SUMMARY OF THE BNL 200 MEV LINAC HIGH POWER RF SYSTEM AND ITS INITIAL OPERATING PERFORMANCE*

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ABSTRACT

This report presents a brief description of the rf system and its components. Operational experience with the 10 MeV linac section and the introduction of high power into the third linac section are described.

Summary

The rf system for the 200 MeV linac will power nine accelerator cavities with 201.25 MHz, maintaining a constant tank gradient and phase with beam loading of 100 mA requiring a peak power of 6 MW. To date Tank 1 which requires 1.5 MW peak has been operational for a period of five months; Tank 3 has been powered at 4.5 MW without beam loading.

Description of the RF System

Each linac tank together with its rf system and other services forms a module, operated independently of other modules from a Local Control Station (LCS). The arrangement of the eight major units comprising one module is shown in Fig. 1.[1]

The 60 kV power supply provides 60 kV, 2 A via the charge control amplifier to charge the capacitor bank. The modulator controls the pulsed anode voltage delivered to the power amplifier anode; 201.25 MHz drive power for the power amplifier is provided by the driver amplifier. Phase and amplitude controls, monitoring, pulsing and timing circuitry together with interlocks, ac turn on, and HV turn on, are located in the Local Control Station.

The rf signal for each LCS is obtained from a reference line driven by the low level rf system shown in Fig. 2.

The crystal controlled oscillator frequency source (master OSC) has a stability of $1:10^8$/day, $1:10^6$/year. Two outputs are available -- cw at 1 dbm into 50 Ω load and 20 mW pulsed into 50 Ω load. A solid state 200 MHz amplifier provides inputs to main and standby rf distribution amplifiers, and each of the buncher drive amplifiers. (See Fig. 3.) A standby frequency source, distribution amplifier, and reference line are provided.

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At the module, the rf signal is processed by the frequency and phase control systems[2] (See Fig. 4). Both manual and motor driven phase shifters are provided enabling both buncher and tank phase adjustment. Each tank is connected to the LCS with rigid and coaxial lines for monitoring, frequency and phase control.

The reference line supplying rf to the LCS locations is a rigid 1-5/8" line with a power rating of 3 kW average with a VSWR 1:0 at 201.25 MHz, and a stability of better than 5 parts/million/°F at room temperature. Directional couplers are arranged to provide 160 mW at each LCS location.

The LCS rf output is at the 10 W level and is amplified by the driver amplifier providing 350 kW input to the power amplifier.

The output of the power amplifier is delivered to the linac cavity by a 12" coaxial transmission line system. Provisions are made for adjusting the loading position on the power amplifier for optimum output. Line electrical length adjustments are made by a variable phase shifter, and a power splitter provides power to each of the two tank coupling loops. Motor drives on the loops vary their penetration into the tank allowing for any variation in tank loading.

Preset tuners are provided for adjusting the tank frequency and field flatness. One tuner at the center of the tank is motor driven and controlled by the frequency control system.

Timing of the pulsed power supply and the driver amplifier is provided by a multiple delay generator triggered by the linac timing and synchronizing system.[3]

The generator output is processed by a "pulsing turn on" circuit ensuring that the phase relationship between pulses applied to various parts of the system is correct, and with provisions for pulse inhibiting in case of a fault condition being detected (plate arc, etc.).

Fast fault detection, crowbar, pulse inhibit, and stop charge circuits protect equipment components and provide indications of the source of trouble. Timing and fault protection circuits have been developed using standard multi-purpose printed circuit cards.[4]

RF System Performance

Tank 1 was powered and after the early multipactoring levels were broken through; we were able to drive the tank during the build-up period with a forward power of twice the value required for the design gradient. The large power reserve capability of 4.5 MW enabled us to obtain a closed loop rise time of 10 μsec to working gradient level.

Proper adjustment of the tank coupling loops and the tank tuner produced ideal loading conditions for the power amplifier during beam acceleration at 150 mA (See Fig. 5).

