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PULSE GROUP OPERATION OF HIGH POWER LINE TYPE MODULATOR*

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Summary

The development of a high power double pulse line type modulator is described. The design goal output of this modulator was two 185 kilovolt 2.5 microsecond pulses with an interpulse separation of 23 microseconds.

In order to produce two closely spaced pulses the network of a SLAC standard 65 megawatt single pulse modulator was split electrically, but not physically. An additional hold off diode, thyratron and end of line clipper were installed thus enabling the two networks to function independently while sharing a common charging inductor and power supply.

The interaction problems, i.e., sympathetic firing, etc., encountered and the methods used to solve them are discussed.

Introduction

One of the proposals for increasing the beam energy of the Stanford Linear Accelerator requires that the electron beam be recirculated through the accelerator before being delivered to the experimental area. This will result in a doubling of the energy of the delivered beam, but also requires that the 245 high power line type modulators and klystrons deliver two accelerate pulses separated in time by approximately 23 microseconds (the transit time of the 10,000 meter accelerator structure and return drift tube).

General Description

In order to determine the feasibility of obtaining this type of performance from a conventional line type modulator as quickly and inexpensively as possible it was decided to use one of our standard modulators as the development vehicle. Also, to further reduce costs, as much of the existing circuitry and hardware as feasible was to be used. With those constraints in mind the following overall design objectives (including the output pulse transformer) were drawn up:

Peak power output (each pulse)	30 MW
Average power output	65 kW
Output voltage	185 kV max
Output current	160 A
Load impedance	1160 ohms
Pulse length, flat top (each pulse)	2.5 μs
Risetime (each pulse)	0.7 μs
Falltime (each pulse)	1.2 μs
Pulse top ripple (each pulse)	± 0.5%
Pulse separation (nominal)	23 μs
Pulse group repetition rate	360 per second

If one looks at the schematic diagram (Fig. 1) of the standard SLAC single pulse modulator, an approach to the problem immediately suggests itself. Since the network is already split into two parallel 10 section networks, which are discharged simultaneously into a common load, it would also appear to be possible to discharge them individually into the common load. In order to accomplish this a second switch tube and driver are needed as well as duplicate charging diodes. The latter are required to properly isolate network number 2 after network number 1 has been discharged. The single charging transformer is retained and the networks are charged in parallel, as usual. In order to protect the second network from over voltages due to load arcs, an additional end of line clipper circuit is also required. (These modifications are shown schematically in Fig. 2.)

Changing from a 20 section series parallel network to two ten section series networks without changing the values of the individual pulse capacitors necessitated a change in value of the network inductance and turns ratio of the pulse transformer. Assuming an equivalent rectangular output pulse width of 3.4 microseconds and a total network capacity, C_n, of 0.14 μF, the new network inductance, L_n, was determined from the familiar expression,

$$L_n = \frac{\tau^2}{4C_n}$$

This yielded a network inductance of 20.6 μH, or about 2 μH per coil. Each coil can be roughly tuned by changing tap points and finely tuned by means of an aluminum slug. The P.F.N. and switch tube compartment of the standard single pulse modulator is shown in Fig. 3. The double pulse modulator is the same except the single switch tube is replaced by two GE 7890's which are placed side by side on the mounting plate. The driver chassis for the second thyratron was outboarded for this experiment.

The pulse transformer was the last major item required for the system. The transformer that is used on the Stanford Linear Accelerator to match the high power RF drive klystron amplifiers to the main modulators is rated 75 kW average power at 250 kV peak pulse voltage and thus appeared suitable for the job. This transformer has a 72 turn secondary and a 6 turn primary. The turns ratio required to match the new 12.3 ohm networks of the double pulse modulator to the 1160 ohm klystron load is 9.7 to 1. However, it has been our experience that a 5 - 10% positive mismatch between P.F.N. and load results in improved switch tube operation and increased modulator efficiency. A turns ratio of 9:1 will prodice the desired mismatch and was easily obtained by increasing the primary turns from 6 to 8. No other modifications were made to the output pulse transformer.

