

COMPACT HIGH EFFICIENCY, LIGHT WEIGHT 200-800 MHZ HIGH POWER RF SOURCE

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Introduction

There has long been a need for a new more efficient less bulky high power RF power source to drive accelerators in the 200 to 800 MHz region. Results on a recent 5-year EIMAC sponsored R & D program which have lead to the introduction of the Klystrode™ for UHF television and troposcatter applications indicate that at power levels of 1MW or more efficiencies in excess of 75% can be obtained at 450 MHz. Efficiencies of this order coupled with potential size and weight parameters which are a fraction of those of existing high power UHF generators open up new applications which heretofore would have been impractical if not impossible. Measurements at 470 MHz on existing Klystrons are given. Projected operating conditions for a 1MW 450 MHz Klystrode having an overall length of 60 inches and a total tube, circuit, and magnet weight of 250 pounds is presented.

Background

For the past quarter century, power in the UHF power spectrum has been generated either by tetrodes or klystrons. At the lower frequencies and power levels (few tens of kilowatts) the tetrode has reigned supreme, meeting the requirements of reasonable efficiencies (40-60% depending upon bandwidth) with practical size and cost. As the requirement for greater power levels grew, the Klystron has become the unchallenged leader where high power gain with reasonable efficiency (30-50%) is required. However, at the megawatt level, though recent development here and abroad toward improving efficiency beyond 50% have been moderately successful, the physical size and weight of the resulting devices tend toward being impractical. Devices 15-18 feet in length and weighing in excess of 1,000 lbs. are now available. Due to the fundamental klystron requirement for multiple cavities and long drift tube lengths to get high efficiency there is little hope of drastically reducing either size or weight. While such devices are adequate for powering current scientific experiments, size, weight, and efficiency become exponentially more important in large multiple tube installations where there is a premium on all three parameters.

The Klystrode, although developed for more efficient UHF TV station operation has turned out to have the fortuitous combination of all three desirable parameters.

The Klystrode's efficiency is somewhat better than a klystron because it is a density modulated device and does not depend upon classical klystron velocity modulation to generate the "bunched" electron beam from which RF power is extracted when the "bunch" passes through the output resonator gap. It is more efficient than a tetrode because the higher operating beam voltage limits transit time losses, and the re-entrant output cavity circuit losses are lower than typical tetrode circuit losses.

The Klystrode is basically a single cavity device with a very short beam length relative to the klystron. This results in a shorter more compact structure with attendant weight savings in the tube itself. Even greater weight and size reductions can be realized in the focussing magnets because of the short magnetic field requirement.

The Klystrode's fundamental advantage over the klystron in TV service is the fact that it is a Class B device, e.g., the beam current follows the picture modulation exactly whereas the klystron, being a Class A device, expends the full dc beam current continuously regardless of the modulation.

Conventional tetrodes are Class B devices but are hard to apply at UHF because power gain tends to be low, the power density is high, and the difficulties of circuiting a tetrode at high CW powers increase exponentially as the power level is increased.

The Class B vs. Class A characteristic of the devices may not be important for the generation of raw CW power; however, in applications requiring modulation of the RF power level, all of the above advantages apply. The Klystrode power input is automatically controlled by the RF drive thus saving the weight of high power control circuitry.

Tube Description

Fig. 1 shows the tube schematically. In its simplest form it is a pentode or five-element device with a

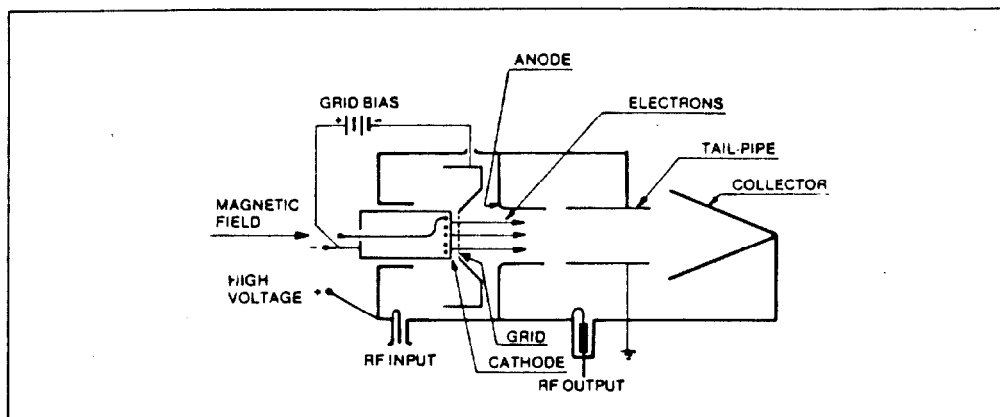


Figure 1. The structure of the Klystrode, which combines the features of a klystron and a tetrode.