The prototype amplitude control system produced automatic amplitude correction for beam loading up to 150 mA to within 4%. The prototype phase control system was tried during the time that Tank 1 was accelerating beam -- some oscillations were observed, due it is thought, to interactions between phase and amplitude control loops. (See Fig. 5d.)

Tank 3 was brought up to working gradient without the multipactoring that was experienced with Tank 1, although it took several days of conditioning before the tank would hold gradient (3 MW) reliably. The maximum power that the tank was able to hold without sparking was 4 MW. The opportunity was taken to test the tank coupling loops by terminating the second drive port with a 50 Ω load. As in Tank 1 the vacuum window ceramics glowed during the breaking in period, after a week of operation at the 3 MW level, arcing started to occur during the turn off portion of the pulse. The condition worsened until all forward power above 2.5 MW was completely reflected. The loop assembly was removed and inspected. There was evidence of arcing from the loop capacitor plate to the outer conductor and also to the ceramic window. The capacitor plate was modified and the ceramic cleaned (vacuum maintained) after re-assembly the loop was found to handle 4.5 MW without breakdown.

The upper power limitation was caused by the inability to further increase the coupling. Also, the 7835 tube was prone to arc during cavity build up and during tank breakdown when running with a high capacitor bank voltage (50 kV). Sparking during tank build up was cured by programming the reference voltage applied to the amplitude control circuit during the tank build up. (Before and after reverse power waveforms are shown in Fig. 6.) High reverse power due to cavity or line sparking was controlled by gating the servo off, before exceeding breakdown levels of the power amplifier.

Conclusion

A programmed reference signal will reduce the gradient error of 4% during the beam loading period to within the tenth of one percent desired. Included in the program will be a pre-determined rate of rise of reference voltage, eliminating excessively high reflected power at the power amplifier.

All the high power and low level rf system components performed satisfactorily. During operation of Tank 1 some integrated circuit failures occurred as a result of crowbar or shorting switch operation (discharging capacitor bank) during "turn on" and "turn off" sequences. Proper shielding and some re-routing of cables have reduced these problems in Modules 3 and 4 which of course work at higher power levels.

Theoretical studies investigating the phase and amplitude control loop interactions are currently being performed.

Acknowledgement

Norman Fewell was responsible for the design and installation of the low level rf and buncher rf systems.

References

1. "The Prototype RF System for the 200 MeV Linac for the AGS", IEEE Trans., NS-16, No. 3, Pt. 1, page 351, (June, 1969).
2. I. Weitman, "Phase Control and Frequency Control of 200 MeV Linac for the AGS", to be published in the Proceedings of this Conference.
3. I. Pyros and A. Rosenfeld, "Analysis & Design of a Digital Timing and Synchronization System Used to Control a 200 MeV Linear Accelerator", to be published in the Proceedings of this Conference.
4. D. Greenberg, "Linac Control System AC Turn On for 200 MeV Linac", to be published in the Proceedings of this Conference.

