LOW DISTORTION RF AMPLIFIER VIDEO PULSES

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Summary

Modern high energy particle accelerators require that the high power r.f. amplifiers generate r.f. waveforms which are essentially distortion free. This usually is accomplished through the use of very expensive and complicated high power regulation equipment. This paper will discuss an alternate, relatively simple means of obtaining this regulation through the use of a unique high vacuum switch tube used directly in series with the r.f. amplifier.

Introduction

This paper will discuss the use of a unique type of high vacuum switch tube to generate low distortion, high power video waveforms to r.f. amplifiers used in particle accelerators. This modulation scheme makes use of a Magnetron Injection Gun (MIG) switch tube placed directly in series with the r.f. amplifier. This switch tube acts both as a modulator tube and as a constant current source during the entire pulse length.

The Magnetron Injection Gun Switch Tube

The basic configuration of the MIG switch tube is shown in Figure 1. The geometrical features which give these tubes their extremely high plate resistance can be observed by noting that the electric field at the cathode emission surface is determined solely by the potential of the mod-anode in respect to the cathode. This is demonstrated by the fact that only 200 volts of bias is required to obtain a cut off impedance of greater than 1000 megaohms with 180 KV across the tube. As long as the electron beam is not deccelerated as it leaves the mod-anode region, the collector current is virtually independent of the collector potential. In a well designed MIG switch tube this condition exists over 90 to 95% of the operating voltage range of the tube.

The configuration of the MIG switch tube has proven to be particularly advantageous in high voltage applications. Tubes of this construction have been used reliably up to the 250 dc kilovolt level with extremely low arc rates. Since the beam current is magnetically cut off from the mod anode by a permanent magnet structure, there is no induced arcing due to high average power grid heating which exists in many other types of switch tubes.

An additional feature effecting the high voltage design is that the portion of the mod-anode in the high voltage region has no relation to the control function of this electrode. Thus, the mod anode and shield configurations can be determined from high voltage considerations alone. In this manner, electric field gradients can be minimized for a conservative high voltage design.

The shielding of the cathode emission surface by the mod anode has made the use of oxide coated cathodes practical in high voltage, high power switch tubes. It is practically impossible for evaporation products from the cathode to terminate on the negative electrodes in the high voltage region giving rise to high emission currents and eventual arcing. Additionally, the use of oxide coated cathodes results in very low filament power requirements. Typical values are 90 to 110 watts of filament power for a 30 kilowatt switch tube.

Figure 2 shows the L-5130 MIG switch tube. This tube has been designed specifically for series switching service. It is capable of delivering a 140 kilovolt, 8.5 megawatt pulse at an average dissipation of 10 kilowatts using forced oil collector cooling. Average power ratings can be greatly increased simply by cooling the collector with water rather than oil since grid dissipation is not a factor.

A single L-5130 can be used to modulate a 2 or 3 megawatt klystron or crossed field amplifier. Two of these tubes operated in parallel extend a system to the 5 or 6 megawatt range. The hold off voltage of the L-5130 is 180 kilovolts. These tubes are all metal-ceramic construction and processed at a temperature of 625° centigrade. All MIG switch tubes are readily repairable at a fraction of the initial cost.

The Series Switching Circuit

Figure 3 shows the typical collector current characteristics of the L-5130. In the series modulation scheme which will be discussed, only that portion of the curve to the right of the dashed diode line is of importance. This is the region of high dynamic plate resistance which gives the MIG switch tube its regulation properties. Typically, this resistance, defined as the change in collector current with a change in collector voltage, is 200,000 ohms or greater.

Figure 4 shows a typical series switching circuit using a MIG switch tube. The r.f. amplifier is represented as a diode load. C(f) represents the filter capacitor bank which for many applications can be relatively small as will be discussed later. C(s1) and C(s2) represent the system stray capacity which must be charged and discharged during each pulse. These consist of the r.f. amplifier gun capacitance, the amplifier filament transformer capacitance, the switch tube collector capacitance and the capacity of these various components to the outside world. The only regulation required to obtain very low distortion pulses is in the modulator to drive the mod anode of the switch tube. This is reasonably easy to obtain since the mod anode intercept current is only on the order of 100 milliamperes peak at 60 amperes peak collector current. Assuming a 15 kilovolt drive voltage to the mod anode, this represents a 150 kilo-ohm load to the modulator during the pulse. There is no need to regulate the main dc power supply for line voltage variation or load variations as long as the total system voltage is high enough to keep the switch tube out of the diode line region.

