# X-BAND HIGH POWER PULSED KLYSTRON

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## Summary

An X-band pulsed klystron is a key device to make a compact medical and industrial electron linear accelerator system. A 4 MW (average 4 kW), 5 μs, 9.3 GHz klystron is described in this paper. A prototype klystron had been built, and 4.6 MW peak power was measured at the 151 kV, 60A beam input. Typical electrical and mechanical characteristics of production-type klystrons are presented.

## Introduction

Electron linear accelerators are widely used for medical and industrial purposes. Since most of them use S-bands or lower frequency RF sources at present, the equipment size is large. If the X-band RF source is used, the system can be made compact and light. This will expand the applications and market of linear accelerators. However, available X-band power source at present is limited to be a tunable magnetron or CFA whose output power is up to 1 MW, and even in the future, it is supposed to be up to 2 MW. And these power levels are quite insufficient for present linac systems. On the other hand, a klystron has potentiality of higher output, but there is no commercially available X-band klystron in the world. Therefore, expecting the demand of the linac system, we are now developing an X-band high power pulsed klystron.

## Development Plan

Since the X-band is three times higher in frequency than the S-band, the klystron size becomes approximately 1/3. However, the following hinder the scale down.

(1) Fine and uniform electron beam with high beam power
(2) Higher power density (ninefold)
(3) Higher field gradient

These factors make the output power of the X-band klystron smaller by approximately one order than that of the S-band.

With the above considerations, the basic design characteristics are shown in Table 1. The operating frequency is selected to be 9.3 GHz, because it is used in the commercially available RF sources or RF components in X-band. The peak output power is aimed to be 4 MW, which is the minimum value required for linac systems, and which considerably exceeds that of the existing tunable magnetron and CFA. The RF pulse width and the repeating rate are estimated to be 5 μs and 200 pps respectively. The saturation gain is 60 dB, which enables the use of a solid-state amplifier as the RF input.

The most important thing in designing linear beam tubes is to determine a perveance of electron gun, because most parameters depend upon the perveance. If a low perveance (i.e. low beam current and high beam voltage) is selected, the cathode loading or the area convergence is reduced. Therefore, with such a design, it is easier to get a fine and uniform electron beam. This selection is also advantageous to improve the efficiency of the klystron and decrease the focusing magnet field strength. However, the high voltage or the high field gradient reduces the operating reliability against breakdown. Furthermore, the insulating areas (gun, cable, tank and pulser) becomes large and expensive. Considering both merits and demerits, a relatively low perveance is selected for the design. Additionally, the following must be developed:

(1) An electron gun which draws out the required current, produces fine beams and moderates the voltage gradient
(2) A cavity arrangement which prevents reduction of the efficiency and oscillation, and output cavity and output window which moderate the thermal concentration and surface electric field gradients.

Table 1 Design criteria for the X-band klystron

| | |
|---|---|
| Operating frequency | 9.3 GHz |
| Peak output power | 4 MW |
| RF pulse width | 5 μs |
| Pulse repetition rate | 200 pps |
| Saturation gain | 60 dB |

## Prototype Design and Manufacturing

**Electron Gun :** The maximum beam voltage is set at 150 kV, a microperveance of 1.1 is chosen assuming efficiency is 45 ~ 50%. A high area convergence and moderate voltage gradient electron gun is designed. However, the gun needs 1.5 times higher current density than that of the S-band klystron gun with the impregnated cathode. And it is noted that the heater current is set at a small value by saving heater power and using high resistant heater wire. The gun was manufactured for the performance tests of heater and cathode at high voltage and it is now under the cathode life test.

**Cavity :** Cavity parameters were simulated by a one-dimensional disk model calculation. Six cavities are selected to get the sufficient gain, and the higher mode frequency of each cavity is shifted to suppress the oscillation.

**Window :** Output power is lead through a wave guide (WR-112) to a pill-box-type window. Titanium oxide is coated on the surface of the alumina disk window in order to prevent troubles such as cracks and pin-holes.

The electric parameters of the prototype klystron are shown in

Table 2 Prototype klystron electrical design parameters

| | |
|---|---|
| Beam voltage | 146 kV |
| Beam current | 61 A |
| Microperveance | 1.1 $\mu AV^{-3/2}$ |
| RF pulse width | 5 μs |
| Number of cavities | 6 |
| Efficiency | 45% |
| Maximum gradient in electron gun (at 146 kV) | 21 kV/mm |
| Maximum gradient in output gap (at 4 MW) | 81 kV/mm |
| Brilluin focusing field | 1110 G |

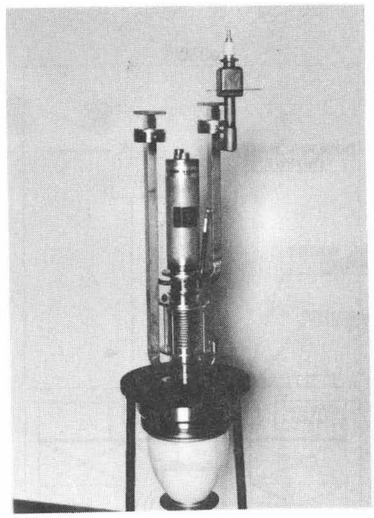

Fig. 1 X-band prototype klystron

Table 2. With the prototype, the gun housing is the same as that of S-band klystrons and the test facility and focusing magnet are also compatible with existing equipment. Fig. 1 shows the prototype klystron.