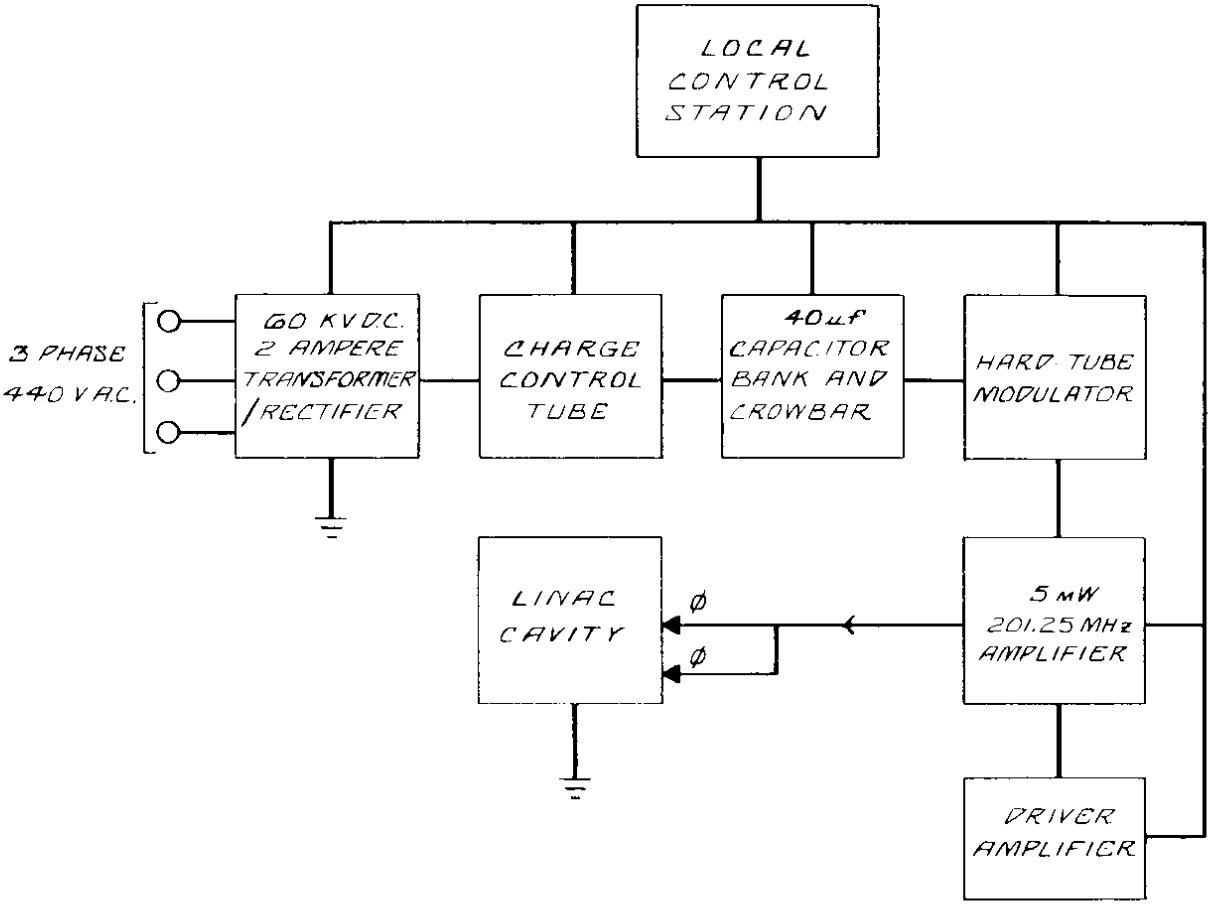

Fig. 1. Block diagram of rf system pulsed anode power supply.