Figure 5 shows a typical constant perveance load line superimposed on the L-5130, 60 ampere current characteristic. Three voltages are indicated on this curve. V(1) is the MIG switch tube drop at the rated collector current level. V(2) is the allowable droop in the filter capacitor bank during the pulse. In addition, V(2) includes the change downward in the total dc system voltage fluctuations. V(3) is the operating voltage of the r.f. amplifier.

The actual value of the filter capacitor can be varied over a wide range and still contribute very little droop to the r.f. amplifier pulse. Assume, for instance, that the amplifier beam impedance is 2000 ohms and the total dc voltage was allowed to droop 10 kilovolts during each pulse. The droop across the elements of the system would in the ratio of the various impedances. Given a 140 kilovolt amplifier operating voltage and a 200,000 ohm switch tube impedance, the voltage droop on the amplifier would be 100 volts or .07% of the amplifier voltage.

Since the total system voltage droop has negligible effect on the amplifier voltage, the size of the filter capacitor can be determined from economic considerations alone. In a multiple unit accelerator, it may be advantageous to allow very little system droop in order to keep the total KVA requirement to a minimum. However, the initial cost of a small system may be minimized without appreciable degradation in system performance. In either case, no exotic dc voltage regulation is required to obtain distortion free r.f. power.

A secondary effect of a small filter capacitance is that the sytem stored energy can be minimized. In many cases, it is possible to get reliable long pulse operation without the use of an electronic crowbar. Experience to date in this type of circuit has shown that load fault currents can be easily controlled through the switch tube drive circuitry resulting in minimum down time due to large energies being absorbed in load arcs. In the rare case when both the switch tube and amplifier arc simultaneously, it is often possible to get adequate protection with a series resistance of 15 to 20 ohms.

The output pulse rise time in a series switching system for the case where the switch tube current rise time is very short is shown in Figure 6. V(o) is the amplifier operating voltage, C(s) is the total stray capacitance and I(o) is the constant switch tube current which is the total current in the system. This curve is based on a constant perveance load shunted by the system stray capacity. By comparison, a constant resistance load shunted by a capacity gives a rise time which is 50% longer. Typical values of stray capacity for a 160 KV, oil immersed system of this type are 200 to 300 picofarads depending on the space available and the mechanical design.

Figure 6 is only an approximation of the actual case, however, since the rise time of switch tube current is not infinitely short. The power required to obtain reasonably fast rise times of the L-5130 mod anode can be determined from the input capacity of the tube. This capacity is about 84 picofarads neglecting the Miller effect. The mod anode to collector capacitance is 3.5 picofarads. Assuming the gain of the tube to be 10, the maximum input capacitance including Miller effect would be 130 picofarads. Thus to obtain a 15 kilovolt mod anode pulse in .5 microseconds, the leading edge drive current would be 3.9 amperes. Typical driver tubes which are used for this purpose are the 4PR60, 4-400 and 4-1000 depending on the repetition rate of the system.

Series switching systems using the L-5130 type of tube generally have been operated at pulse lengths between 5 and 60 microseconds. However, relatively simple modifications to existing switch tubes could extend their usefulness to the millisecond range. The system becomes more attractive at longer pulse lengths since the energy storage required to get adequate regulation does not necessarily increase in the same ratio as the pulse length. Because of this fact the direct series switching system using the MIG switch tube is the only type of hard tube modulator which will reliably generate multi-megawatt pulses for tens of microseconds with less than .1% droop and distortion.

The system efficiency can be determined by the ratio of the r.f. amplifier voltage to the total dc system voltage. For the L-5130 delivering a 140 KV, 60 ampere pulse, this is about 93% assuming no filter capacity droop. If the system voltage during the pulse is allowed to droop 10 KV, the efficiency is about 86%. As previously mentioned, this represents less than .1% load voltage variation and very possibly would eliminate the crowbar requirement.

