, and enhance accuracy. Full use is being made of self-test circuitry, and "expert systems" maintenance and repair concepts. Linearization tables, system constants, module calibration curves, and maintenance history will be stored in on-board E^2PROM memory, and become permanant records in each individual module. All first line maintenance will be by module replacement; the failed modules will then be repaired and recalibrated using automatic test equipment at our central maintenance facility.

The control module will provide phase setability and regulation of the cavity RF phase to better than 1°. The regulator uses a complex phasor modulator (CPM) to provide a smooth, precise, 360° unambiguous computer-generated phase reference, and a similar, less precise device to remove accumulated phase offsets from the system. The fast phase regulator uses the traditional 90° nulling type phase detector and varactor modulator, in a closed loop servo regulator.



COMPLEX PHASOR MODULATOR

*This work was supported by the U.S. Department of energy under contract DE-AC0-84-ER4015.



SYSTEM DIAGRAM

The fast RF amplitude regulator uses a conventional analog control loop with a fast compensated RF level detector for feedback, and a 12 bit DAC as the reference. A slow amplitude control loop continuously keeps the fast loop centered in range to optimize klystron efficiency and system gain by adjusting the klystron modulating anode voltage.

The cavity quench detector is an integral part of the level regulator. When the cavity drive is removed, the voltage in the cavity normally falls at a rate set by the system Q, but during a cavity quench, the fall time can be much shorter. Any fast negative excursion of the cavity voltage will be interpreted as a quench, the RF drive will be immediately removed, and the injector gun inhibited. After a few seconds, the computer will reestablish the cavity voltage and ramp the beam current back to the previous operating level. If a given cavity continues to break down, or quench, its operating gradient will be automatically reduced by the control computer, and the difference made up in nearby cavities.

The frequency control system consists of a coarse mechanically-actuated pretuner, used on a one time basis to bring the cavities into the normal operating frequency range after cooldown. The small operational frequency changes, due primarily to pressure changes in the helium bath, are corrected for by a piezoelectric element in the mechanical tuner linkage. The electronic control circuit uses an unambiguous 360° phase detector to compare the phase of the incident cavity feed voltage, with the phase of the actual voltage induced in the cavity. The RF control microcomputer uses this phase signal to compute cavity load impedance, and readjusts the piezoelectric control voltage to keep the cavity always tuned resistively.

PARAMETER LIST

ACCELERATOR:		
Number of cavities	418	
Type	Superconducting	
Cells Per cavity	5	
Average field gradient	5	Mv/Meter
Maximum field gradient	10 ?	Mv/Meter
Otput energy	4-6	Gev
Number of passes	4	
KLYSTRON:		
Number on line	418	
Location	Klystron Gallery	
Output power	5 Kw max	
Focusing	Permanent magnet	
Control	Mod anode	
Beam powersupply	Central location	
Beam voltage	10	Kv
Frequency	1497	Mhz
Maximum VSWR	50:1	
TRANSMISSION LINE:		
Type	Flexible waveguide	
Size	1/2 high WR-650	
Length	15	Meters
Loss, typical	0.5	DB
CONTROL & REGULATION:		
Field gradient toll.	$1X10^{-4}$	
Phase regulation	1	Degree

KLYSTRON and TRANSMISSION LINE

With superconducting cavities, the RF power load results almost entirely from accelerator beam loading and can fluctuate from full load to no load, on a very short time scale. When beam is turned off, or is adjusted to a small value, the cavity looks like an open circuit at the end of the transmission line system. Under these conditions, the VSWR will be extremely high and unless the system is carefully designed, will cause arcing and klystron instability. The cavity coupling is chosen such that the VSWR will drop to a near matched condition when the accelerator is operating at full beam current. These problems could be circumvented by the installation of a ferrite circulator/isolator; the klystrons would then be operated at near full output and the excess power not required for particle acceleration would be dissipated in the circulator load. Unfortunately, the capital cost as well as the operating cost for such a system would be high.

Our choice then, is to design the transmission line as a voltage matching resonant system, and specify the klystron such that it will couple properly to a wide range of impedances. The klystron output gap is placed an integral 1/2 wavelength from the superconducting cavity accelerating gap. This will lock the klystron gap voltage to the cavity accelerating voltage over the full range of accelerator beam current. The maximum voltage in the transmission line system will be the same for all loading conditions, and the klystron output gap voltage will never exceed the klystron beam voltage. When the accelerator is operating at reduced beam current, the modulating anode regulator automatically adjusts the klystron beam current downward by a corresponding amount. Under these conditions, the system gain is reduced so the loop attenuator is readjusted to increase klystron drive. The transmission line maximum current value will naturally increase under low beam conditions. This is not entirely undesirable, since it tends to increase transmission line loss and help stabilize the klystron at these light load conditions.

An E and H plane, HOM filter is located in the waveguide system adjacent to the cryostat. The filter will absorb beam induced spurious frequencies emanating from the cavity, and prevent them being reflected back to the accelerator. The HOM filter will also absorb harmonics of the klystron output and prevent them from degrading the beam.

SUMMARY

The CEBAF RF system presents a challenging design problem. With over 400 individual RF sub-systems, the cost per system must be carefully controlled, yet system performance must not be compromised by inadequate design. System performance and reliability will be enhanced by using a considerable amount of computing power in the front end electronics. System reliability will be further improved by making the system fault-tolerant, that is to enable near full energy operation with a considerable number of subsystems nonoperational.