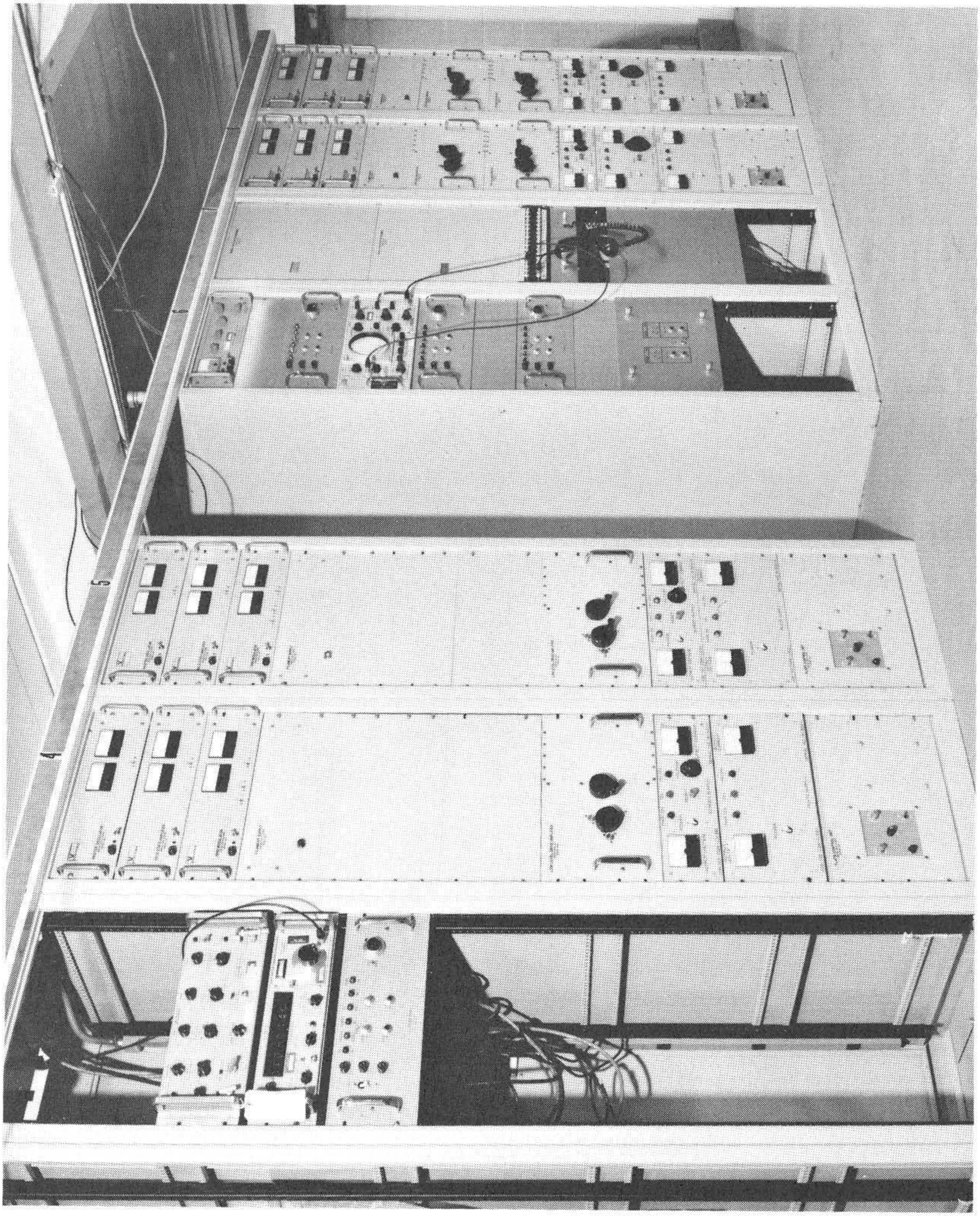

Fig. 2. Low level rf system.