In summary, the use of MIG switch tubes like the L-5130 directly in series with a multi-megawatt r.f. amplifier offers the following features:

A. Proven high voltage operating stability.
B. Distortion free and minimum droop video pulses.
C. Load protection through mod anode control.
D. Elimination of high power regulation equipment.
E. Minimum system stored energy.
F. Hard tube modulator pulse length flexibility.
G. Efficiencies on the order of 90%.

In linear accelerator systems using multi-megawatt r.f. amplifiers, this modulation scheme offers simplicity, reliability and precise regulation.

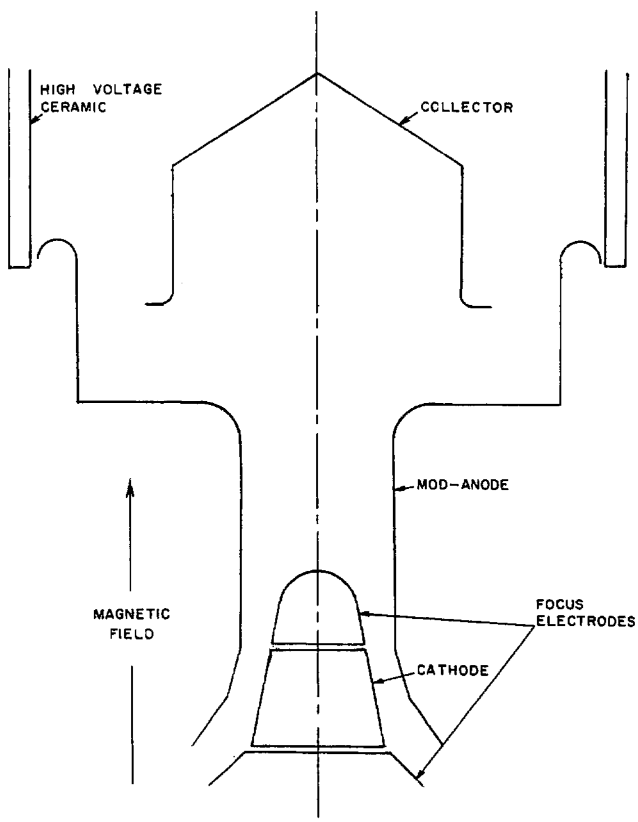

Fig. 1. MIG Switch Tube Geometry.

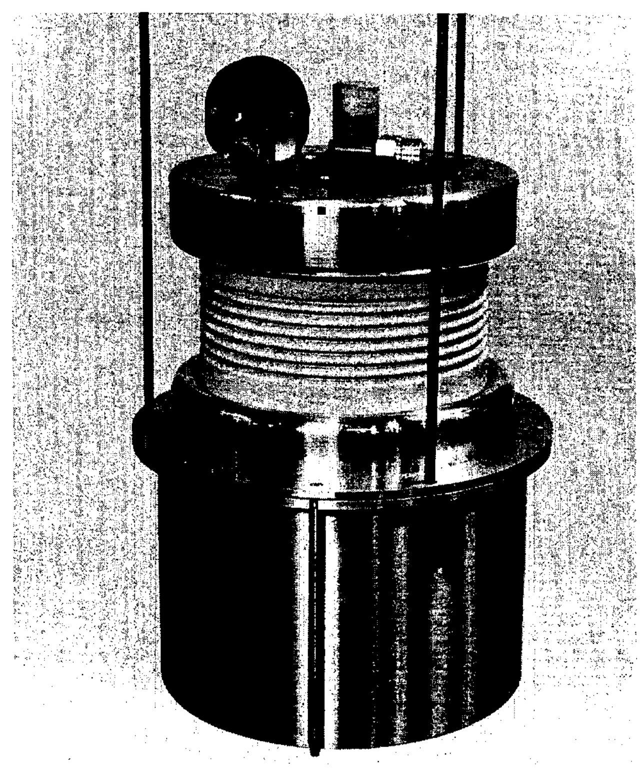

Fig. 2. The L-5130 MIG Switch Tube.