round-disc cathode, planar grid, and apertured anode at high potential. A re-entrant cavity is placed between the anode and the next electrode, called the tailpipe. Insulated from the tailpipe is the final electrode, the collector. The tube is immersed in a uniform magnetic field provided by a solenoid or a permanent magnet. Superficially, then, the tube is similar to a conventional tetrode except that the output circuitry is a resonant cavity.

In operation, an alternating RF voltage is applied between cathode and grid by means of one of several possible circuit arrangements. The resulting bunched or density-modulated electron beam is then accelerated toward the apertured anode at high potential, and passes through it without interception. It then continues through a field-free region at constant velocity. Next, it passes through a gap - called the output gap - in the resonant cavity when the electric field induced by its passage is decelerating. It then passes through a second field-free region, the tailpipe, with minimal interception, and finally traverses the gap between the tailpipe and collector. The tube resembles a conventional UHF tetrode but with several important differences. These are the following: a) the potential of the anode of the Klystron is high compared to that of the screen grid in the tetrode; b) the presence of the field-free regions before and after the output gap; c) the strong decelerating field in the output gap compared to the essentially zero field in the tetrode at the time of maximum current-flow; d) the essentially non-intercepting tailpipe compared to the intercepting anode of the tetrode which also functions as a collector; e) the absence of a dc voltage across the output gap so that a blocking or bypass capacitor is not required; and f) the presence of a magnetic field.

The significance of these differences has been described in some detail in a previous article^[1].

Klystron Performance in UHF/TV Aural Service

This has been measured across the band 470-805 MHz at power output levels from 3 to 30 kW CW. Data is summarized in Figure 2. Because efficiency varies with beam voltage and with frequency, and because the beam voltage used will depend on equipment considerations, tending to be lower at 3kW than at 30 kW, a range of efficiency is shown. The power gain figure of 23 dB is a

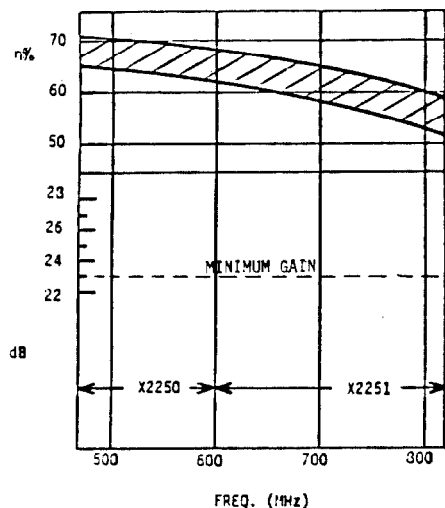


FIGURE 2 EFFICIENCY AND POWER GAIN
SOUND 3-30 KW OUTPUT

minimum across the band. Actual values will depend on bandwidth required and beam voltage used. As can be seen from the curve, efficiencies below 500 MHz are exceeding 70%.

Klystron Performance in UHF/TV Visual Service

Data has already been published for a 30 Kw peak of sync amplifier at 780 MHz.^[2] It appears that the Klystron is in a leading position compared to the other tube types when efficiency, or cost of operation, is the prime consideration.