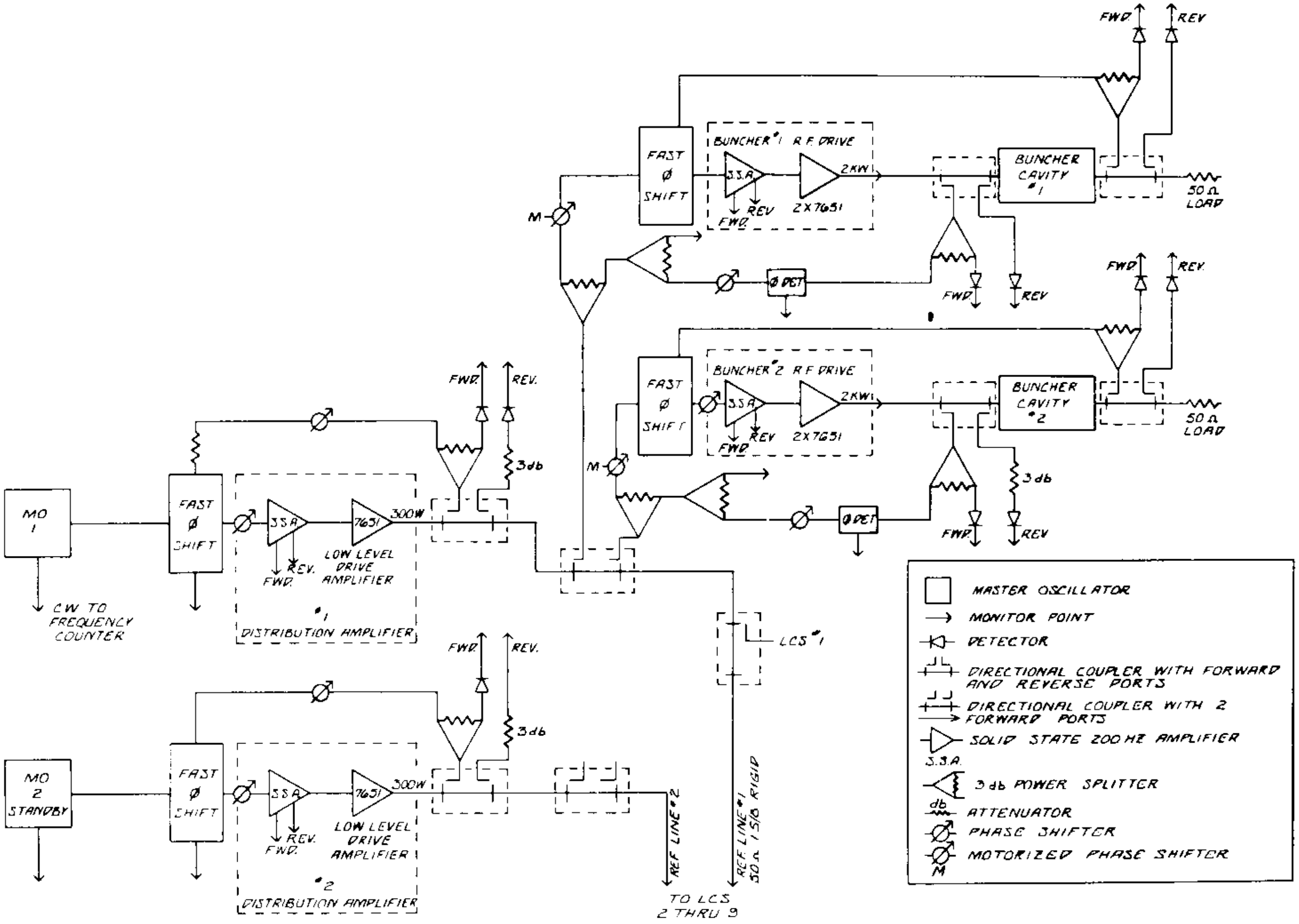

Fig. 3. Buncher low level drive rf system block diagram.