The peak flux density in the pulse transformer core must also be investigated. This is not easy to do with great precision in the case of closely spaced pulses and nonlinear loads. However, some rough approximations can be made. The pulse transformer operates with a biased core. As the result of a 15 A direct reset current the core remanent flux is nominally negative 9 kG. The flux swing per pulse is 13 kG and the recovery between pulses (neglecting any contribution from the reset current since the time constant of this circuit is approximately 1 ms) is approximately 7 kG. Thus, the estimated peak flux density in the core at the end of the second pulse is plus 10 kG. This is approximately the same post pulse core condition that exists under normal single pulse operation of this transformer.

Operating Experience

With all modifications complete, the modulator was ready to try out. In order to facilitate the inevitable debugging procedure, a high power salt water resistor was used to load the pulse transformer for the initial trials. On the first runup all was well until the power supply voltage reached 6 kV (approximately 60 kV peak pulse output per pulse). At that point switch tube number 2 starting firing simultaneously with tube number 1. It was obvious that stray coupling of pulse number 1 into the grid circuit of tube

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number 2 was causing the problem. Two solutions suggested themselves: shield the grid circuit of the second tube or lower its grid circuit impedance. Because of the layout of the swtich tube compartment and the high voltages involved, effective shielding posed some rather formidable mechanical and electrical problems. Therefore, the latter solution was tried first. Stable operation was achieved when the number 2 tube grid shunt capacitance was increased to 500 pF and shunt resistance lowered to 5 ohms (Fig. 2). The resulting output pulses are shown in Figs. 4a, b, c. On the resistance load pulse spacings as close as 10 μs (leading edge to leading edge) were obtained. Maximum pulse output voltage was limited, as predicted, by the onset of pulse transformer core saturation which occurred at approximately 190 kV.

At this point the modulator was turned over to the klystron group for their tests. The beam voltage waveforms obtained on a standard SLAC klystron of microperveance 2 are shown in Figs. 5a, b, c. From the waveforms of Figs. 5b and 5c it can be seen that the pulse top ripple obtained was more like ± 1.7% than the design goal of ± 0.5%. The additional pulse top ripple is principally attributable to the mismatch that exists between the pulse transformer characteristic impedance and the dynamic impedance of the klystron load. (The transformer was designed to drive a 1000 ohm load.)

In summary it appears that pulse group operation of high power line type modulators is entirely feasible and does not require elaborate shielding or other exotic techniques. Required, however, are much lower grid circuit impedances with an attendant substantial increase in grid driving power.