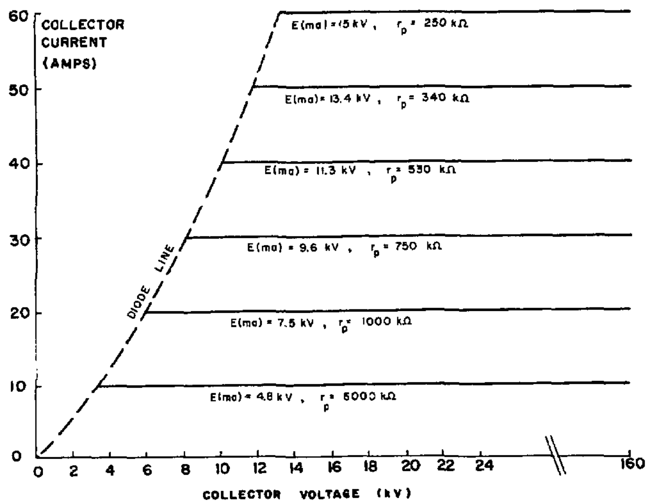

Fig. 3. L-5130 Collector Characteristics.

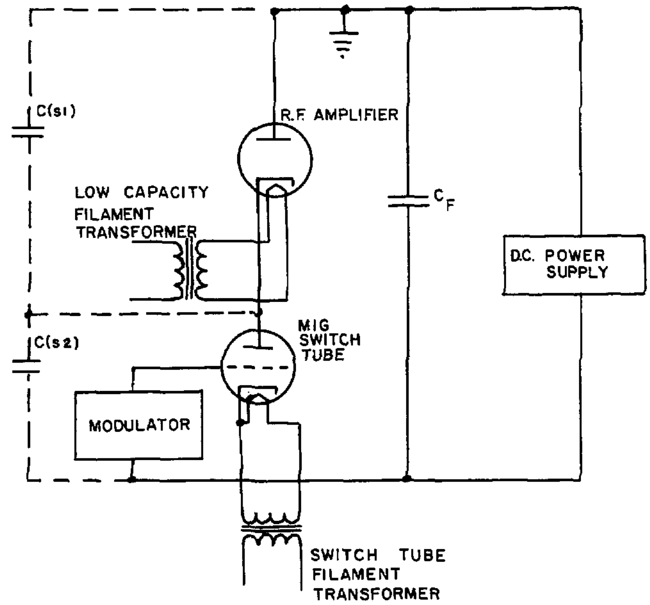

Fig. 4. Typical Series Circuit.

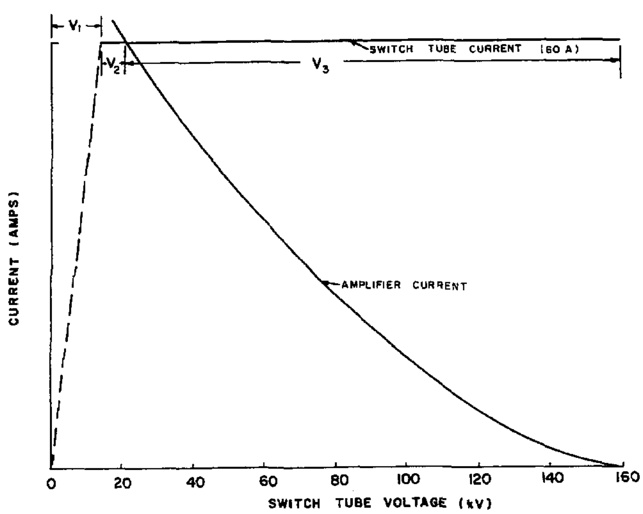

Fig. 5. L-5130 with Constant Perveance Load Line.