The development program at EIMAC on the Klystron has to this point in time concentrated on UHF TV applications. However, the measured performance in the 470-800 MHz region can form the basis for accurately predicting what the Klystron can do at higher power. If, for example, we assume a given perveance of $.33 \times 10^{-6} V^{-3/2}$ with a very modest area convergence ratio of 4:1 and a grid dissipation density of 20 watts per square cm of cathode area, we can project expected output power from 200 to 800 MHz. Fig. 3 is a plot of CW RF output and beam voltage versus frequency. A constant efficiency of 70.5% is assumed based on measured data at 30KW and 470 MHz. Since efficiency measurements at the lower levels indicated increasing efficiency with power output and beam voltage, 75% at 400 MHz seems to be a reasonably conservative projection. Grid dissipation of 20W/cm² are well below the capabilities of the pyrolytic graphite grid used in the UHF TV Klystron. At 450 MHz from Fig. 3 a CW power in excess of 2MW is projected. Fig. 4 lists objective data for a proposed Klystron at the 1MW CW level, and Fig. 5 is a tentative outline of the 1MW tube. As can be seen, the size, weight, and efficiency would put such a device in a class by itself.

KLYSTRON PERFORMANCE PROJECTED FROM MEASURED DATA AT 470 AND 775 MHz

ASSUMPTIONS:

$$\text{CONSTANT PERVEANCE } K_{DC} = 0.33 \times 10^{-6} A / V^{3/2}$$

$$\text{CONSTANT GRID DISSIPATION DENSITY} = 20 \text{ WATTS PER CM OF CATHODE AREA}$$

$$\text{GUN AREA CONVERGENCE} = 4.0$$

$$\text{CONSTANT } \eta = 70.5\%$$

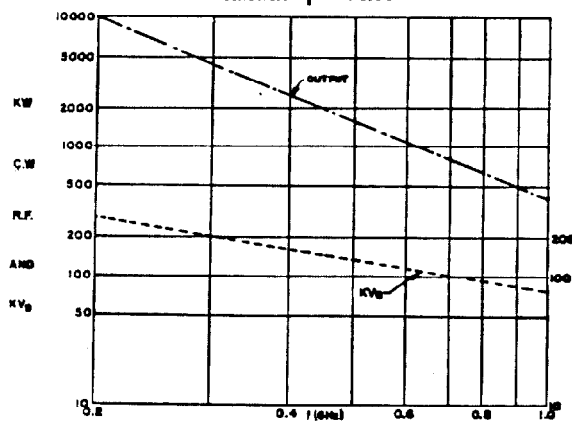


FIGURE 3

Conclusion

In summary, that part of the spectrum where klystrons become too bulky and tetrodes too inefficient and hard to circuit, will be superbly filled by the new EIMAC Klystron. Whereas the tetrode and klystron have had over 30 years of improvement and refinement to reach their present state, the Klystron in a relatively short time has overtaken both and offers great potential for even greater improvement.

Objective Data - X2259 Klystrode Amplifier

Frequency:	450 MHz $\pm$ 5 MHz
RF Power Output:	1 Megawatt
Modulation:	None (CW)
Beam Voltage:	120 KV
Beam Current:	11.1 Amperes
Conversion Efficiency:	75%
Driving Power (RF):	1-10 Kw
Collector Dissipation:	333 Kw

Size:

Length:	60 Inches
Width:	24 Inches
Depth:	16 Inches

Weight:

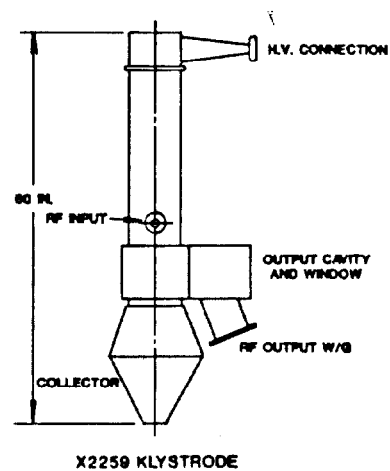
Tube & Circuitry:	150 Lbs.
Magnet:	100 Lbs.
Total Weight:	250 Lbs.

RF Power :	4 Kw per lb.
Weight	

FIGURE 4

References

- [1] D. Preist and M. Shrader, "The Klystrode, an Unusual Transmitting Tube With Potential for UHF-TV", IEEE Proceedings, vol. 70, no. 11, November, 1982
- [2] D. Preist and M. Shrader, "Klystrode Update", Presented at the 1984 International Electron Device Meeting, Held December, 1894 in San Francisco, CA



X2259 KLYSTRODE

SCALE: 1/10 F.S.

FIGURE 5