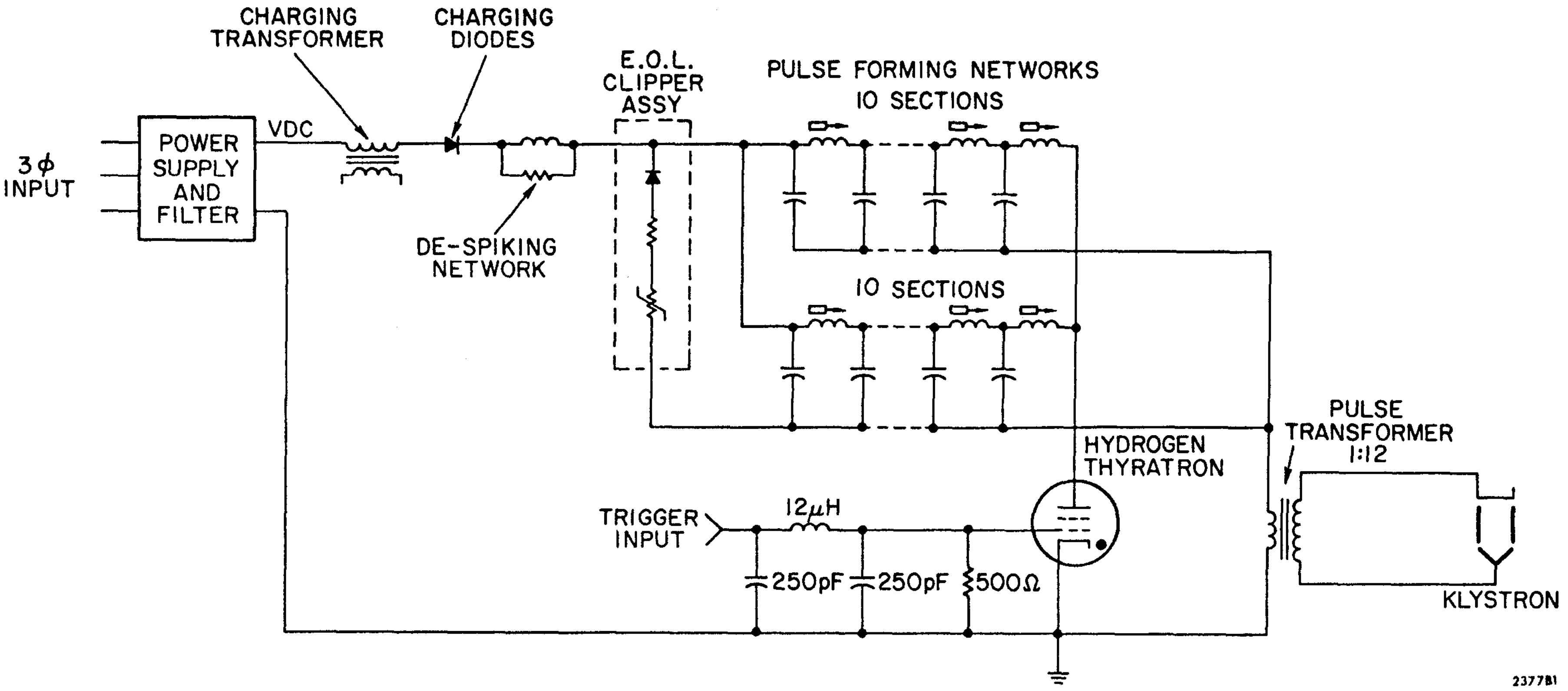

FIG. 1--Schematic diagram of simplified single pulse modulator.