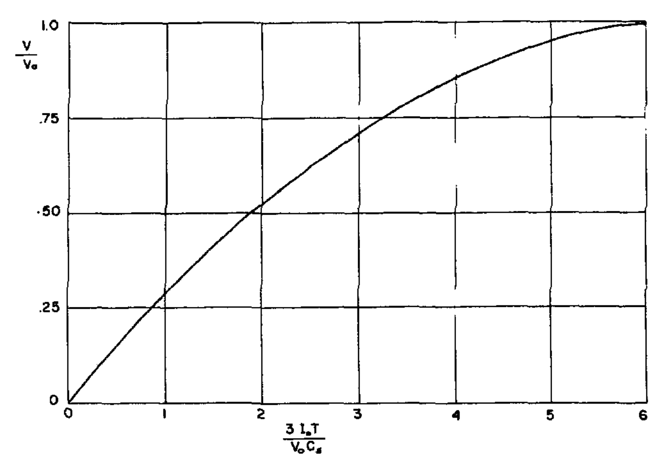

Fig. 6. Series System Rise Time.

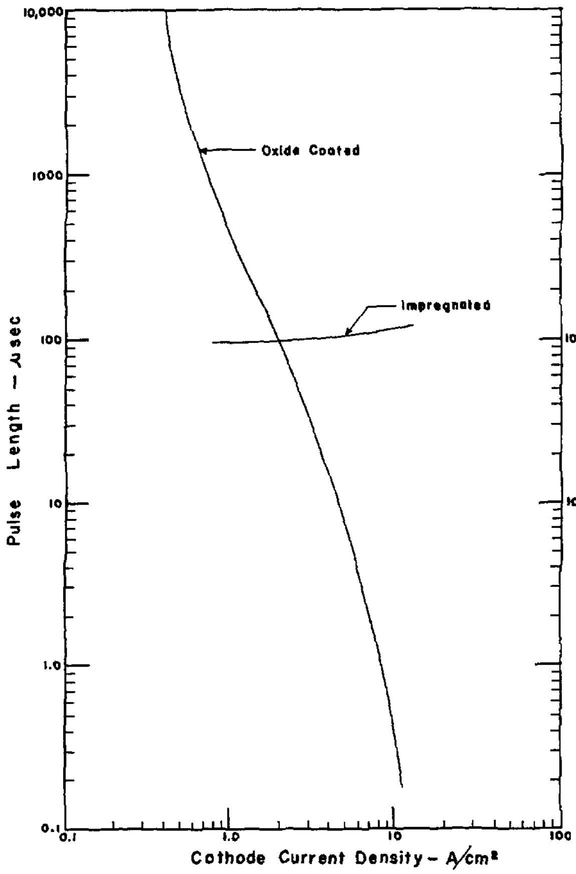

Fig. 1. Cathode current loading.

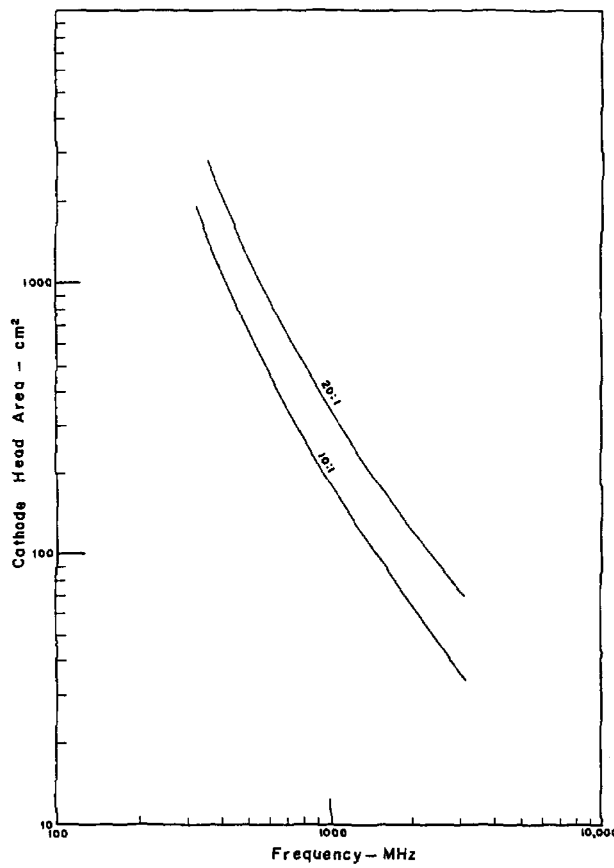

Fig. 2. Cathode convergence.