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R.F. Power Sources

The Stanford University linear accelerator is an electron accelerator with consequent different requirements on rf power. The frequency of the Stanford accelerator is 2856 Mc/s, however, for the purpose of this meeting the discussion will mainly center around power sources of 1000 Mc/s or less.

A brief survey will be given of available power tubes and a few statements will be made regarding possibilities within the present and immediate forseeable state of the art. It should be clearly understood that the following information does not represent in any way final company specifications.

a) Litton industries.

Tube type L3387. This is an experimental tube of which four tubes have been made. The tube is capable of producing a peak power of 30 megawatts and average power of 100 kilowatts. No data are available on life time.

Tube type 3250. This is a tube which has had considerable life experience and is presently used for commercially built linacs. Peak power capability is 10 megawatts*, and average power 15 kilowatts. Pulse length = 30 microseconds. Life time experience is available and is in the region of 2000-5000 hours.

b) Varian Associates.

This company has several tubes under development and as a design objective is considering tubes with peak power of the order of 5 megawatts and average power approaching 300 kilowatts, these should become available on an experimental basis within a year or so.

In existence is a tube (type unknown) with 75 kilowatts average power and frequency up to 955 Mc/s.

*This seems to be definitely an upper limit in power for the quoted tube life.

c) Eimac Co.

This company has under development a tube with the following specifications. 2.4 megawatts peak power, 75 kilowatts average power, 35 db gain and up to 1300 $Mc/_s$ frequency. The types 768 and 798 are available. These are CW types with average power of 120 kilowatts, 10-20 db gain and up to 900 $Mc/_s$ frequency.

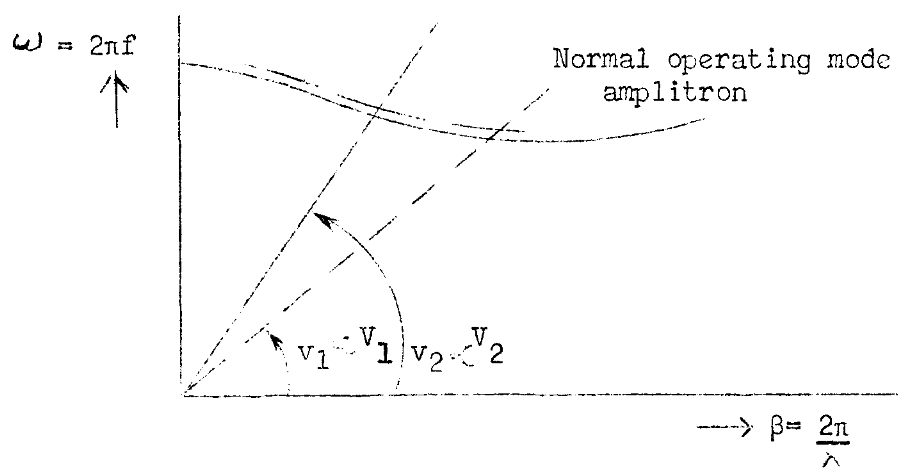
Further, a tube with 5 megawatts peak power, 75 kilowatts average power, 35-40 db gain and up to 1300 $Mc/_s$ frequency is in the design stage. The design aim for this tube is 150 kilowatts average power.

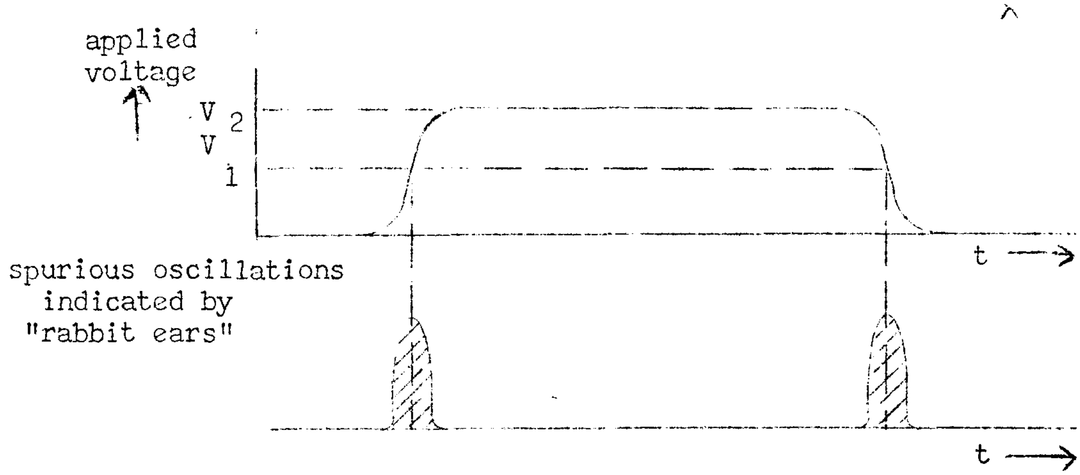
It is generally agreed among klystron developers that peak powers in excess of 20 megawatts and average powers of the order of 300 kilowatts are within the capability of the present state of the art. It is to be expected that developments along these lines will occur within the next few years if economic motivation is provided.

The present limitation for obtaining higher peak powers is set by the capability of the rf window in passing the power and the problems associated with operation at high voltages in order to obtain the desired power level. No serious difficulties have been encountered in passing 100 kilowatts average rf power through the window. However, with peak powers of the order of 30 megawatts, breakdowns, originating on the ceramic window, occur. Stanford experience indicates that there is a mechanism, as yet not understood, for the creation of energetic electrons in the 80 Kev region (as observed by x-rays) which causes a charge buildup on the ceramic window, with a consequent breakdown of the window.