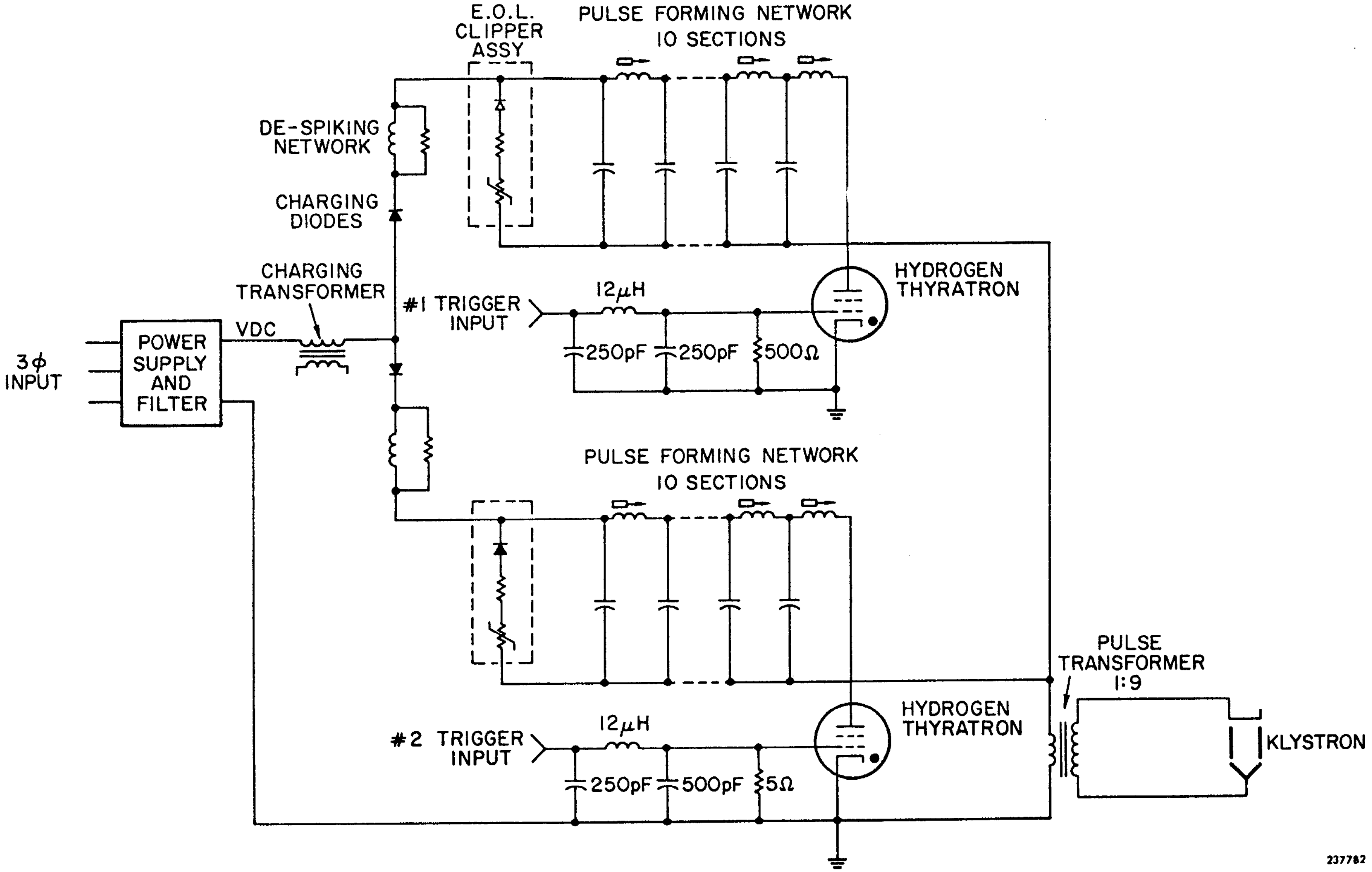

FIG. 2--Schematic diagram of simplified double pulse modulator.