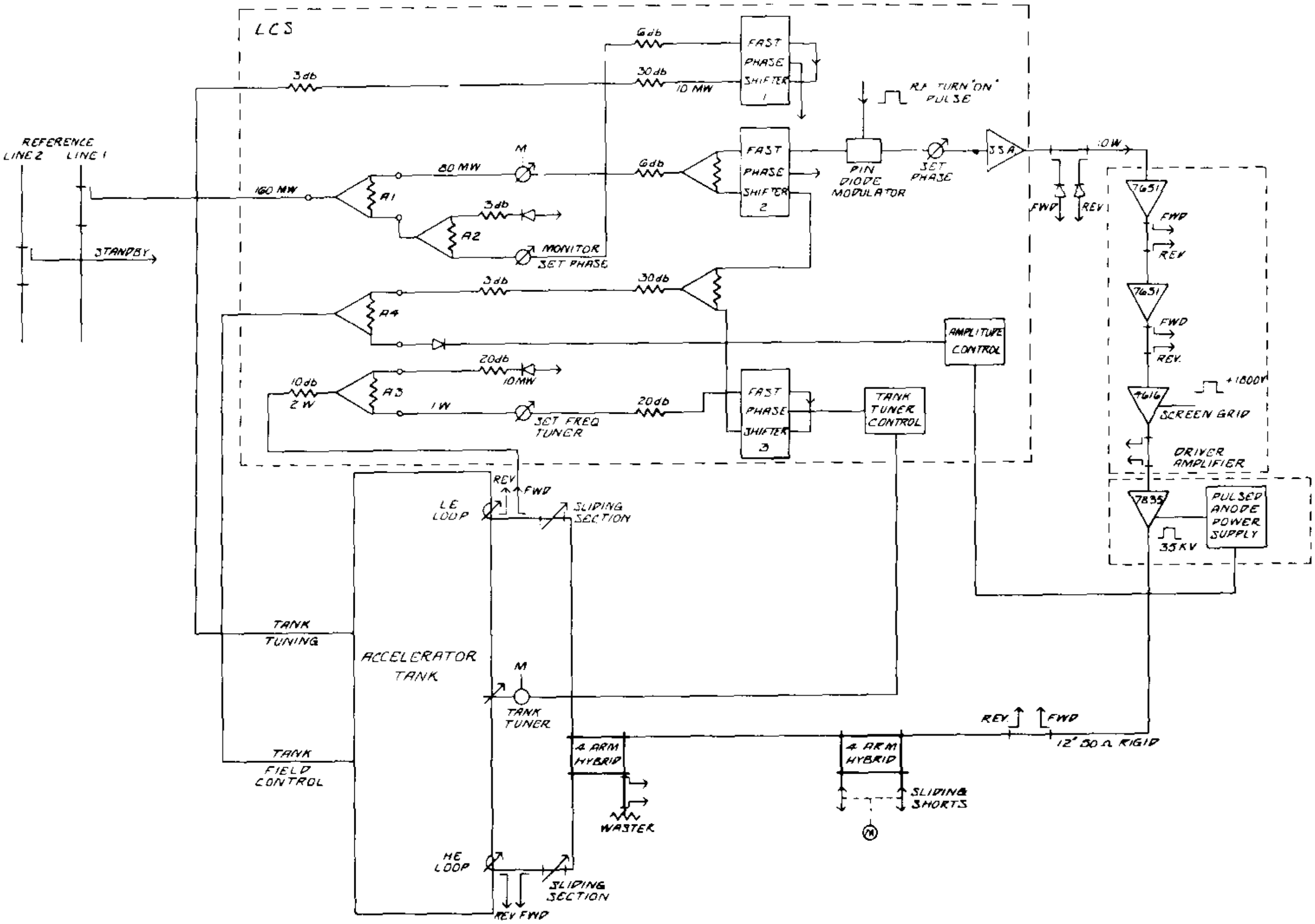

Fig. 4. Intermediate and high power rf system block diagram.

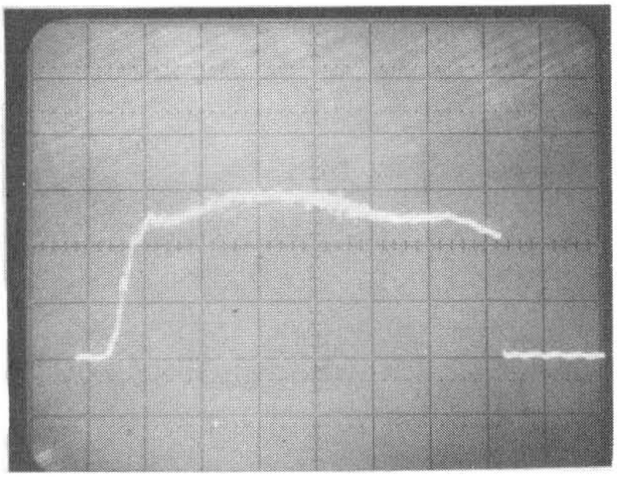

Fig. 5A 150 mA Beam Current(Loop Open) 20 μsec/cm (600 C/S Under Resonance)