The high voltage problem is being attacked by designing electron guns with higher perveance values and hollow beams, so as further to reduce the maximum voltage requirements for a given power. The optical design of these have been worked out using recently developed computor methods. For long pulses (in excess of a few microseconds) it is generally not permissible to employ current densities in excess of 1-3 amps/cm$^2$ from the cathode. Hence, even for high perveance guns the cathode must be rather large in surface area if high peak powers are desired. Regarding the relative merits of klystrons versus "amplitrons", both have their advantages and disadvantages. Some of these are briefly summarized below.

Amplitron. Two advantages of the amplitron are high conversion efficiency and excellent phase stability as a function of applied voltage. It suffers from the following disadvantages. It is a low gain device ( $<$ 10 db). Also it will spontaneously oscillate if it is not continuously driven at the correct frequency. This is because it is operating as a "locked in" amplifier in a backward wave mode. Also, because of the choice of operating mode, the "amplitron" will pass through a region of oscillations as the voltage is applied to the tube. This is illustrated in the Brillouin diagrams below:



Further, the small physical size of the "amplitron" limits its heat dissipating capabilities. Also the input rf window has to be able to withstand as much power as the output window, and last, the "amplitron" is very sensitive to having the correct load impedance in order to avoid oscillation problems.

Klystron.

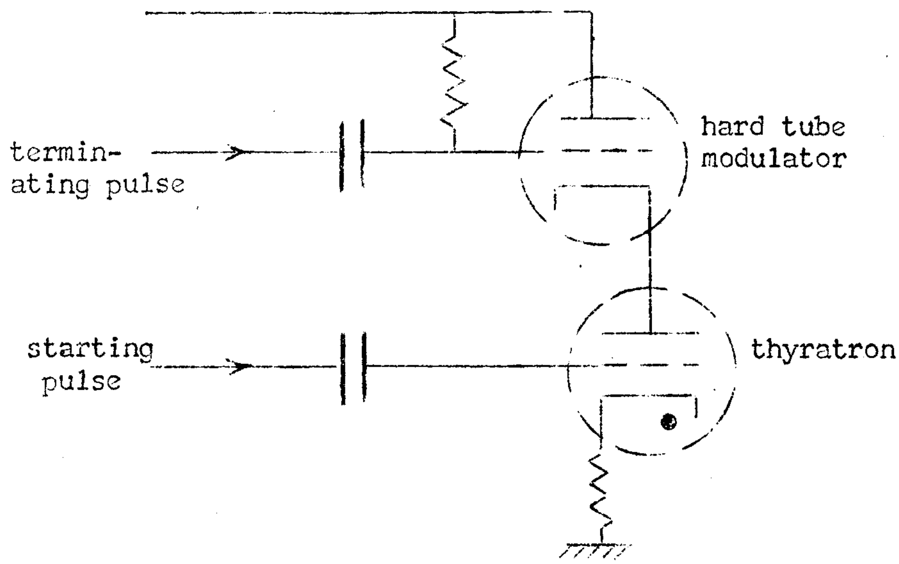
The Klystron is capable of achieving very high gain in a single structure (50 db or more if desired). Properly designed there are no problems with oscillations because input and output rf structures are separated. Its average power and peak power capabilities are high because the beam collector is not an integral part of the rf structure. Further, there are no basic limitations to the size of the emission surface, therefore very high peak and average powers are achievable. Some of the disadvantages are the sensitivity of the phase of the power output to the applied voltage, however, from the point of view of application for a linac, the phase stability demanded seems to be well within present capabilities. Further, the power conversion efficiency is about half that quoted for the "amplitron".

Traveling wave tubes do not seem to offer any great advantage as rf amplifiers at the present time. These tubes are essentially broadband devices and have relatively low power efficiencies. Similar oscillation difficulties as in the "amplitron" are encountered since the input and output rf circuits are coupled inside the tube. Due to the continuous structure spurious oscillations are caused by the backward wave mode.

At Stanford ignitrons (GE) are being used for the purpose of switching rf modulator power. At high repetition rates in either the ignitron or sparkgap, the primary problem is the time available for removal of ionized gases before the next pulse arrives. Hard tube modulators are also available for this purpose but not much experience has been obtained at peak powers in excess of 5 megawatts.

Ling Altec Co., produces a modulator capable of 60 megawatts peak power, 250 kilovolts hold-off voltage, 4 microseconds pulse length and 360 pulses per second repetition rate.

In the discussion following this meeting, G. Wheeler (Yale ) suggested the circuit diagram shown below as an rf power switch which combines the virtues of a hard tube modulator and a thyratron tube but eliminates some of the disadvantages inherent in each one of these elements. The switching capability was in excess of 60 amperes at a 15 kilovolt level.




J.P. Blewett remarked that recently consideration has been given to cryogenic magnets for accelerators in connection with possible lower operating cost. The great advantage being the lowering of the resistive dissipation at lower temperatures. In rf systems this factor is mainly lost. Cooling of a linac structure might, however, offer some advantages in connection with high initial costs of conventional rf power equipment.

R.H. Rheaume mentioned that Westinghouse Electric Corp., recently brought out the modulator triode WX4450 with capabilities of 37.5 megawatts peak power, 700 amperes peak dissipation, 1000 microseconds pulse length and a duty factor of 0.004.