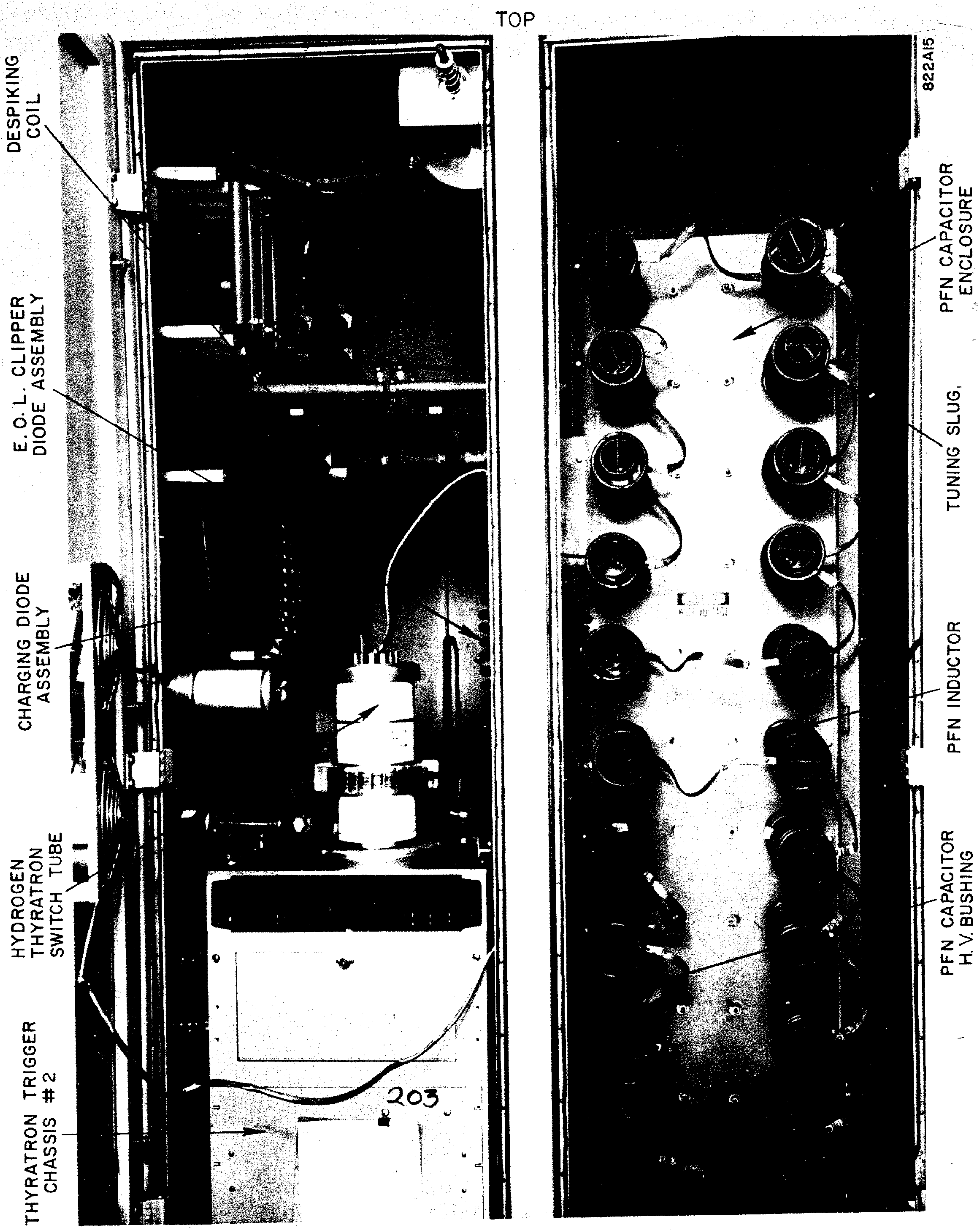

FIG. 3--P.F.N. and switch tube compartment.