## Experimental Results

The measured characteristics of the prototype klystron gun are shown in Fig. 2. The 151 kV beam voltage is easily applied and stable operation for a 6 μs beam pulse width was obtained. With a heater power of 70W, a sufficient beam current of 60A was obtained at 151 kV. Microperveance is 1.0, 0.1 less than the design. Other measured performances in RF output of the prototype klystron are shown in Figs. 3, 4 and 5. As shown, the peak output power reached 4.6 MW at 4 μs pulse width, 20 pulses per second, with an efficiency of about 50% and a saturation gain of about 60 dB. The gain, as well as the power output, are affected significantly by the focusing magnetic field. The field is optimized at 151 kV beam voltage to get 4.6 MW peak output power. The maximum field strength is 2300G in this case. The bandwidth of the prototype tube is measured to be 39 MHz centering around 9300

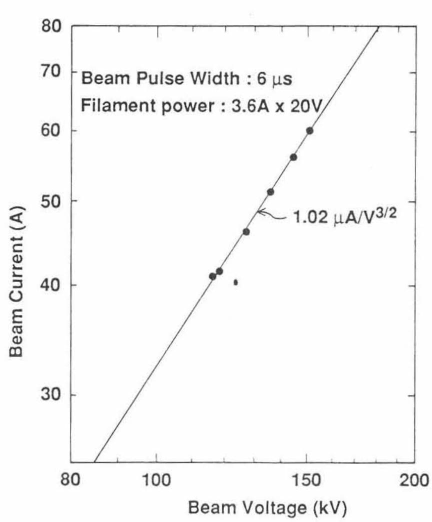


Fig. 2 Electron gun characteristics

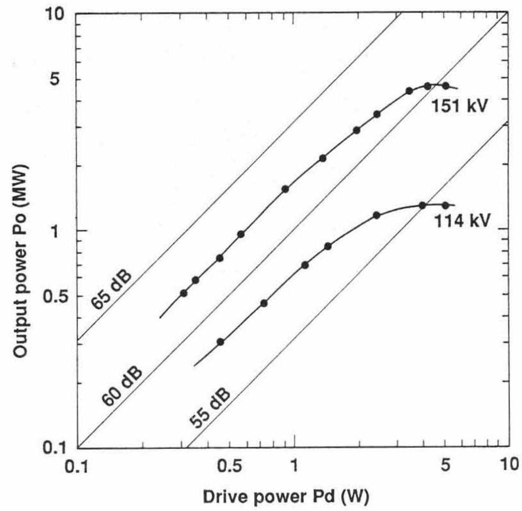


Fig. 3 Output power and gain versus RF input power at different beam voltages

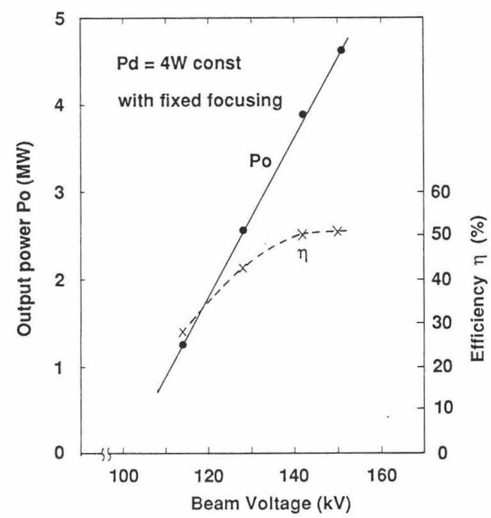


Fig. 4 Output power and efficiency versus beam voltage

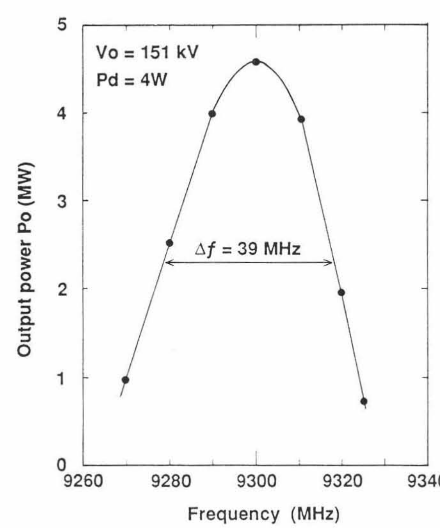


Fig. 5 Frequency characteristics

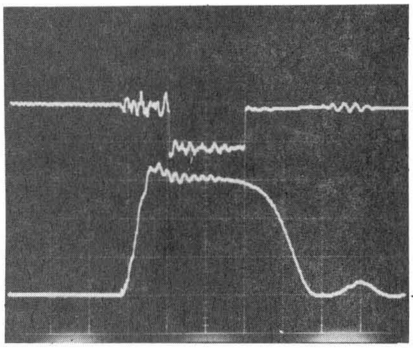


Fig. 6 Wave form of RF output and beam current

MHz. The output power was measured calorimetrically with an RF pulse width 4 µs, pulse repetition rate 20 pps. The photograph of the beam current and RF output wave form is shown in Fig. 6. Efforts to increase the average output power are under-going.