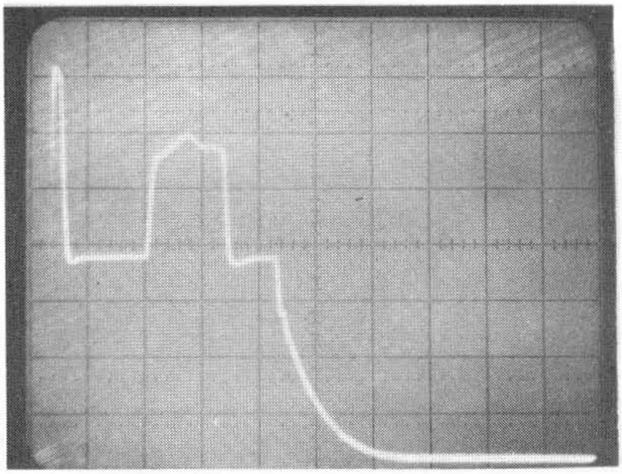

Fig. 5B Forward Power(Phase Loop Open)

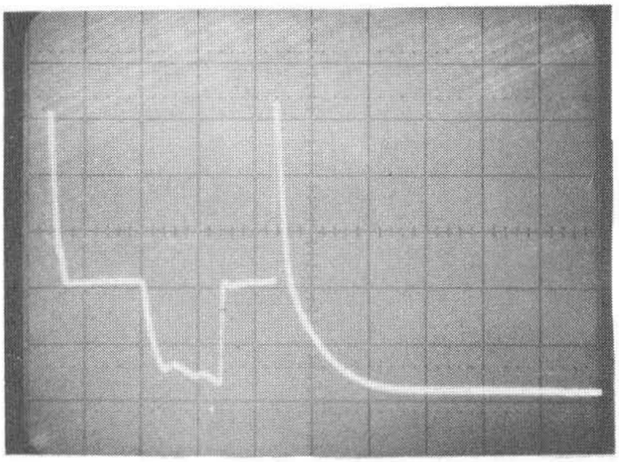

Fig. 5C Reverse Power(Phase Loop Open)

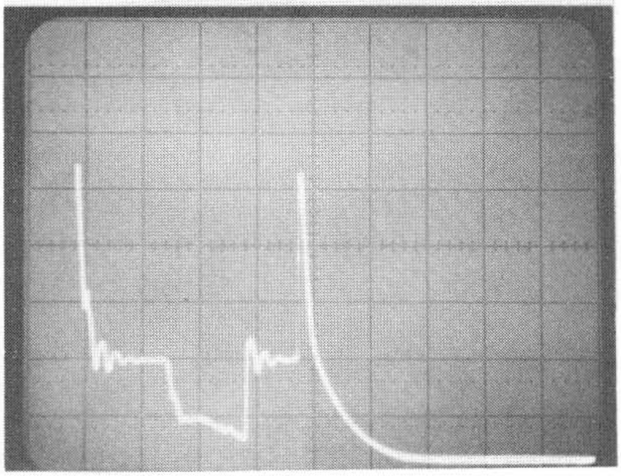

Fig. 5D Reverse Power(Closed Phase Loop)