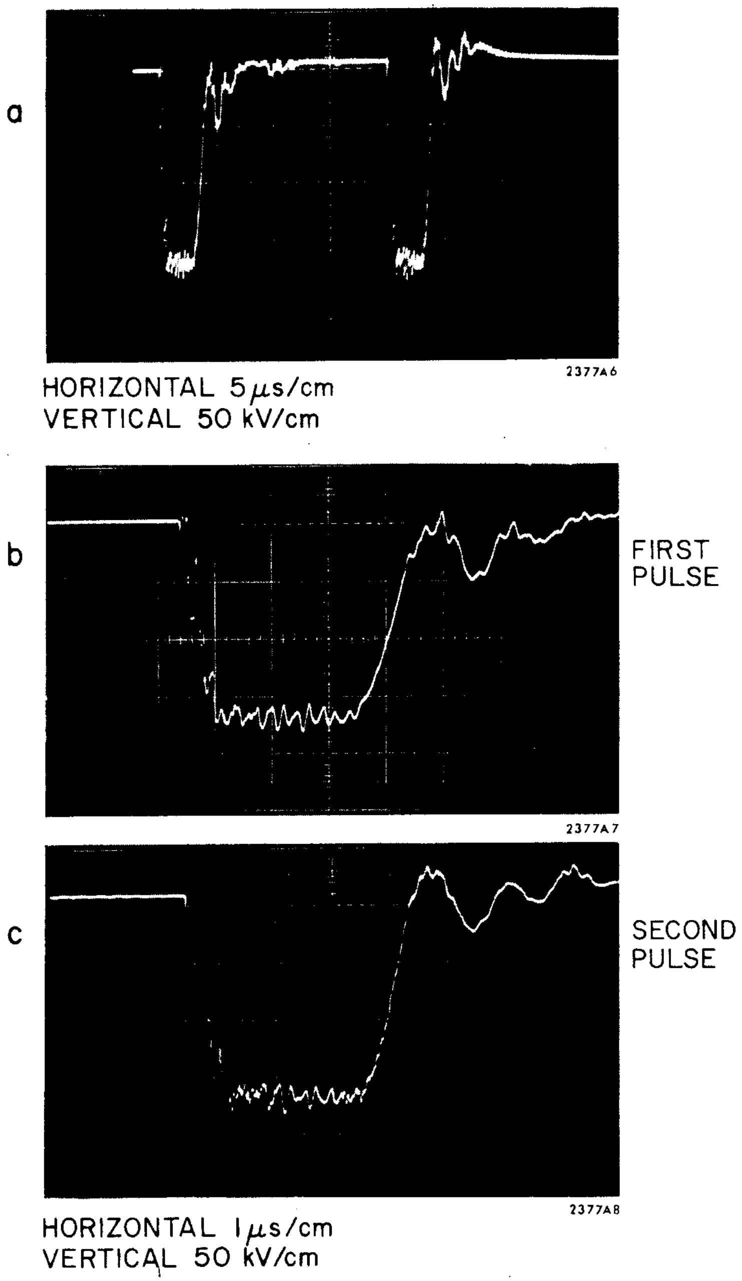

FIG. 4--Modulator output to resistive load.

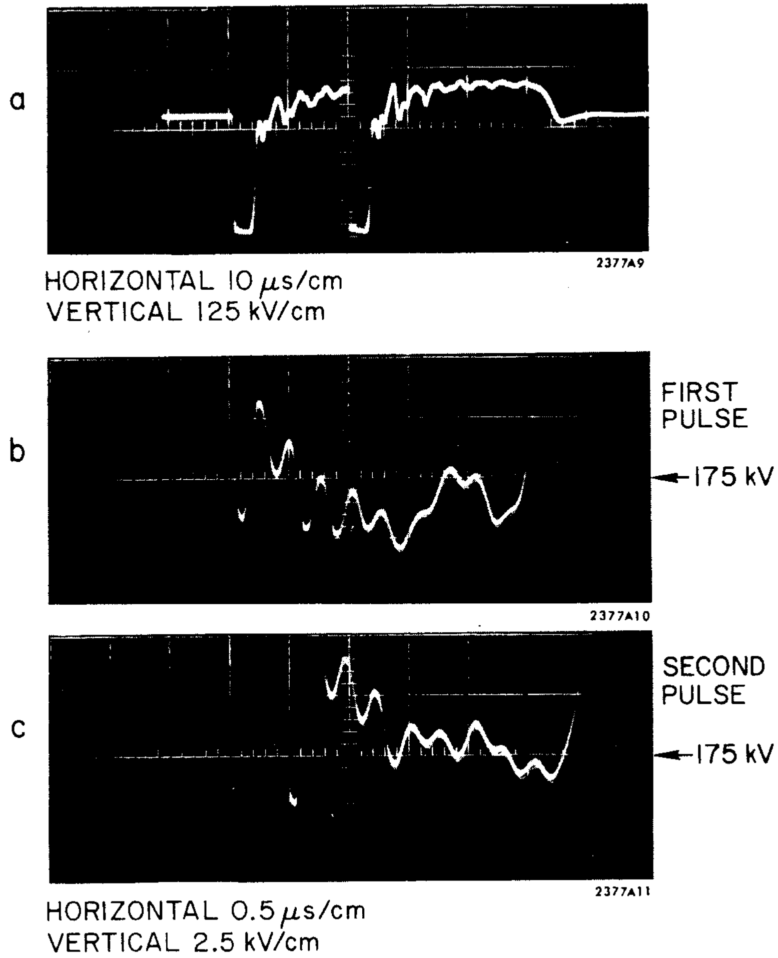

FIG. 5--Modulator output to klystron load.