Compared to the computer simulations, the measured efficiency is low by 4 percentage points and measured gain is low by 2 dB.

## Production Tube Design

The production tube characteristics are shown in Table 3, based on the test data of the prototype tube. The main revised points come from reducing the tube size (see Fig. 7 outline drawing). Following are main items to be solved;

(1) Heat removal design of output cavity and window
(2) A smaller magnet
(3) A smaller gun housing

The total length of the klystron will be 740 mm, the weight will be 15 kg.

## Conclusion

A 4 MW, 9.3 GHz prototype klystron was designed and built. The peak output power; 4.6 MW, the saturated gain; 60 dB, and the efficiency; 50% are measured with 4 µs RF pulse width. It will be tested up to 5µs, 200 pps. Development of production-type klystron has been started on the basis of the prototype tube. This klystron will have much feasibility to make small size linear accelerators.

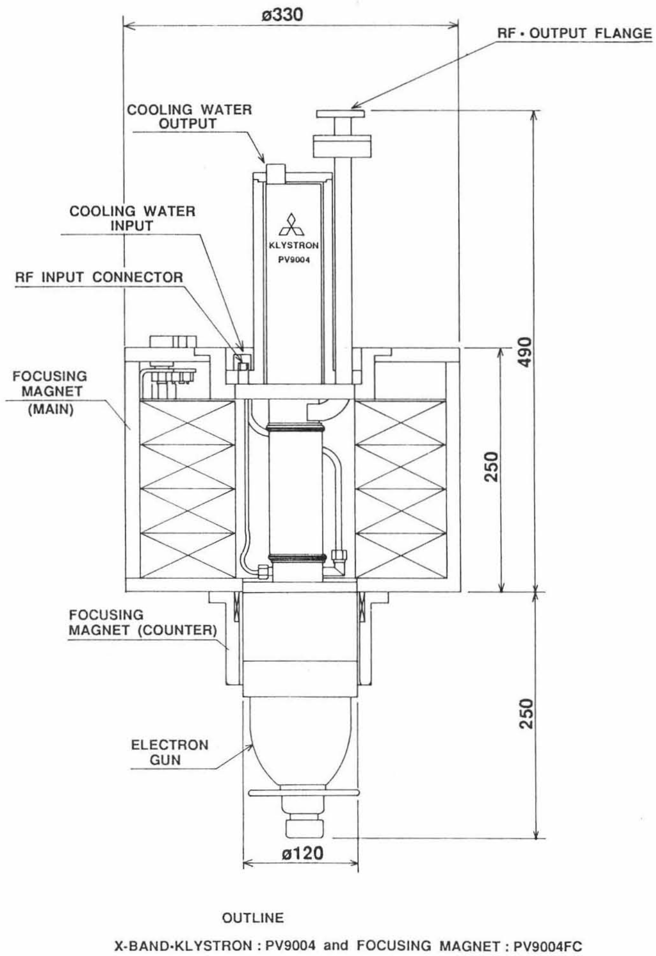


Fig. 7 Outline drawing of X-band klystron PV-9004 with focusing magnet

Table 3 X-band klystron characteristics (typical)

| | | | |
|---|---|---|---|
| Output power | 4 MW or more | Dimensions | See outline drawing |
| Beam voltage | 145 kV | Weight | |
| Beam current | 60A | tube | 15 kg |
| Heater voltage | 20V | tube with magnet | 140 kg |
| Heater current | 4A | Electro-magnet | |
| Drive power | 4W | Cooling water | 25 ℓ /min. |
| Saturation gain | 60 dB | Input connector | SMA |
| Efficiency | 50% | Output flange | UG-1734/u |
| Beam pulse width | 6 µs | | with 2 kg/cm$^2$g SF$_6$ gas |
| RF pulse width | 5 µs | | |
| Pulse repetition rate | 200 pps | | |