RF SYSTEM WAVEFORMS WITH BEAM LOADING

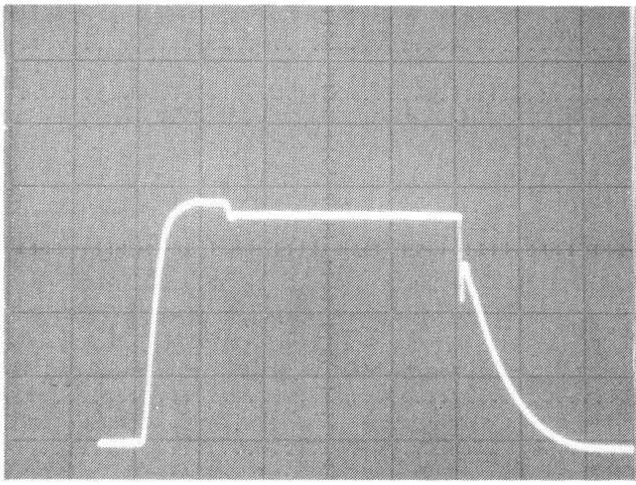

Fig. 6A Forward Power With Power Limitation During Tank Buildup

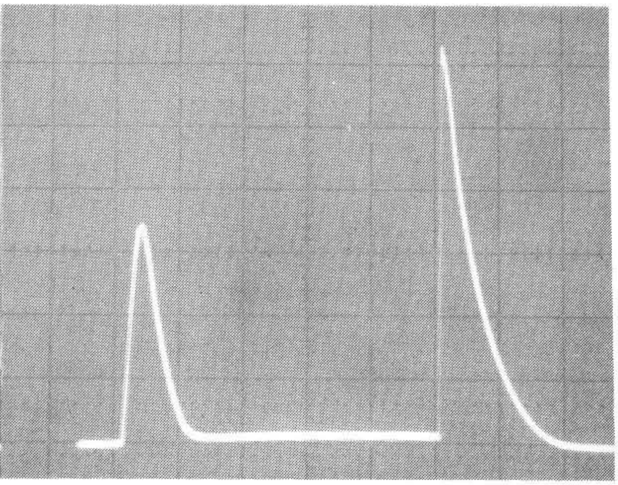

Fig. 6B Reverse Power with Power Limitation During Tank Buildup

T. = 100 μsec/cm →

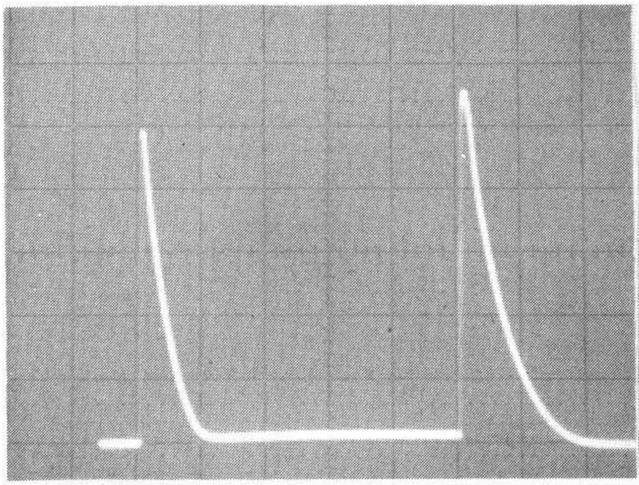

Fig. 6C Reverse Power Without Power Limitation During Buildup

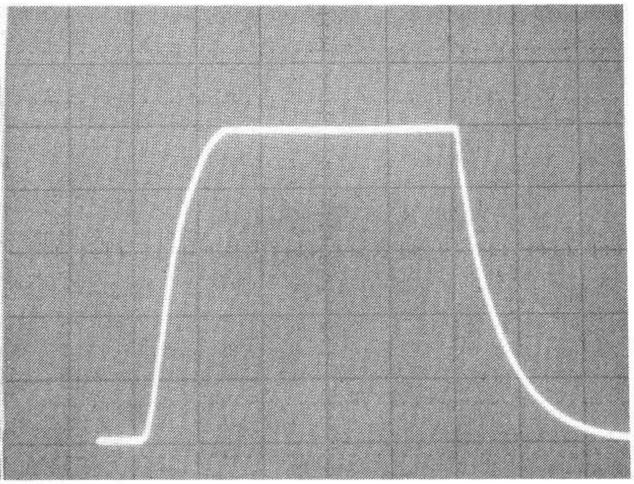

Fig. 6D Tank Gradient With Power Limitation During Buildup

TANK 3 RF SYSTEM WAVEFORMS WITHOUT BEAM LOADING